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Effect of an integrated intervention package of preventive chemotherapy, community-led total sanitation and health education on the prevalence of helminth and intestinal protozoa infections in Côte d'Ivoire

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Abstract

Background: Preventive chemotherapy with donated anthelmintic drugs is the cornerstone for the control of helminthiasis. However, reinfection can occur rapidly in the absence of clean water and sanitation coupled with unhygienic behaviour. The purpose of this study was to assess the effect of an integrated package of interventions, consisting of preventive chemotherapy, community-led total sanitation (CLTS) and health education, on the prevalence of helminth and intestinal protozoa infections and on participants' knowledge, attitude, practice and beliefs (KAPB) towards these diseases including water, sanitation and hygiene (WASH).

Methods: A cross-sectional survey was carried out in nine communities of south-central Côte d'Ivoire to assess people's infection with helminths and intestinal protozoa and KAPB. Subsequently, interventions were targeted to five communities, while the remaining communities served as control. The intervention encouraged latrine construction and an evaluation was done 6–7 months later to determine open defecation status of the respective communities. Anthelmintic treatment was provided to all community members. A follow-up cross-sectional survey was conducted approximately one year later, using the same procedures.

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Results: Overall, 810 people had complete baseline and follow-up data and were given anthelmintic treatment. The baseline prevalence of hookworm, *Schistosoma haematobium*, *Trichuris trichiura*, *Schistosoma mansoni* and *Ascaris lumbricoides* was 31.1%, 7.0%, 2.0%, 1.0% and 0.3%, respectively. Four of the five intervention communities were classified open-defecation free. For hookworm infection, we observed higher negative changes in terms of proportion of decrease (-0.10; 95% confidence interval (CI): -0.16, -0.04) and higher egg reduction rate (64.9 vs 15.2%) when comparing intervention with control communities. For intestinal protozoa, prevalence reduction was higher in intervention compared to control communities (8.2 vs 2.6%) and WASH indicators and intervention outcomes associated with lower odds for infection at follow-up. The intervention significantly impacted on reported latrine use (before: 15.5%, after: 94.6%), open defecation in the community surroundings (before: 75.0%, after: 16.7%) and awareness for environmental contamination through open defecation (before: 20.4%, after: 52.2%).

Conclusions: An integrated package of interventions consisting of preventive chemotherapy, health education and CLTS reduces the prevalence of helminth and intestinal protozoa infection. Additional studies in other social-ecological settings are warranted to confirm our findings.

Keywords: Community-led total sanitation, Côte d'Ivoire, Health education, Integrated control, Intestinal protozoa, Neglected tropical diseases, Schistosomiasis, Soil-transmitted helminthiasis

Background

More than half of the human population is at risk of soil-transmitted helminthiasis and schistosomiasis, over 1 billion people are infected and the global burden of these neglected tropical diseases in 2015 was 6.3 million disability-adjusted life years (DALYs) [1]. The strategy put forth by the World Health Organization (WHO) for the control of helminthiasis is preventive chemotherapy that is the periodic administration of anthelmintic drugs to at-risk populations, particularly school-aged children. Albendazole and mebendazole against soil-transmitted helminthiasis and praziquantel against schistosomiasis are the drugs of choice [2]. However, reinfection may occur rapidly as long as access to clean water, adequate sanitation and hygiene behaviour have not been improved [3]. Often control efforts do not take these latter aspects sufficiently into account, despite the evidence that water supply and sanitation are key factors for prevention and sustainable control of helminthiasis [4–6].

Additionally, the use of improved over unimproved sanitation and excreta disposal (use of any type of latrine/toilet vs open defecation) were associated with significantly lower odds of diarrhoea [7, 8]. While recent randomised controlled trials assessing the effect of water, sanitation and hygiene (WASH) on the prevalence and incidence of intestinal parasite infections and diarrhoeal diseases revealed somewhat mixed results, integrated approaches consisting of preventive chemotherapy, WASH interventions and health education were more effective [9–12] than single interventions [13]. It is important to note that measurability of protective effects from sanitation interventions depends on social-ecological contexts (e.g. resource-scarce environment vs area with improved facilities at baseline [14], rural vs urban [15]), latrine

coverage [16] and how rigorously interventions were implemented (such as elimination of open defecation vs increase of latrine ownership) [17]. Prior research underscores the importance of integrated approaches for effective control of helminthiasis and diarrhoeal diseases [18–20]. Yet, there is a need for well-designed studies on water and sanitation interventions, health education and preventive chemotherapy against neglected tropical diseases.

Community-led total sanitation (CLTS) is a participatory approach that aims to achieve and sustain an open defecation free (ODF) status at the community level [21]. This approach has the potential to reduce the incidence of helminth and intestinal protozoa infections and, when implemented alongside preventive chemotherapy, might provide a sustainable way to control neglected tropical diseases. However, to our knowledge, the effect on reinfection patterns with helminth and intestinal protozoa infections has yet to be determined. CLTS employs participatory rural appraisal and is based on the belief that the learning effect is much higher if the knowledge is acquired through self-experience and self-reflexion [22]. The approach facilitates the critical analysis by the community of their own sanitation-profile, inappropriate defecation practices and the consequences, leading to collective action to become ODF [23]. CLTS is a community-based and -led strategy that triggers community empowerment via feelings like shame and disgust induced through observation of the defecation situation in a specific setting and its environment, which is much harder to address by health education [24, 25].

The purpose of this study was to assess the effect of an integrated approach that combines preventive

chemotherapy with CLTS and health education, on reinfection patterns with helminths and intestinal protozoa and on knowledge, attitude, practice and beliefs (KAPB) of hygiene in the Taabo health and demographic surveillance system (HDSS) in south-central Côte d'Ivoire.

Methods

Study area and population

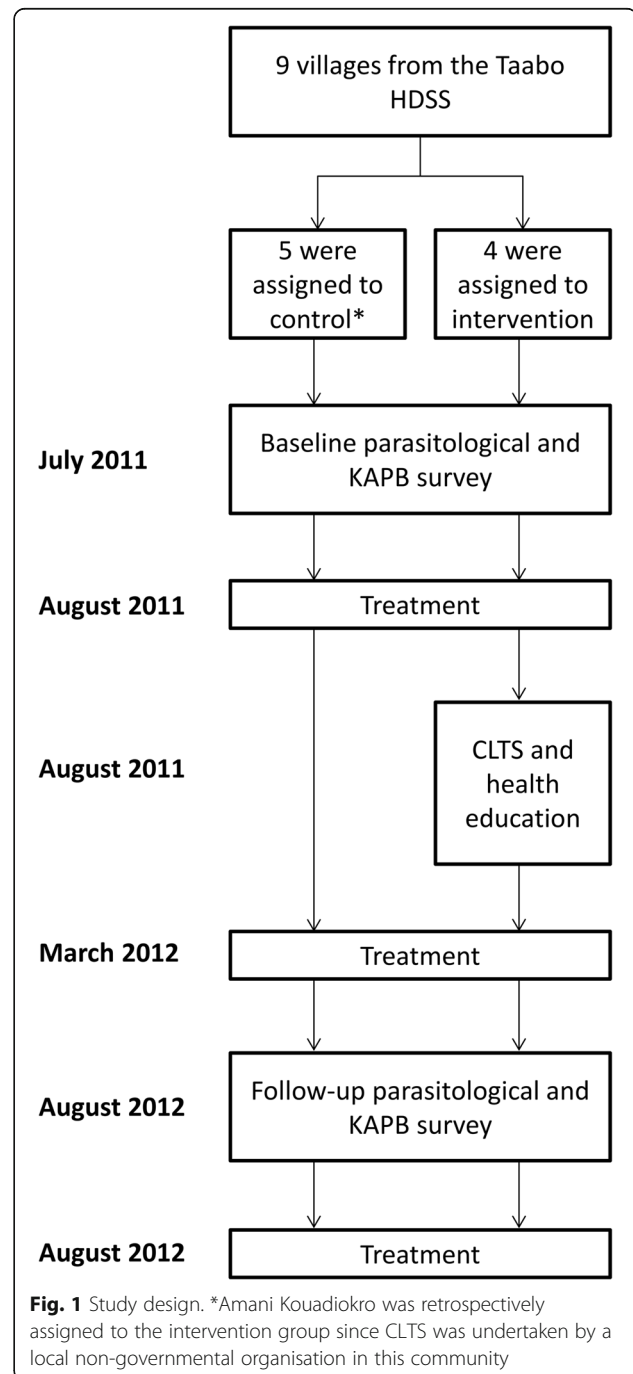
The study was carried out in the Taabo HDSS, located in south-central Côte d'Ivoire [26]. The study area and the baseline situation with regard to hygiene and sanitation conditions have been described elsewhere [27]. In brief, open defecation is common. In addition to agricultural activities, local populations raise animals such as pigs, goats, sheep and chicken in their immediate living environment that may also influence disease transmission (e.g. pigs consume human faeces). Preventive chemotherapy was implemented in 2008, 2009 and 2010 using albendazole, praziquantel and ivermectin for the control of soil-transmitted helminthiasis, schistosomiasis, onchocerciasis and lymphatic filariasis.

The study was implemented in two villages (Katché-nou and Sahoua), and seven hamlets belonging to different villages, Yobouékro (village Sahoua), Ouattafouékro and Kouadio Kouamékro (Ahondo), Boussoukro (Tokohiri), Amani Kouadiokro (Sokrogbo) and Bêh N'Guesankro and Allah Thérèse-kro (Léléblé). These villages and hamlets were selected because of their characteristics that are in favour of meaningful and successful implementation of CLTS, namely (i) small population sizes; (ii) clear signs of practiced open defecation; (iii) inhabitants that have the potential to become natural leaders; and (iv) relatively homogeneous population structure in terms of culture and socioeconomic status. Communities were randomly assigned to the intervention and control group taking into account for matching characteristics such as population size, hygiene status, village affiliation and geographic position. All residents of the villages and hamlets were invited to participate. During the study period a non-governmental organisation (NGO) visited Amani Kouadiokro and carried out CLTS. Given that for our study this hamlet was a control site, we considered this location retrospectively to be within the intervention group for analysis. Although this community had not received the additional health education package it qualified as intervention community in light of rapidly achieved ODF status that is the ultimate goal of the intervention and to be related with all outcomes assessed at follow-up.

Study design

Figure 1 shows the study design. In July 2011, shortly before the annual round of preventive chemotherapy,

a cross-sectional survey was conducted to determine peoples' infection status with helminths and intestinal protozoa and to assess their KAPB regarding helminthiasis and hygiene [27]. Interventions (i.e. CLTS and health education) were implemented subsequently, including a second round of preventive chemotherapy. Approximately 1 year after baseline, a follow-up survey was conducted, using the same field and laboratory procedures.



Parasitological survey

Our research team visited all villages and hamlets to obtain local approval and to explain the parasitological survey and questionnaire interviews. The day before the survey, field enumerators from the Taabo HDSS and community health workers distributed plastic containers (125 ml) to all households for stool and urine collection. Participants were invited to submit early morning stool and urine samples on the following day to a communal central place in the village/hamlet. For parasitological examinations, faecal and urine samples were transferred to a mobile field laboratory in Léléblé or Sokrogbo, or the laboratory of the hospital in Taabo-Cité depending on the sampled localities' proximity to the respective laboratories.

Stool and urine samples were processed and examined by experienced laboratory technicians on the day of collection. In brief, stool samples were subjected to duplicate Kato-Katz thick smears, using 41.7 mg plastic templates [28]. The number of eggs of *Schistosoma mansoni*, *Ascaris lumbricoides*, *Trichuris trichiura* and hookworm were counted and recorded separately. Egg counts were multiplied by a factor of 24 to estimate the number of eggs per gram of stool (epg) [29]. Urine samples were subjected to a filtration method. Ten ml of vigorously shaken urine was passed through a Nytrel filter (Sefar AG; Heiden, Switzerland; diameter: 13 mm, mesh size: 20 µm). Individual filters were placed on a microscope slide, a drop of Lugol's iodine added and then examined under a microscope. The number of *S. haematobium* eggs were counted and expressed as eggs per 10 ml of urine [30]. For quality control, 10% of the samples were re-examined by a senior laboratory technician and discrepancies discussed until concordance was reached.

Additionally, from each stool sample 1–2 g was processed using an ether-concentration method. The sodium acetate-acetic acid-formalin (SAF)-fixed stool samples were forwarded to a laboratory at the Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS; Abidjan, Côte d'Ivoire) for examination of intestinal protozoa infections. Standard protocols were followed and intestinal protozoa (*Blastocystis* sp., *Chilomastix mesnili*, *Entamoeba coli*, *Entamoeba hartmanni*, *Entamoeba histolytica*/E. *dispar*, *Endolimax nana*, *Giardia intestinalis* and *Iodamoeba bütschlii*) recorded semi-quantitatively [31].

Questionnaire survey

For the interviews with KAPB questionnaires, households were visited by a researcher accompanied by a trained field enumerator from the Taabo HDSS who speaks the local language. The questionnaire was addressed to the household head or a present adult household member in case of absence of the earlier. The

questionnaire has been presented in detail elsewhere [27]. In brief, the questionnaires consisted of basic questions pertaining to demographic factors, socioeconomic indicators, sanitation, hygiene and defecation behaviour, opinions, taboos and beliefs, and concepts on intestinal parasitic infections.

CLTS and health education

The CLTS intervention was carried out according to Kar & Chambers [21]. Pre-triggering was integrated in the information visit to communities about the upcoming surveys and further enhanced during the KAPB survey, while information was collected and defecation sites located. Subsequently, a workshop was organised to train personnel from the Taabo HDSS, local health authorities, members of the mayor's office and other stakeholders from the sub-prefecture of Taabo with regard to the CLTS approach. At this event, experienced CLTS facilitators from different institutions (CSRS, UNICEF and the Ministry of Health and Public Hygiene) presented the CLTS approach and the different tactics of implementing CLTS and leading the community to the ignition moment. Teams were then built, each including a lead-facilitator, co-facilitators, content and process recorders and one person responsible for organisational issues and communities that were chosen for the intervention visited. The visit (triggering) lasted half a day and went as follows. First, a meeting with the community leaders was held, encouraging all community members to participate. Secondly, several activities were done with the community members, including mapping of community and defecation areas, identifying dirtiest neighbourhoods on the map, calculation of "caca" and medical expenses due to diarrhoea, transect walk through the open defecation areas ("walk of shame"), triggering disgust of faecal contamination of food, water or hands [showing, for example, how flies fly from faeces to food ("caca-to-food")]. The latter activity is where the ignition moment took place in general, namely when people realise that they are eating each other's faeces. In a next step, the community was motivated to plan their decisions, actions and time schedule until when the community will be ODF. Third, a closing ceremony was organised by the team where active and motivated community members identified during the intervention (natural leaders) were invited to present in front of all invited local authorities their plan of action (Fig. 2).

After triggering, the action of the community was supported and followed-up by regular visits every 2 weeks by the facilitators. During these follow-ups, the facilitators visited the communities to assist and monitor the construction of latrines. People were constantly encouraged to help each other to build latrines or share latrines until every household had its



Fig. 2 Community members presenting their action plans for CLST (a), including a map of their community with indicated defecation sites (b) during a workshop held at Taabo-Cité

own latrine [21, 22, 32]. ODF status was evaluated 10 and 28 weeks after triggering through active search for remaining open defecation sites during unannounced visits in the community and its surroundings.

The whole process of CLTS was supported by specific health education sessions using participatory rural appraisal tools. This approach included three major aspects, namely (i) evaluating existing knowledge; (ii) health education provided to the whole community and to separate groups (e.g. men, women, children and health committees) through focus group discussions led by a social scientist; and (iii) set up of an action plan for continued provision of health education. The facilitators discussed the health risks associated to inappropriate hygiene, open defecation and other risk behaviour with groups of community members. Risk behaviour for helminth and intestinal protozoa infections, transmission cycles and preventive measures were described using visual tools such

as booklets, posters and pictures. These tools were handed over to community health committees in charge of promoting good hygiene behaviour in the community that were built as part of the intervention.

Statistical analysis

Data were double-entered and cross-checked using EpiInfo version 3.5.1 (Centers for Disease Control and Prevention, Atlanta, GA, USA) and analysed using STATA version 10.0 (Stata Corp., College Station, TX, USA). Only participants with complete datasets (i.e. those with duplicate Kato-Katz thick smears, one SAF-fixed faecal sample and one urine filtration) and confirmed administration of albendazole treatment were included in the final analyses. Participants were stratified into five age groups (i.e. <6; 6–15; 16–29; 30–45; and >45 years). Logistic regression models for infection status, behaviour and awareness with regard to defecation and hygiene were used to assess the association with the intervention at baseline and the 1-year follow-up. Prevalence reduction was defined as (prevalence at baseline – prevalence at follow-up). Negative binomial regression models were used to assess the association between faecal egg counts of single helminth species infections and the intervention. Egg count reduction, expressed as egg reduction rate (ERR), was calculated as $[1 - (\text{geometric mean epg at follow-up}/\text{geometric mean epg at baseline})]$ multiplied by a factor of 100. Significant changes between baseline and follow-up frequencies for infection status, behaviour and awareness with regard to defecation and hygiene within the respective group were analysed using the McNemar's test. To assess differences over time in infection status between control and intervention communities, taking into account for different baseline prevalence levels, we compared (i) total proportion of change; (ii) proportion of decrease; and (iii) proportion of increase [33, 34]. Differences in proportion of change were considered significant in case of non-overlapping 95% confidence intervals (CIs) based on the following formula:

$$SE(p_{g1}-p_{g2}) = \sqrt{\left[\frac{p_{g1}(1-p_{g1})}{N_{g1}} \right] + \left[\frac{p_{g2}(1-p_{g2})}{N_{g2}} \right]}$$

where SE is the standard error, p_{g1} is the proportion of change in group 1, p_{g2} is the proportion of change in group 2, N_{g1} is the number of subjects in group 1, and N_{g2} is the number of subjects in group 2.

Univariate and multivariable relationship analysis to assess guiding risk factors for the follow-up infection

status was done using logistic regression modelling, including a random effect coefficient on community level. Results of this analysis were presented as crude and adjusted odds ratios (ORs). The latter were adjusted for sociodemographic indicators, namely sex, age group, socioeconomic status and ethnic origin.

Results

Participants

There were 3420 people living in the nine selected communities according to the Taabo HDSS census database and 3289 were present and participated during the baseline survey in 2011. A total of 2413 provided stool samples, 2294 submitted urine samples and questionnaire data were available from 3152 people. Overall, 1894 people had complete parasitological and questionnaire data. Results from the baseline survey have been presented elsewhere [27]. For the 1-year follow-up survey done in 2012, a total of 3290 people were present, of which 2064 provided stool and 1902 urine samples, while questionnaire data were obtained from 3182 people. Complete parasitological and questionnaire data were available from 1481 people.

A total of 810 individuals had complete parasitological and questionnaire data from both the baseline and 1-year follow-up surveys and had received anthelmintic treatment after the second ODF evaluation in March 2012. Age and sex characteristics of this final cohort are presented in Additional file 1: Table S1.

Community response following the interventions

Table 1 summarises information on latrines owned by households before and after the intervention. At baseline, coverage of latrine ownership at the unit of the community varied from 0% (i.e. Katchéneou) to 50% (i.e. Allah Thérèsekro). Following two rounds of evaluations, four out of five intervention communities reached a 100% household coverage with latrines and were verified ODF. The remaining intervention community reached a latrine coverage of more than 80% but continued open defecation was still recorded. The proportion of latrine ownership at follow-up in control communities remained comparable with the baseline proportion. Dynamics of latrine construction among intervention communities are shown in Fig. 3. Kouadio Kouamékro and Amani Kouadiokro (not shown in figure) already reached 100% latrine coverage and ODF status after the first environmental evaluation 10 weeks after triggering. The other three intervention communities only started to extensively construct latrines following a specific health education package.

Impact of the intervention on prevalence and intensity of infection

The prevalence of helminth and intestinal protozoa infection at baseline and follow-up is shown in Table 2. Baseline helminth infections were not comparable between control and intervention communities. *S. haematobium* infection, the predominant *Schistosoma* species, was mainly found in Sahoua, belonging to the control group. This is reflected in a significantly reduced OR for schistosomiasis in intervention communities (OR = 0.05, $P < 0.001$). Intervention communities were more affected by soil-transmitted helminth infection (mainly hookworm) than control communities at baseline (38.0 vs 25.7%, OR = 1.77, $P < 0.001$). However, at follow-up helminth infection prevalence was low among both control and intervention communities with 7.0% and 11.8% for soil-transmitted helminths and 5.7% and 1.4%, respectively, for *Schistosoma* spp. infections. For intestinal protozoa infections that were equally frequent in both groups at baseline, a significant decline from 72.0% to 63.8% was observed in intervention communities whereas control communities still showed similar frequencies as at baseline (73.0% and 70.4%).

Helminth infection intensities at baseline and follow-up are shown in Additional file 2: Table S2. ERRs for hookworm were considerably higher for intervention than control communities (64.9 vs 15.2%) due to higher baseline egg counts in the intervention communities. There was no significant difference in hookworm egg counts between intervention and control group after treatment.

Table 3 shows significant differences in the proportion of change in helminth and intestinal protozoa infections between intervention and control communities. Intervention communities showed a significantly higher proportion of decrease for soil-transmitted helminth infection, hookworm and *E. histolytica/E. dispar* infection, while control communities showed significantly higher changes in proportion of increase for *E. nana* and *Blastocystis* sp. infections.

Risk factors guiding infection status at follow-up

Figure 4 shows reinfection patterns with STHs in intervention and control communities, stratified by age group and sex. While soil-transmitted helminth reinfection patterns by age group in control communities followed baseline patterns with highest infection rates among adolescent and young adults (16–29 years), a peak shift towards school-aged children (6–15 years) was observed in intervention communities. In intervention communities 19.8% of school-aged children were found soil-transmitted helminth-positive compared to 4.4% in control communities ($P < 0.001$). In the former, almost half of all new infections (23/50, 46%), were diagnosed in

Table 1 Characteristics of the selected villages/hamlets and results from the evaluation prior to certification

Type of intervention	Community	Registered inhabitants (n = 3420)	Registered households (n = 487)	Households with latrines at baseline (%)	Households with latrines at follow-up (%)	ODF status ^c
Preventive chemotherapy	Allah Thérésekro	320	56	28 (50.0)	34 (60.7)	
Preventive chemotherapy ^a	Boussoukro	294	48	12 (25.0)	15 (31.3)	
Preventive chemotherapy ^a	Ouattafouékro	157	29	1 (3.4)	1 (3.4)	
Preventive chemotherapy	Sahoua	872	118	25 (21.2)	31 (26.3)	Yes
Preventive chemotherapy + CLTS ^b	Amani Kouadiokro	253	24	0 (0)	24 (100)	Yes
Preventive chemotherapy + CLTS + health education	Bèh N'Guessankro	393	55	15 (27.3)	45 (81.82)	No
Preventive chemotherapy + CLTS + health education	Katchénou	713	91	0 (0)	91 (100)	Yes
Preventive chemotherapy + CLTS + health education	Kouadio Kouamékro	171	29	1 (3.4)	29 (100)	Yes
Preventive chemotherapy + CLTS + health education	Yobouékro	247	37	3 (8.1)	37 (100)	Yes

Abbreviations: CLTS community-led total sanitation, ODF open defecation free

^aBoussoukro and Ouattafouékro are two hamlets situated 1 km apart from each other. For randomisation these two hamlets were considered as one unit

^bAmani Kouadiokro, a hamlet at the border of the sub-prefecture, was initially attributed to the control group during randomisation, however, an NGO intervening at the adjacent sub-prefecture erroneously visited the hamlet and carried out a CLTS intervention. Thus, this community was attributed to the intervention group for analysis of parasitological data

^cTwo evaluations took place. The first evaluation was implemented on 26–27 November 2011, the second took place on 19–25 March 2012. Kouadio Kouamékro and Amani Kouadiokro were certified ODF following the first evaluation, whereas Katchénou and Yobouékro were certified ODF following the second evaluation

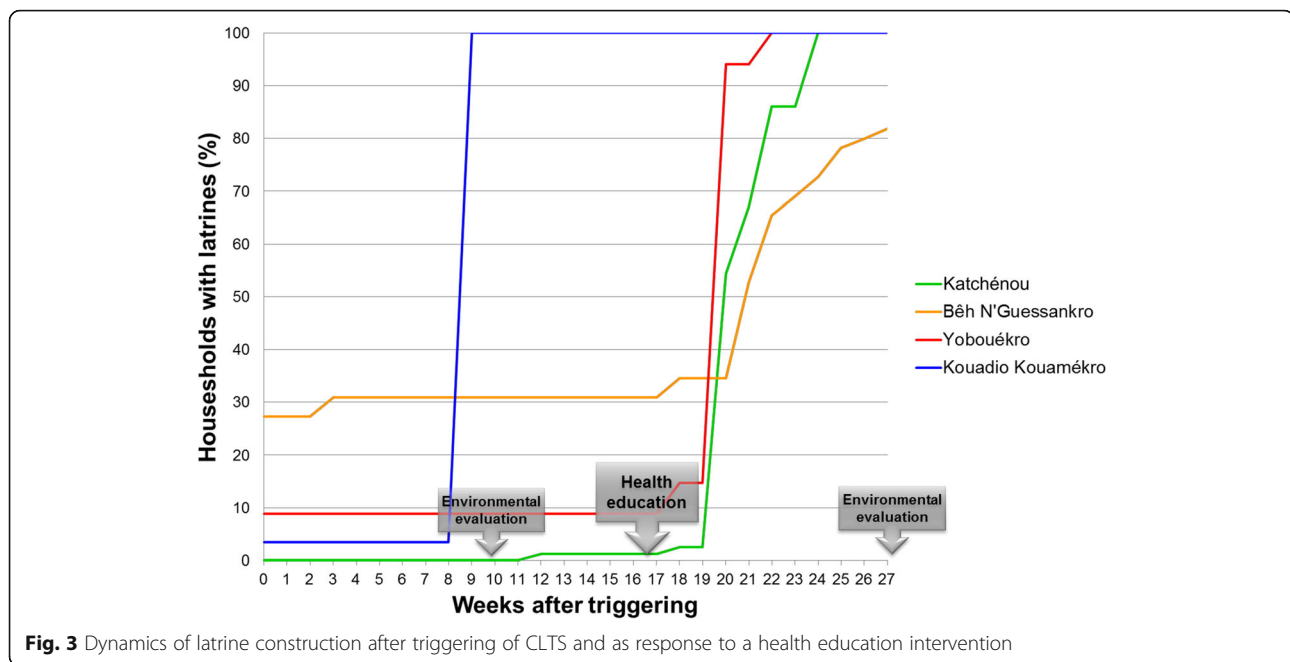


Fig. 3 Dynamics of latrine construction after triggering of CLTS and as response to a health education intervention

school-aged children. Similar to age, reinfection patterns in control communities showed continued sex differences, as already observed at baseline with significantly higher rates of males infected in 2012 than females (11.2 vs 2.7%, $P = 0.001$), while no significant sex differences in infection status in 2012 was observed among intervention communities (14.4 vs 8.9%, $P = 0.076$).

Multivariable regression modelling adjusted for age, sex, socioeconomic status and ethnic origin showed no significant relationship between specific WASH indicators (e.g. toilet ownership and use) and intervention indicators (i.e. ODF status and group) with the 1-year follow-up soil-transmitted helminth infection status (Table 4). Sociodemographic and socioeconomic factors, such as male gender (OR = 2.63, $P < 0.001$) and age groups 6–15 years (OR = 2.46, $P = 0.017$) or 16–29 years (OR = 3.08, $P = 0.010$), were positively associated with reinfection with soil-transmitted helminths, whereas individuals from households with higher socioeconomic status showed significantly lower adjusted ORs (OR = 0.80, $P = 0.007$). Stratification into control and intervention communities revealed that socioeconomic factors associated with soil-transmitted helminth infection in 2012 diverged. In intervention communities, socioeconomic status (OR = 0.77, $P = 0.015$) and age group 6–15 years (OR = 3.00, $P = 0.010$) were still significantly related to reinfection. In control communities, in contrast, male gender (OR = 5.90, $P = 0.001$) and age groups 16–29 years (OR = 9.03, $P = 0.012$) and 30–45 years (OR = 5.66, $P = 0.033$) still had higher odds for soil-transmitted helminth infection in 2012.

In contrast to soil-transmitted helminth infection, WASH indicators and intervention group (OR = 0.68, P

= 0.015) and ODF community (OR = 0.69, $P = 0.017$) had lower odds for intestinal protozoa infection at the 1-year follow-up. Among the WASH indicators, households with newly constructed latrines (OR = 0.63, $P = 0.007$) showed the highest effect on reduction of intestinal protozoa infection.

Impact of the intervention on KAPB

Table 5 compares changes in defecation and hygiene behaviour as reported from the household-based questionnaire between control and intervention communities. At baseline, use of latrines and reported hand washing after defecation was significantly lower among households of intervention communities than in control communities (15.5% and 14.9% vs 46.7% and 29.7%, respectively). This, however, dramatically changed into the opposite direction after implementation of CLTS (intervention: 94.6% and 41.1%; control: 40.1% and 25.8%). Nearby bushes as the most often stated place for open defecation in 2011 (69.2% and 75.0% in control and intervention communities, respectively) was significantly less often mentioned among households of intervention communities (16.7%, McNemar's OR = 0.10, $P < 0.001$) in 2012, while it remained constantly high in control communities (64.8%). With regard to children's defecation behaviour, a similar trend was observed. In 2012, children from households of intervention communities were reported to mainly use latrines/toilets (81.4%), while nearby bushes (64.1%) was still the major place for defecation of children from control communities.

Table 2 Comparison of infection prevalences among 810 participants, stratified by control and intervention communities during baseline and follow-up surveys. Logistic regressions were used to derive odds ratios for comparison of prevalences of control and intervention communities at baseline and follow-up. The prevalence reduction was calculated as baseline prevalence minus follow-up prevalence for control and intervention communities separately

Parasite	Group	Baseline prevalence (%)	OR (95% CI)	P-value	Follow-up prevalence (%)	OR (95% CI)	P-value	Prevalence reduction (%)
<i>Schistosoma</i> spp.	Control	15.58	1		5.71	1		9.87*
	Intervention	0.94	0.05 (0.02–0.14)	< 0.001	1.41	0.24 (0.10–0.59)	0.002	-0.47
<i>Schistosoma mansoni</i>	Control	1.04	1		1.04	1		0.00
	Intervention	0.94	0.90 (0.22–3.64)	0.888	0.71	0.68 (0.15–3.04)	0.611	0.23
<i>Schistosoma haematobium</i>	Control	14.81	na		4.68	1		10.13*
	Intervention	0	na		0.71	0.15 (0.04–0.50)	0.002	-0.71
Soil-transmitted helminths	Control	25.71	1		7.01	1		18.70*
	Intervention	37.97	1.77 (1.32–2.40)	< 0.001	11.76	1.77 (1.08–2.89)	0.023	26.21*
Hookworm	Control	25.19	1		7.01	1		18.18*
	Intervention	36.47	1.70 (1.26–2.31)	0.001	10.59	1.57 (0.95–2.58)	0.076	25.88*
<i>Ascaris lumbricoides</i>	Control	0	na		0	na		0.00
	Intervention	0.71	na		0.24	na		0.47
<i>Trichuris trichiura</i>	Control	1.30	1		0	na		1.30*
	Intervention	2.59	2.02 (0.70–5.87)	0.196	1.41	na		1.18
Intestinal helminths ^a	Control	26.23	1		7.79	1		18.44*
	Intervention	38.44	1.77 (1.31–2.38)	< 0.001	12.47	1.69 (1.05–2.70)	0.030	25.97*
Intestinal protozoa	Control	72.99	1		70.39	1		2.60
	Intervention	72.00	0.95 (0.70–1.30)	0.753	63.76	0.74 (0.55–0.99)	0.046	8.24*
<i>Entamoeba histolytica/E. dispar</i>	Control	9.87	1		9.61	1		0.26
	Intervention	17.65	1.96 (1.29–2.97)	0.002	10.59	1.11 (0.70–1.76)	0.645	7.06*
<i>Entamoeba coli</i>	Control	44.16	1		40.52	1		3.64
	Intervention	40.47	0.86 (0.65–1.14)	0.289	39.53	0.96 (0.72–1.27)	0.774	0.94
<i>Entamoeba hartmanni</i>	Control	1.30	1		4.94	1		-3.64*
	Intervention	1.65	1.27 (0.40–4.04)	0.683	1.18	0.23 (0.05–0.62)	0.004	0.47
<i>Endolimax nana</i>	Control	26.23	1		29.61	1		-3.38
	Intervention	29.65	1.18 (0.87–1.61)	0.280	24.00	0.75 (0.55–1.02)	0.072	5.65
<i>Iodamoeba bütschlii</i>	Control	15.58	1		8.05	1		7.53*
	Intervention	18.35	1.22 (0.84–1.76)	0.296	7.76	0.96 (0.58–1.60)	0.880	10.59*
<i>Giardia intestinalis</i>	Control	16.36	1		14.03	1		2.33

Table 2 Comparison of infection prevalences among 810 participants, stratified by control and intervention communities during baseline and follow-up surveys. Logistic regressions were used to derive odds ratios for comparison of prevalences of control and intervention communities at baseline and follow-up. The prevalence reduction was calculated as baseline prevalence minus follow-up prevalence for control and intervention communities separately (*Continued*)

Parasite	Group	Baseline prevalence (%)	OR (95% CI)	P-value	Follow-up prevalence (%)	OR (95% CI)	P-value	Prevalence reduction (%)
<i>Chilomastix mesnili</i>	Intervention	16.94	1.04 (0.72–1.51)	0.826	12.24	0.86 (0.57–1.29)	0.451	4.70*
	Control	4.42	1		4.94	1		-0.52
<i>Blastocystis</i> sp.	Intervention	5.18	1.18 (0.62–2.26)	0.614	5.18	1.05 (0.56–1.97)	0.876	0.00
	Control	34.03	1		29.09	1		4.94
	Intervention	35.53	1.07 (0.80–1.43)	0.654	23.53	0.75 (0.55–1.03)	0.073	12.0*

Abbreviations: OR odds ratio, CI confidence interval, na not applicable

^aIncludes soil-transmitted helminth and *S. mansoni* infections

*Significant change between 2011 and 2012 according to McNemar's test ($P < 0.05$)

Table 3 Significant differences in proportion of change in helminth and intestinal protozoa infections between intervention and control group. Positive differences in proportion of change indicate higher changes in control communities, while negative differences attribute a higher proportion of change in intervention communities

Parasite	Group	Change	Proportion of change	Difference in proportion (SE)	95% CI
Soil-transmitted helminth infection	Control	All	0.23	-0.12 (0.03)	-0.18 ₂ , -0.06 ₂
		Intervention	0.35		
	Control	Decrease	0.21	-0.10 (0.03)	-0.16 ₂ , -0.04 ₂
		Intervention	0.31		
	Control	Increase	0.02	-0.02 (0.01)	-0.05 ₂ , 0.00 ₂
		Intervention	0.04		
Hookworm	Control	All	0.23	-0.10 (0.03)	-0.16 ₂ , -0.04 ₂
		Intervention	0.33		
	Control	Decrease	0.21	-0.09 (0.03)	-0.15 ₂ , -0.03 ₂
		Intervention	0.29		
	Control	Increase	0.02	-0.01 (0.01)	-0.04 ₂ , 0.01 ₂
		Intervention	0.04		
<i>E. histolytica/E. dispar</i>	Control	All	0.16	-0.08 (0.03)	-0.14 ₂ , -0.03 ₂
		Intervention	0.24		
	Control	Decrease	0.08	-0.07 (0.02)	-0.12 ₂ , -0.03 ₂
		Intervention	0.16		
	Control	Increase	0.08	-0.01 (0.02)	-0.04 ₂ , 0.03 ₂
		Intervention	0.09		
<i>E. nana</i>	Control	All	0.41	0.05 (0.03)	-0.02 ₂ , 0.11 ₂
		Intervention	0.37		
	Control	Decrease	0.19	-0.02 (0.03)	-0.08 ₂ , 0.03 ₂
		Intervention	0.21		
	Control	Increase	0.22	0.07 (0.03)	0.01 ₂ , 0.12 ₂
		Intervention	0.16		
<i>Blastocystis</i> sp.	Control	All	0.44	0.04 (0.03)	-0.03 ₂ , 0.11 ₂
		Intervention	0.40		
	Control	Decrease	0.25	-0.01 (0.03)	-0.07 ₂ , 0.05 ₂
		Intervention	0.26		
	Control	Increase	0.20	0.06 (0.03)	0.00 ₂ , 0.11 ₂
		Intervention	0.14		

Abbreviations: SE standard error, CI confidence interval
 *Significant difference in proportion of change between control and intervention group with a non-overlapping 95% confidence interval

Not only reported practice with regard to defecation and hygiene changed among households from intervention communities, but also awareness for problems associated with open defecation. Table 6 shows that the ranking changed from aspects of safety and comfort primarily mentioned in 2011 to contamination of the environment and hygiene perceived as main problems associated with open defecation in 2012. The spontaneous reporting of “polluting environment” exclusively significantly increased among households from intervention communities (from 20.4% to 52.2%, McNemar’s OR = 6.56, $P < 0.001$).

Discussion

Our study presents new evidence on potential gains of an integrated control approach consisting of preventive chemotherapy, CLTS and health education against helminthiases and intestinal protozoa infection in a rural setting of south-central Côte d’Ivoire. Over the past decade, CLTS as a means to prevent diarrhoeal diseases has gained traction and is being applied at large scale in various low- and middle-income countries [22, 35]. Yet, there is relatively little scientific inquiry about the specific effects of CLTS alone or in combination with other interventions against neglected tropical diseases [13, 36–39], and hence, the public health impact of CLTS [40]. We discuss the effect of an integrated package of interventions, placing emphasis on latrine construction by the community, levels of helminth and intestinal protozoa infections, infection patterns at follow-up and people’s behaviour and attitudes (e.g. latrine use vs continued open defecation).

Community response and latrine construction

Our package of interventions resulted in a strong response in the five selected communities. Indeed, four out of the five communities were declared ODF within six months, whilst in the fifth community more than

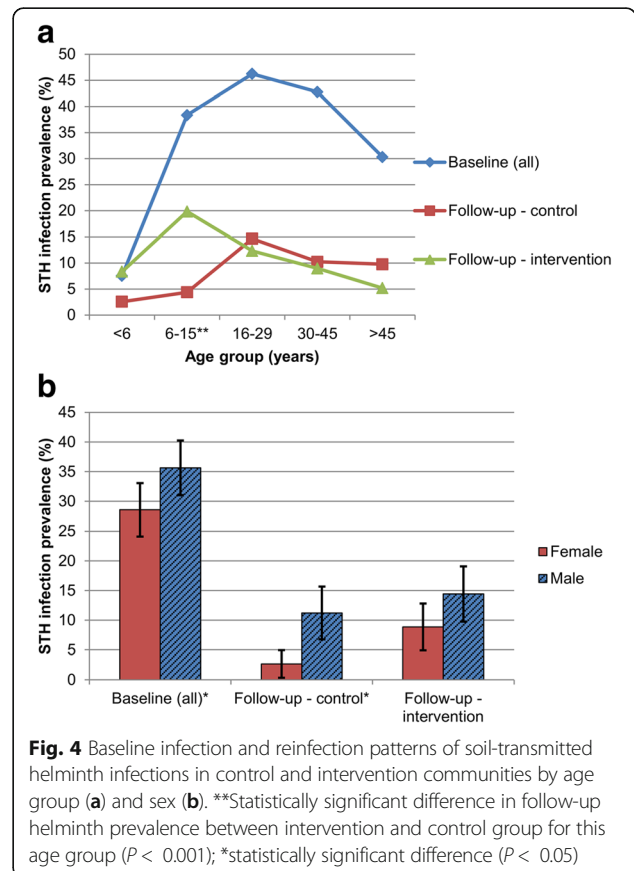


Fig. 4 Baseline infection and reinfection patterns of soil-transmitted helminth infections in control and intervention communities by age group (a) and sex (b). **Statistically significant difference in follow-up helminth prevalence between intervention and control group for this age group ($P < 0.001$); *statistically significant difference ($P < 0.05$)

Table 4 Potential risk and preventive factors guiding reinfection with soil-transmitted helminths and intestinal protozoa in 2012 from multivariable logistic regression modelling

Explanatory factor	All communities (n = 810)		Control group (n = 385)		Intervention group (n = 425)	
	Crude OR (95% CI)	Adjusted OR (95% CI) ^a	Crude OR (95% CI)	Adjusted OR (95% CI) ^a	Crude OR (95% CI)	Adjusted OR (95% CI) ^a
<i>Soil-transmitted helminth infection</i>						
Sociodemographic indicators						
Sex (male)	2.35 (1.40–3.93)**	2.63 (1.55–4.44)**	4.79 (1.76–13.02)**	5.90 (2.11–16.50)**	1.67 (0.90–3.11)	1.72 (0.91–3.24)
Age group (6–15 years)	2.22 (1.07–4.63)*	2.46 (1.18–5.14)*	1.84 (0.36–9.40)	2.14 (0.41–11.09)	2.69 (1.17–6.15)*	3.00 (1.30–6.94)*
Age group (16–29 years)	2.33 (1.00–5.41)*	3.08 (1.30–7.28)*	6.33 (1.20–33.41)*	9.03 (1.63–50.07)*	1.53 (0.55–4.22)	1.79 (0.64–4.98)
Age group (30–45 years)	1.70 (0.76–3.81)	1.95 (0.87–4.40)	4.15 (0.86–19.98)	5.66 (1.15–28.00)*	1.05 (0.37–2.98)	1.18 (0.42–3.36)
Age group (> 45 years)	1.27 (0.47–3.42)	1.39 (0.51–3.76)	4.24 (0.73–24.52)	4.29 (0.72–25.51)	0.63 (0.16–2.46)	0.71 (0.18–2.75)
Socioeconomic index (score)	0.84 (0.71–0.98)*	0.80 (0.68–0.94)**	0.83 (0.65–1.07)	0.82 (0.66–1.02)	0.80 (0.63–1.01)	0.77 (0.62–0.95)*
Ethnic origin (autochthonous) ^b	1.34 (0.62–2.94)	1.76 (0.79–3.95)	2.68 (0.67–10.76)	1.92 (0.65–5.64)	0.92 (0.35–2.39)	1.29 (0.51–3.28)
Religion (Muslim)	0.69 (0.29–1.63)	0.61 (0.29–1.28)	0.44 (0.16–1.24)	0.50 (0.17–1.52)	1.06 (0.33–3.36)	0.84 (0.27–2.65)
Religion (animist)	1.31 (0.76–2.25)	1.42 (0.84–2.41)	1.31 (0.52–3.33)	0.86 (0.31–2.36)	1.32 (0.69–2.52)	1.54 (0.81–2.92)
Religion (other)	0.38 (0.05–3.09)	0.33 (0.04–2.51)	0.31 (0.04–2.52)	0.33 (0.04–2.78)	na	na
WASH/intervention indicators ^c						
Group (intervention)	1.62 (0.72–3.65)	1.55 (0.93–2.59)	na	na	na	na
ODF status (odf)	1.47 (0.64–3.37)	1.48 (0.90–2.42)	na	na	na	na
Toilet ownership (new owner)	1.62 (0.77–3.40)	1.53 (0.88–2.68)	0.81 (0.10–6.61)	1.04 (0.12–9.26)	1.88 (0.48–7.31)	1.37 (0.35–5.34)
Toilet ownership (still owner)	0.79 (0.33–1.85)	1.12 (0.48–2.65)	0.87 (0.34–2.18)	1.20 (0.45–3.19)	0.46 (0.04–4.92)	0.48 (0.04–5.38)
Possession of functional latrine in 2012	1.25 (0.66–2.36)	1.52 (0.88–2.61)	0.93 (0.39–2.23)	1.23 (0.49–3.09)	1.55 (0.42–5.80)	1.26 (0.35–4.52)
Toilet use in 2012	1.04 (0.52–2.09)	1.44 (0.82–2.56)	0.59 (0.24–1.47)	0.87 (0.36–2.12)	na	na
Strict toilet use in 2012	1.25 (0.70–2.22)	1.40 (0.84–2.34)	0.72 (0.29–1.82)	0.89 (0.34–2.35)	1.82 (0.68–4.85)	1.20 (0.43–3.30)
<i>Intestinal protozoa infection</i>						
Sociodemographic indicators						
Sex (male)	0.78 (0.58–1.05)	0.80 (0.60–1.08)	0.67 (0.43–1.04)	0.69 (0.44–1.08)	0.90 (0.61–1.34)	0.94 (0.63–1.41)
Age group (6–15 years)	1.06 (0.71–1.58)	1.10 (0.74–1.65)	0.95 (0.52–1.74)	0.97 (0.52–1.79)	1.09 (0.64–1.85)	1.16 (0.67–2.00)
Age group (16–29 years)	1.23 (0.74–2.05)	1.22 (0.73–2.03)	0.73 (0.33–1.61)	0.68 (0.30–1.52)	1.73 (0.90–3.34)	1.81 (0.93–3.53)
Age group (30–45 years)	1.58 (1.00–2.49)	1.58 (0.99–2.51)	1.42 (0.71–2.85)	1.35 (0.67–2.73)	1.61 (0.87–2.97)	1.65 (0.89–3.06)
Age group (> 45 years)	1.12 (0.67–1.88)	1.14 (0.68–1.92)	0.81 (0.36–1.81)	0.81 (0.36–1.85)	1.36 (0.70–2.63)	1.41 (0.72–2.76)
Socioeconomic index (score)	1.00 (0.92–1.08)	1.02 (0.94–1.10)	0.96 (0.87–1.04)	1.00 (0.91–1.11)	1.04 (0.91–1.18)	1.04 (0.91–1.18)
Origin (autochthonous) ^b	1.51 (1.03–2.22)*	1.54 (1.04–2.28)*	1.50 (0.96–2.34)	1.50 (0.91–2.48)	1.63 (0.93–2.88)	1.70 (0.96–3.04)
Religion (Muslim)	0.62 (0.40–0.97)*	0.61 (0.39–0.96)*	0.61 (0.36–1.04)	0.63 (0.35–1.11)	0.48 (0.25–0.94)*	0.46 (0.23–0.91)*
Religion (animist)	1.01 (0.70–1.45)	1.01 (0.70–1.46)	0.73 (0.39–1.35)	0.74 (0.39–1.41)	1.17 (0.76–1.81)	1.20 (0.77–1.86)

Table 4 Potential risk and preventive factors guiding reinfection with soil-transmitted helminths and intestinal protozoa in 2012 from multivariable logistic regression modelling (Continued)

Explanatory factor	All communities (n = 810)		Control group (n = 385)		Intervention group (n = 425)	
	Crude OR (95% CI) ^a	Adjusted OR (95% CI) ^a	Crude OR (95% CI)	Adjusted OR (95% CI) ^a	Crude OR (95% CI)	Adjusted OR (95% CI) ^a
Religion (other)	1.43 (0.57–3.60)	1.45 (0.58–3.67)	1.27 (0.50–3.21)	1.35 (0.53–3.44)	na	na
WASH/intervention indicators ^c						
Group (intervention)	0.74 (0.55–0.99)*	0.68 (0.49–0.93)*	na	na	na	na
ODF status (odf)	0.73 (0.55–0.98)*	0.69 (0.50–0.93)*	na	na	na	na
Toilet ownership (new owner)	0.65 (0.47–0.91)*	0.63 (0.44–0.88)**	0.69 (0.25–1.95)	0.79 (0.27–2.31)	0.80 (0.35–1.81)	0.76 (0.33–1.77)
Toilet ownership (still owner)	0.87 (0.55–1.37)	0.88 (0.54–1.42)	0.79 (0.49–1.28)	0.84 (0.50–1.42)	1.78 (0.46–6.91)	1.58 (0.39–6.33)
Toilet ownership (no longer owner)	0.58 (0.16–2.12)	0.61 (0.17–2.25)	0.57 (0.16–2.08)	0.61 (0.17–2.27)	na	na
Possession of functional latrine in 2012	0.72 (0.52–0.98)*	0.69 (0.50–0.95)*	0.79 (0.50–1.25)	0.85 (0.52–1.38)	0.82 (0.36–1.87)	0.78 (0.33–1.81)
Toilet use in 2012	0.67 (0.48–0.94)*	0.67 (0.47–0.94)*	0.79 (0.51–1.23)	0.86 (0.54–1.38)	0.19 (0.02–1.54)	0.21 (0.03–1.67)
Strict toilet use in 2012	0.73 (0.54–0.99)*	0.73 (0.53–0.99)*	0.81 (0.51–1.29)	0.87 (0.53–1.43)	0.79 (0.45–1.37)	0.79 (0.44–1.43)

Abbreviations: OR odds ratio, CI confidence interval, na not applicable

^aAll indicators are adjusted for sex, age group, socioeconomic index, and ethnic origin

^bEthnic origin and religion are closely associated therefore ethnic origin only was used for adjustment

^cThe different water, sanitation and hygiene (WASH)/intervention indicators are closely related with each other therefore separate models adjusting each for sociodemographic indicators and including a random effect coefficient on community level were applied

*Statistically significant with a P-value < 0.05

**Statistically significant with a P-value < 0.01

Reference categories for explanatories: sex = female, age group = 0–5 years, ethnic origin = allochthonous (all other ethnic groups than the local Baoulé group), religion = Christian, group = control, open defecation free (ODF) status = not odf, toilet ownership = never owner of any latrine in 2011 and 2012, possession of functional latrine in 2012 = no functional latrine in 2012, toilet use in 2012 = household head never used any latrine/toilet in 2012, strict toilet use in 2012 = household head never or irregularly used latrine/toilet for defecation in 2012

Table 5 Comparison of changes in defecation and hygiene behaviour as reported from the household-based questionnaire (*n* = 350) between control and intervention communities

Behaviour	Group	Proportion (%) in 2011	OR (95% CI)	P-value	Proportion (%) in 2012	OR (95% CI)	P-value	Change between 2011 and 2012 (McNemar's test)	P-value
Open defecation (OD)	Control	92.31	1		81.32	1		0.31 (0.13–0.67)	0.002
	Intervention	95.83	1.92 (0.75–4.87)	0.172	44.64	0.19 (0.12–0.30)	< 0.001	0.04 (0.01–0.12)	< 0.001
Place for OD	Control	69.23	1		64.84	1		0.71 (0.38–1.31)	0.312
	Intervention	75.00	1.33 (0.83–2.13)	0.230	16.67	0.11 (0.07–0.18)	< 0.001	0.10 (0.05–0.19)	< 0.001
Bushes (close to community)	Control	65.93	1		71.43	1		1.27 (0.81–2.01)	0.326
	Intervention	48.81	0.49 (0.32–0.76)	0.001	41.07	0.28 (0.18–0.44)	< 0.001	0.73 (0.46–1.15)	0.193
Close to river/pond	Control	4.40	1		0.00	1		0.20 (0.04–1.79)	0.219
	Intervention	2.98	0.67 (0.21–2.08)	0.486	0.60	na	na	na	na
Behind the house	Control	2.75	1		3.30	1		1.25 (0.27–6.30)	1.000
	Intervention	1.19	0.43 (0.82–2.23)	0.312	0.60	0.18 (0.02–1.47)	0.109	0.50 (0.01–9.60)	1.000
Toilet use ^a	Control	46.70	1		40.11	1		0.43 (0.17–0.98)	0.043
	Intervention	15.48	0.21 (0.13–0.35)	< 0.001	94.64	26.38 (12.66–54.96)	< 0.001	134.00 (23.64–5331.72)	< 0.001
Strict toilet use ^b	Control	26.92	1		29.67	1		1.28 (0.66–2.51)	0.533
	Intervention	12.50	0.39 (0.22–0.68)	0.001	79.17	9.01 (5.52–14.70)	< 0.001	17.00 (8.00–43.20)	< 0.001
Spontaneously mentioned to wash hands after defecation	Control	29.67	1		25.82	1		0.83 (0.50–1.34)	0.483
	Intervention	14.88	0.41 (0.24–0.71)	0.001	41.07	2.00 (0.25–3.15)	0.003	3.93 (2.20–7.47)	< 0.001
Place of defecation of households' children ^c	Control	26.95	1		26.95	1		1.00 (0.49–2.04)	1.000
	Intervention	8.92	0.27 (0.14–0.51)	< 0.001	81.35	11.97 (7.05–20.30)	< 0.001	58.00 (15.70–484.61)	< 0.001
Toilet/latrine	Control	62.28	1		64.07	1		1.19 (0.58–2.47)	0.736
	Intervention	78.34	2.19 (1.34–3.58)	0.002	4.52	0.03 (0.01–0.06)	< 0.001	0.17 (0.00–0.06)	< 0.001
Bushes (close to community)	Control	13.77	1		14.37	1		1.05 (0.54–2.04)	1.000
	Intervention	1.91	0.12 (0.04–0.42)	0.001	0.00	na	na	0.00 (0.00–2.42)	0.250
Behind the house	Control	11.38	1		47.31	1		11.00 (4.79–31.05)	< 0.001
	Intervention	19.75	1.92 (1.03–3.56)	0.039	65.97	2.16	0.001	9.34 (4.52–22.51)	< 0.001
Potty	Control	5.99	1		7.19	1		1.22 (0.46–3.34)	0.824
	Intervention	5.73	0.96 (0.38–2.42)	0.922	0.00	na	na	0.00 (0.00–0.51)	0.003
On the field/plantation	Control	0.00	1		18.56	1		na	na
	Intervention	0.00	na	na	20.13	1.11 (0.64–1.92)	0.722	na	na

^aToilet use defined as use of a latrine/toilet (private or shared) of any frequency and unconditional of other places used for defecation
^bStrict toilet use defined as use of a latrine/toilet (private or shared) of a minimum frequency of 2 (includes "regularly", "often" and "always") combined with no open defecation except for defecation in the plantation far away from the community
^cOnly for households with children (*n* = 324)

Table 6 Comparison of changes in awareness and attitudes towards continued open defecation and latrine ownership as reported spontaneously from the household-based questionnaire between control and intervention communities

Awareness and attitude	Group	Proportion (%) in 2011	OR (95% CI)	P-value	Proportion (%) in 2012	OR (95% CI)	P-value	Change between 2011 and 2012 (McNemar's test)	
								OR (95% CI)	P-value
Problems associated with open defecation (n = 315), spontaneously mentioned									
Safety	Control	51.90	1		28.48	1		0.30 (0.16–0.54)	< 0.001
	Intervention	56.05	1.18 (0.76–1.84)	0.460	23.57	0.77 (0.47–1.28)	0.321	0.23 (0.12–0.40)	< 0.001
Hygiene	Control	24.05	1		34.18	1		1.70 (0.99–2.97)	0.056
	Intervention	26.11	1.12 (0.67–1.86)	0.673	36.31	1.10 (0.69–1.74)	0.693	1.55 (0.95–2.57)	0.081
No comfort	Control	22.15	1		6.33	1		0.19 (0.07–0.47)	< 0.001
	Intervention	28.66	1.41 (0.85–2.35)	0.185	8.28	1.34 (0.57–3.14)	0.507	0.22 (0.09–0.46)	< 0.001
Privacy	Control	22.15	1		22.78	1		1.04 (0.57–1.90)	1.000
	Intervention	5.73	0.21 (0.10–0.46)	< 0.001	11.46	0.44 (0.24–0.81)	0.009	2.8 (0.95–9.93)	0.064
Pollutes environment	Control	20.89	1		18.35	1		0.85 (0.47–1.54)	0.672
	Intervention	20.38	0.97 (0.56–1.67)	0.912	52.23	4.86 (2.92–8.10)	< 0.001	6.56 (3.23–15.04)	< 0.001
Difficulties for elderly or sick people	Control	9.49	1		1.90	1		0.14 (0.02–0.62)	0.004
	Intervention	2.55	0.25 (0.08–0.77)	0.016	1.91	1.01 (0.20–5.06)	0.994	0.75 (0.11–4.43)	1.000
Visitors	Control	5.06	1		8.23	1		1.83 (0.62–6.04)	0.332
	Intervention	1.27	0.24 (0.05–1.16)	0.076	5.10	0.60 (0.24–1.49)	0.269	4.00 (0.80–38.67)	0.109
Abundance of flies/insects	Control	2.53	1		20.25	1		8.00 (2.84–31.14)	< 0.001
	Intervention	5.73	2.34 (0.71–7.77)	0.164	18.47	0.89 (0.51–1.56)	0.689	3.86 (1.64–10.49)	< 0.001
Drinking water quality	Control	2.53	1		0.63	1		0.25 (0.01–2.53)	0.375
	Intervention	1.27	0.50 (0.09–2.75)	0.423	0.64	1.01 (0.06–16.23)	0.996	0.50 (0.01–9.61)	1.000
Reasons to possess a latrine (n = 89 in 2011, n = 249 in 2012, n = 69 with data for both years) ³ , spontaneously mentioned									
Comfort	Control	44.12	1		8.22	1		0.05 (0.00–0.30)	< 0.001
	Intervention	33.33	0.63 (0.23–1.77)	0.383	9.09	1.12 (0.42–2.98)	0.825	0.00 (0.00–0.85)	0.031
Clean environment	Control	32.35	1		31.51	1		0.80 (0.27–2.25)	0.815
	Intervention	42.86	1.57 (0.58–4.27)	0.379	46.02	1.85 (1.04–3.30)	0.036	1.00 (0.13–7.47)	1.000
Safety	Control	32.35	1		30.14	1		0.54 (0.18–1.45)	0.263
	Intervention	28.57	0.84 (0.29–2.45)	0.744	18.75	0.53 (0.29–1.00)	0.051	1.00 (0.19–5.37)	1.000
Privacy	Control	20.59	1		23.29	1		0.86 (0.27–2.76)	1.000
	Intervention	19.05	0.91 (0.26–3.13)	0.878	21.59	0.91 (0.47–1.74)	0.769	1.67 (0.32–10.73)	0.727
Avoid diseases	Control	19.12	1		38.36	1		2.50 (0.92–7.86)	0.078
	Intervention	14.29	0.71 (0.18–2.76)	0.616	39.77	1.06 (0.61–1.86)	0.835	5.00 (0.56–236.49)	0.219

Table 6 Comparison of changes in awareness and attitudes towards continued open defecation and latrine ownership as reported spontaneously from the household-based questionnaire between control and intervention communities (Continued)

Awareness and attitude	Group	Proportion (%) in 2011	OR (95% CI)	P-value	Proportion (%) in 2012	OR (95% CI)	P-value	Change between 2011 and 2012 (McNemar's test)	
								OR (95% CI)	P-value
Easier for elderly or sick people	Control	17.65	1		10.96	1		0.38 (0.06–1.56)	0.227
	Intervention	0.00	na	na	1.70	0.14 (0.04–0.55)	0.005	na	
Hygiene/Health	Control	8.82	1		39.73	1		16.00 (2.49–670.96)	< 0.001
	Intervention	19.05	2.43 (0.62–9.61)	0.205	28.41	0.60 (0.34–1.07)	0.082	2.50 (0.41–26.25)	0.453
Visitors	Control	8.82	1		13.70	1		1.40 (0.38–5.59)	0.774
	Intervention	0.00	na	na	9.09	0.63 (0.27–1.46)	0.282	na	na
Reason to practice open defecation (n = 349 for 2011, n = 188 for 2012, n = 149 with data for both years) ^a , spontaneously mentioned	Control	77.71	1		72.79	1		0.91 (0.46–1.77)	0.875
No functional latrine on spot	Intervention	90.10	2.61 (1.43–4.78)	0.002	41.46	0.27 (0.13–0.54)	< 0.001	na	< 0.001
Traditional habit	Control	22.93	1		10.88	1		0.25 (0.08–0.63)	0.001
	Intervention	18.23	0.75 (0.44–1.26)	0.279	7.32	0.65 (0.18–2.34)	0.506	0.17 (0.02–0.75)	0.013
Comfort	Control	4.46	1		2.04	1		0.40 (0.04–2.44)	0.453
	Intervention	2.60	0.57 (0.18–1.84)	0.350	0.00	na	na	na	na
Difficulties with maintenance/construction	Control	0.64	1		5.44	1		5.00 (0.56–236.49)	0.219
	Intervention	0.00	na	na	9.76	1.88 (0.54–6.58)	0.324	na	na

^aSelective question type; total number of respondents therefore changed by year and only households who did not undergo change in toilet ownership or practice of open defecation could be analysed for changes over time, as assessed by McNemar's test

80% of the households had latrines (Fig. 3). Particularly small communities (e.g. Amani Kouadiokro and Kouadio Kouamékro) rapidly reached 100% latrine coverage, and hence, were certified ODF. This corroborates recent findings from a CLTS programme conducted in Ghana that found the largest impact in small, remote villages with low exposure to prior water and sanitation projects [41]. Hamlets and small villages have the advantage to be usually socially cohesive with a more clear and respected hierarchy that may result in a faster and higher degree of social mobilisation of the associated community members. In larger villages, such as Katchénou where 17 weeks after triggering still fewer than 10% of the households possessed a latrine, conducting a health education campaign showed an impressive boosting effect. This underlines the need for integrated approaches combining CLTS or other sanitation programmes with health education. Future interventions in large communities, however, may represent a challenge for community mobilisation and need to address the role of communication and leadership (e.g. by repeated triggering, choice of “good” religious and/or secular leaders and community facilitators) [21, 42]. Compared to other CLTS programmes conducted in Eastern Africa, we reached ODF status within a relatively short period of time. Crocker et al. [43] explain low changes in open-defecation reduction and increase in latrine ownership with generally low open-defecation in Ethiopia.

Impact on helminth and intestinal protozoa infection

Interestingly, we did not observe significant differences in soil-transmitted helminth reinfection rates when comparing intervention and control communities. This may be partly explained by still relatively low reinfection rates in both groups (control: 7.0%, intervention: 11.8%), perhaps indicating a too short follow-up period (in our case five months). Our assumption was that infection levels in the control communities after a single round of preventive chemotherapy would have approached baseline levels (here > 25%) within about a year [3]. Impact assessment for helminth infection was further hampered by significant discrepancies in baseline infection levels between groups. While soil-transmitted helminth infections were more prevalent among intervention communities, schistosomiasis showed a highly focally distribution, as it mainly occurred in a single locality that was part of the control group. It should be noted, however, that a negative relationship between hookworm infections and toilet ownership and use was evident in the baseline data of the same study cohort [27]. Further, the finding on a significant difference in the extent of proportion of decrease in hookworm infection indicates that baseline positives that became negative were also

more likely to remain negative five months after treatment within the intervention group (Table 3).

For intestinal protozoa, although not tackled through the administration of anthelmintic drugs as part of the preventive chemotherapy component, we found significantly lower infection rates in the intervention communities at follow-up, while infection levels in control communities remained unchanged (Table 2). Baseline uninfected individuals were further found to be less likely to become newly infected with *E. nana* or *Blastocystis* sp. if they belonged to the intervention group as highlighted by a statistically significantly lower proportion of increase (Table 3). In the multivariable logistic regression analysis, the following variables were associated with significantly lower odds for intestinal protozoa infections: intervention community, ODF status, ownership and use of toilet. Lower intestinal protozoa infection levels and lower hookworm egg counts in intervention communities may serve as biological indicators for decreased environmental faecal pollution [44] and reduced abundance of flies acting as potential carriers [45]. Hence, our findings strengthen the assumption of a direct impact from the intervention package.

Other studies on community level incorporating a sanitation package to fight enteric parasite infections showed mixed results. Studies that reached high latrine coverage and with long-term follow-up [10] resulted in higher impact on prevalence and incidence, compared to studies achieving low latrine coverage [16] and high levels of continued open defecation [15].

Potential factors guiding infection status at follow-up

Reinfection patterns for soil-transmitted helminths highlight potential sources for continued transmission despite ODF status in intervention communities. School-aged children were at the highest risk of reinfection (23 out of 50 new infections in the intervention communities), which might, at least partly, be explained by children attending the nearest school that might be located in another community not yet declared ODF. Such reinfections might be considered as imported infections, dampening the impact for soil-transmitted helminthiasis control in intervention communities. Another potential source for reinfection could be seen in plantation sites, where open defecation is continued, as latrines were only built in close proximity to the households. In intervention communities, reported open defecation while people pursue agricultural activities remained relatively high (41.1%). Logistic regression modelling indicated potential cultural difference in hygiene practices, as expressed by a higher risk for intestinal protozoa (re)infections among the autochthonous population and reduced risk among Muslim community members. In previous research, males have been found to be more

prone for reinfection, as they are less adhering to good defecation practices and hygiene behaviour [9, 46, 47]. In our study, however, this gender-related reinfection pattern was no longer observed in the intervention communities compared to control communities where it persisted. How much of this can be related to positive change in defecation and hygiene behaviour among males and to what extent the interventions triggered it remains to be clarified.

Impact on behaviour and attitudes

Apart from access to sanitation facilities, attitudes towards defecation and hygiene practices, acceptance and (appropriate) use of these infrastructures are key determinants for discontinuation of open defecation and thus successful interruption of faecal contamination of the environment [15, 16]. Our findings showed high proportion of behaviour change within the intervention communities with considerably reduced reported open defecation in general (before: 95.8%, after: 44.6%), going hand-in-hand with an increase in stated toilet use (before: 15.5%, after: 94.6%). Especially open-defecation in close proximity to the households, which probably serves as the main source for infections and transmission via flies, plummeted in both adults (before: 75.0%, after: 16.7%) and children (before: 78.3%, after: 4.5%). Similarly to findings from a CLTS trial in rural Mali [13], household heads from intervention communities significantly more often reported washing hands after defecating. The intervention significantly increased perceptions of open defecation as polluting the environment among beneficiary communities. This may be explained by the emphasis given to activities focusing on projection of the extent of environmental contamination through faeces during CLTS triggering (e.g. mapping, calculating “caca”, transect walk and identifying the dirtiest neighbourhoods) [22].

Nevertheless, it is difficult to say to what extent CLTS alone or the combination of health education and preventive chemotherapy improved people’s behaviour of defecation and general hygiene and cleanliness. Lawrence et al. [48] identified shame from the CLTS triggering as one of the most important factors for behavioural change in rural Zambia. Yet, CLTS may also influence adherence through other social and emotive factors that include disgust, pressure from hierarchical powers and community groups, and competition among villages to achieve ODF status. Health education complements by addressing lacking knowledge on disease transmission and prevention. Raising awareness is particularly important where local concepts of helminthiasis and diarrhoeal diseases may foster risk-related behaviour or reduce adherence to best practices [49]. Further research on factors improving adherence to

CLTS and health education interventions is warranted and may contribute to enhancing community effectiveness of such interventions.

Strengths and limitations

A strength of our study is the rigorous sanitation approach, namely CLTS, which implies a very high private latrine ownership coverage and, ideally, the certification of ODF status in an intervention community. Furthermore, adherence may be enhanced due to non-subsidized latrine provision [16, 50, 51]. However, our assessment on behaviour change and adherence to hygiene practices is based on reported frequencies from cross-sectional questionnaire surveys administered to household heads and is not supported by direct observations. Thus, the assumption of the link between access to a private latrine and its use might not be entirely valid.

Certain considerations with regard to study design should be taken into account in future studies to generate stronger evidence. Specifically, inclusion of more localities is pivotal, so that bias from local heterogeneity of helminth and intestinal protozoa infection can be mitigated. Furthermore, a cluster randomised controlled trial design generates stronger evidence, since potential baseline differences in disease prevalence, population size, level of existing water and sanitation infrastructure are addressed through randomisation [7]. Sustainability of CLTS is a critical issue [36] and remains to be assessed in different social-ecological settings. Our study had a relatively short follow-up period between the last round of anthelmintic treatment and the follow-up parasitological assessments and thus might not have allowed measuring the full impact on helminth infections. A prolonged survey period would thus improve surveillance data with regard to reinfection patterns as well as create new evidence on long-term effects of CLTS and health education as a means for controlling and eliminating neglected tropical diseases [10].

Conclusions

CLTS in combination with health education and preventive chemotherapy holds promise as an effective participatory approach that can be applied at community level to improve people’s health and wellbeing. In our view, the results obtained here from a primarily rural setting of Côte d’Ivoire with high levels of open-defecation and low access to sanitation programmes at the start of the interventions are relevant for other settings in low- and middle-income countries [13]. CLTS implemented at a large scale can further contribute to reach the sixth of the defined Sustainable Development Goals, namely to ensure availability and sustainable

management of water and sanitation for all [52]. To assess potential gains in neglected tropical diseases control from such an integrated approach compared to preventive chemotherapy alone and to evaluate its sustainability, additional research is warranted, using rigorous study designs, such as cluster-randomised trials.

Additional files

Additional file 1: Table S1. Characteristics of the final cohort. (DOCX 14 kb)

Additional file 2: Table S2. Mean infection intensity in control and intervention communities during baseline and follow-up surveys. (DOCX 17 kb)

Abbreviations

CI: Confidence interval; CLTS: Community-led total sanitation; CSRS: Centre Suisse de Recherches Scientifiques en Côte d'Ivoire; DALY: Disability-adjusted life year; egg: Eggs per gram of stool; ERR: Egg reduction rate; HDSS: Health and demographic surveillance system; KAPB: Knowledge, attitudes, practices and beliefs; NGO: Non-governmental organisation; ODF: Open defecation free; OR: Odds ratio; SAF: Sodium acetate-acetic acid-formalin; UNICEF: United Nations Children's Fund; WASH: Water, sanitation and hygiene; WHO: World Health Organization

Acknowledgements

We thank all medical staff, students, field technicians, drivers, the whole team of the Taabo health and demographic surveillance system, the Centre Suisse de Recherches Scientifiques en Côte d'Ivoire and the Unité de Formation et de Recherche Biosciences from the Université Félix Houphouët-Boigny for their excellent performance and cooperation in the field and the laboratory. We are grateful to all community authorities and members for their acceptance, commitment and eager participation in this project.

Funding

This study received financial support from the UBS Optimus Foundation (Zurich, Switzerland).

Availability of data and materials

The data supporting the conclusions of this article are included in the article and its additional file. The raw data used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Authors' contributions

JU and GR conceived and designed the experiments. EH, KDS, FZ, MO, TS, RBY, CAH, KD, BAK, CAA-D and GR performed the experiments. EH and GR analysed the data. KDS, SK, BB, EKN, JU and GR contributed reagents/materials/analysis tools and provided scientific input. EH and GR wrote the paper. BB, EKN, JU and GR supervised the study. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study received clearance from the ethics committees of Basel (Ethikkommission beider Basel; reference no. 177/11) and Côte d'Ivoire (Comité National d'Ethique et de la Recherche; reference no. 13324 MSLS/CNER-P). Study participants were informed about the aims, procedures, and potential risks and benefits of the study. Participants and parents/guardians of minors provided written informed consent (signature of a witness for illiterate participants). It was emphasised that participation was voluntary and one could withdraw from the study at any time without further obligation. Each study participant was given a unique identification number to guarantee anonymity.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Received: 16 August 2017 Accepted: 12 January 2018

Published online: 27 February 2018

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