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Epidemiology of intestinal parasite infections in three departments of south-central Côte d'Ivoire before the implementation of a cluster-randomised trial

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ABSTRACT

Hundreds of millions of people are infected with helminths and intestinal protozoa, particularly children in low- and middle-income countries. Preventive chemotherapy is the main strategy to control helminthiases. However, rapid re-infection occurs in settings where there is a lack of clean water, sanitation and hygiene. In August and September 2014, we conducted a cross-sectional epidemiological survey in 56 communities of three departments of south-central Côte d'Ivoire. Study participants were invited to provide stool and urine samples. Stool samples were examined for helminth and intestinal protozoa infections using the Kato-Katz technique and a formalin-ether concentration method. Urine samples were subjected to a filtration method for the diagnosis of *Schistosoma haematobium*. Information on sociodemographic characteristics, knowledge, attitude, practices and beliefs with regard to hygiene, sanitation and intestinal parasitic diseases were collected using a questionnaire administered to household heads. Multivariable logistic regression models were employed to analyse associations between parasite infections and risk factors. Overall, 4,305 participants had complete parasitological and questionnaire data. Hookworm was the predominant helminth species (21.2%), while *Ascaris lumbricoides*, *Trichuris trichiura*, *Schistosoma mansoni* and *S. haematobium* showed prevalences below 10%. Infections with pathogenic intestinal protozoa (e.g. *Entamoeba histolytica/E. dispar* and *Giardia intestinalis*) were similarly prevalent in the three departments. Hookworm infection was associated with open defecation and participants' age and sex. *Entamoeba coli* infection was negatively associated with the use of tap water at home (odds ratio (OR) = 0.66; $p = 0.032$). Disposal of garbage in close proximity to people's home was positively associated with *G. intestinalis* (OR = 1.30; $p = 0.015$). Taken together, helminth and intestinal protozoa infections affected a considerable proportion of rural dwellers in south-central Côte d'Ivoire at the onset of a

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cluster-randomised intervention trial. Our results will serve as baseline to monitor the effect of a package of interventions, including preventive chemotherapy, sanitation and health education on re-infection with helminths and intestinal protozoa.

Trial registration: ISRCTN53102033 (date assigned: 26 March 2014)

1. Introduction

Intestinal parasitic diseases due to infections with helminths (e.g. soil-transmitted helminthiasis (STH) and schistosomiasis) and intestinal protozoa (e.g. amoebiasis and giardiasis) are widespread in tropical and subtropical regions, where climatic, ecological, socioeconomic and hygienic conditions favour their transmission (Hotez et al., 2014; Utzinger et al., 2012). More than a billion people are affected by STH, schistosomiasis and intestinal protozoa infections, causing an estimated 26.1 million disability-adjusted life years (GBD 2015 DALYs and HALE Collaborators, 2015; Pullan et al., 2014). School-aged children in low- and middle-income countries are at highest risk of infection, and hence, developing morbidity (Nematian et al., 2004; Ostan et al., 2007).

For the control of STH and schistosomiasis, the World Health Organization (WHO) recommends preventive chemotherapy, which is the periodic treatment with albendazole or mebendazole against STH and praziquantel against schistosomiasis, mainly targeting school-aged children (WHO, 2006). Preventive chemotherapy primarily aims at reducing worm loads, and hence, reducing associated morbidity (WHO, 2011). However, preventive chemotherapy does not protect from re-infection (Hotez et al., 2008; Jia et al., 2012). To sustain control and move towards elimination, it is necessary to complement preventive chemotherapy with other measures, such as interventions improving water, sanitation and hygiene (WASH) and information, education and communication (IEC) (Grimes et al., 2014; Jia et al., 2012; McManus et al., 2014; Strunz et al., 2014; Ziegelbauer et al., 2012).

In Côte d'Ivoire, STH, schistosomiasis, giardiasis and amoebiasis are of considerable public health relevance (Ouattara et al., 2010; Yapi et al., 2016). Coverage of improved water and sanitation is low among rural populations. In turn, open defecation is common (Schmidlin et al., 2013). In 2011 and 2012, a pilot study was implemented to evaluate the effect of an intervention package to reduce re-infection with helminths and intestinal protozoa and to initiate changes in hygiene and defecation behaviour (Hürlimann et al., 2018). Results were promising, and hence, a research project was launched in August 2013, designed as a cluster-randomised trial to be conducted in 56 communities of three departments in south-central Côte d'Ivoire. The aim was to document the effect of an integrated control approach, consisting of preventive chemotherapy, community-led total sanitation (CLTS) and health education, on re-infection with helminths and intestinal protozoa and diarrhoeal incidence. Here, we focus on the baseline situation before implementing the aforementioned cluster-randomised trial and describe the epidemiology of helminthiases and intestinal protozoa infections.

2. Material and methods

2.1. Ethics approval and consent to participate

Institutional approval of the study protocol was granted by the research commission of the Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS). Ethical clearance was granted by the ethics committees of Basel (EKBB, reference no. 300/13) and Côte d'Ivoire (reference no. 76-MSLS-CNER-dkn). Local authorities (village chiefs) and community members were informed on the objectives, procedures, and potential risks and benefits of the study. Written informed consent of each participant was obtained (for children aged below 18 years, consent was given by parents or legal guardians). It was emphasised that participation was voluntary and withdrawal from the study was possible anytime without further obligations.

All members of the 56 communities received a single oral dose of albendazole (400 mg for participants aged > 2 years and 200 mg for children aged 1–2 years, respectively) against STH. A single 40 mg/kg oral dose of praziquantel against schistosomiasis was administered to community members aged 5 years and above in localities where the prevalence of schistosomiasis was greater or equal to 5%, while individual case treatment was applied in localities with lower prevalences. Drug administration was implemented by the 'Programme National de Lutte contre les Maladies Tropicales Négligées à Chimiothérapie Préventive' (PNLMTN-CP) in collaboration with personnel from local health districts and our research team.

2.2. Study area and population

The study was conducted in August and September 2014 in the departments of Taabo, Djékanou and Toumodi, located in the south-central part of Côte d'Ivoire. The department of Taabo belongs to the Agnéby-Tiassa region, while Djékanou and Toumodi are part of the Bélier region (Fig. 1). The area of the three departments is drained by the tributaries of the Bandama and N'Zi rivers. The former crosses the Taabo department and is impounded by a large dam creating Lake Taabo that is used for hydroelectric power production (N'Goran et al., 1997). Additionally, there are seasonal streams that are usually dried out between November and February. The study zone is characterised by a forest savannah ecology (Koffi et al., 2013) and a tropical climate with a recent tendency to a single rainy season (March to July) (Bassa et al., 2016). The mostly rural population is engaged in subsistence farming (e.g. banana, cassava, maize and yams) and cultivation of cacao, coffee and rubber for cash. In communities living in close proximity to Lake Taabo, fishery constitutes an important livelihood activity.

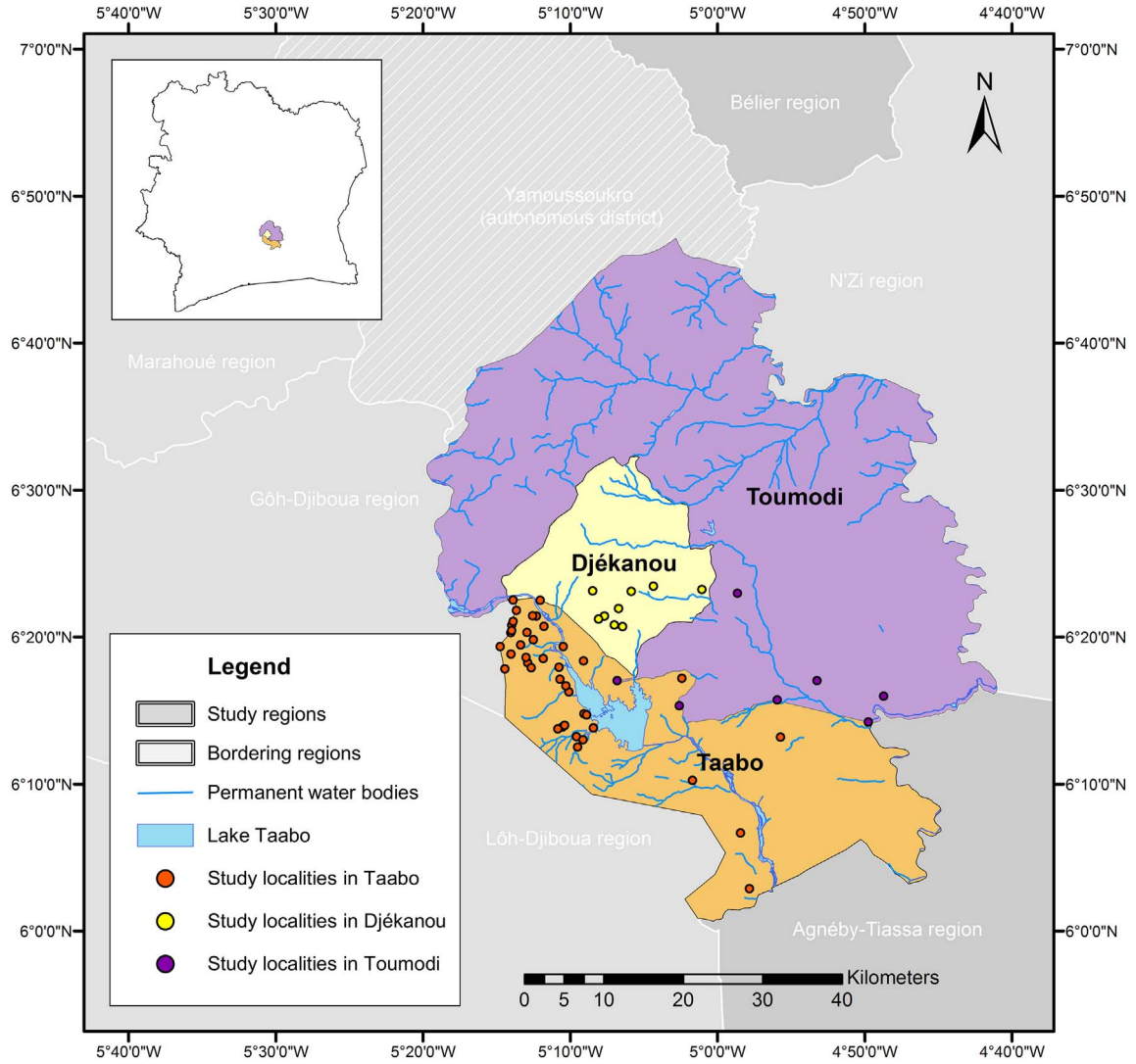

Fig. 1. Study area. The cross-sectional study was carried in August and September 2014 in 56 communities of three departments in south-central Côte d'Ivoire: seven localities were in the Toumodi department, nine localities in the Djékanou department and the remaining 40 localities in the Taabo department.

Initially, the study was planned to comprise 56 localities in the department of Taabo alone, because of the presence of the Taabo health and demographic surveillance system (HDSS) that monitors a population of about 42,000 people since 2008 (Koné et al., 2015). However, the number of appropriately sized communities in the Taabo department was lower than expected and consequently the study was extended into the adjacent Djékanou and Toumodi departments to obtain the required number of localities. To that end, our study involved 40 localities in the Taabo department, nine in the Djékanou department and seven in the Toumodi department (Fig. 1). In each locality, households were selected as follows: six transects were set from the centre of the community in different directions towards the edge of the village and, subsequently, on each transect five households with at least one child aged 5–15 years were selected. Thus, a total of 30 households were chosen per locality. In small hamlets comprising less than 30 households, all households were invited to participate. In each household, all school-aged children (5–15 years), one adolescent or adult (aged > 15 years) and one preschool-aged child (< 5 years) were selected and invited to participate.

2.3. Collection of stool and urine samples

In each study community, project-associated community health workers (CHWs) and field enumerators from the Taabo HDSS provided participants with two plastic containers; one for stool and one for urine collection, the day before the field team's visit. All participating household members were asked to return the filled containers the next morning (between 08:00 and 12:00 h). On the day of collection, the research team labeled each container with a unique identification code and stored them in racks to be transferred to nearby laboratories at the general hospitals of Taabo and Djékanou, the community health centre of Kpouébo in the department of Toumodi and a mobile field laboratory set up at the dispensary of Léléblé in the Taabo department.

2.4. Laboratory procedures

Stool samples were processed by the Kato-Katz technique (Katz et al., 1972). In brief, duplicate thick smears were prepared on microscope slides using standard 41.7 mg templates. The slides were allowed to clear for 30–45 min before examination under a microscope by one of eight experienced laboratory technicians. The number of eggs of each helminth species (e.g. *Schistosoma mansoni*, *Ascaris lumbricoides*, *Trichuris trichiura* and hookworm) was recorded and multiplied by a factor of 24 to obtain the number of eggs per gram of stool (EPG). A portion of stool (1–2 g) was preserved in 10 ml of sodium acetate-acetic acid-formalin (SAF) solution for further diagnostic work-up. Urine samples that were positive for microhaematuria from reagent strip testing (Hemastix, Siemens Healtheare; Zurich, Switzerland) were subjected to a filtration method for quantification of *Schistosoma haematobium* eggs (Plouvier et al., 1975).

SAF-preserved stool samples were transferred to the Université Félix Houphouët-Boigny (Abidjan, Côte d'Ivoire). An ether

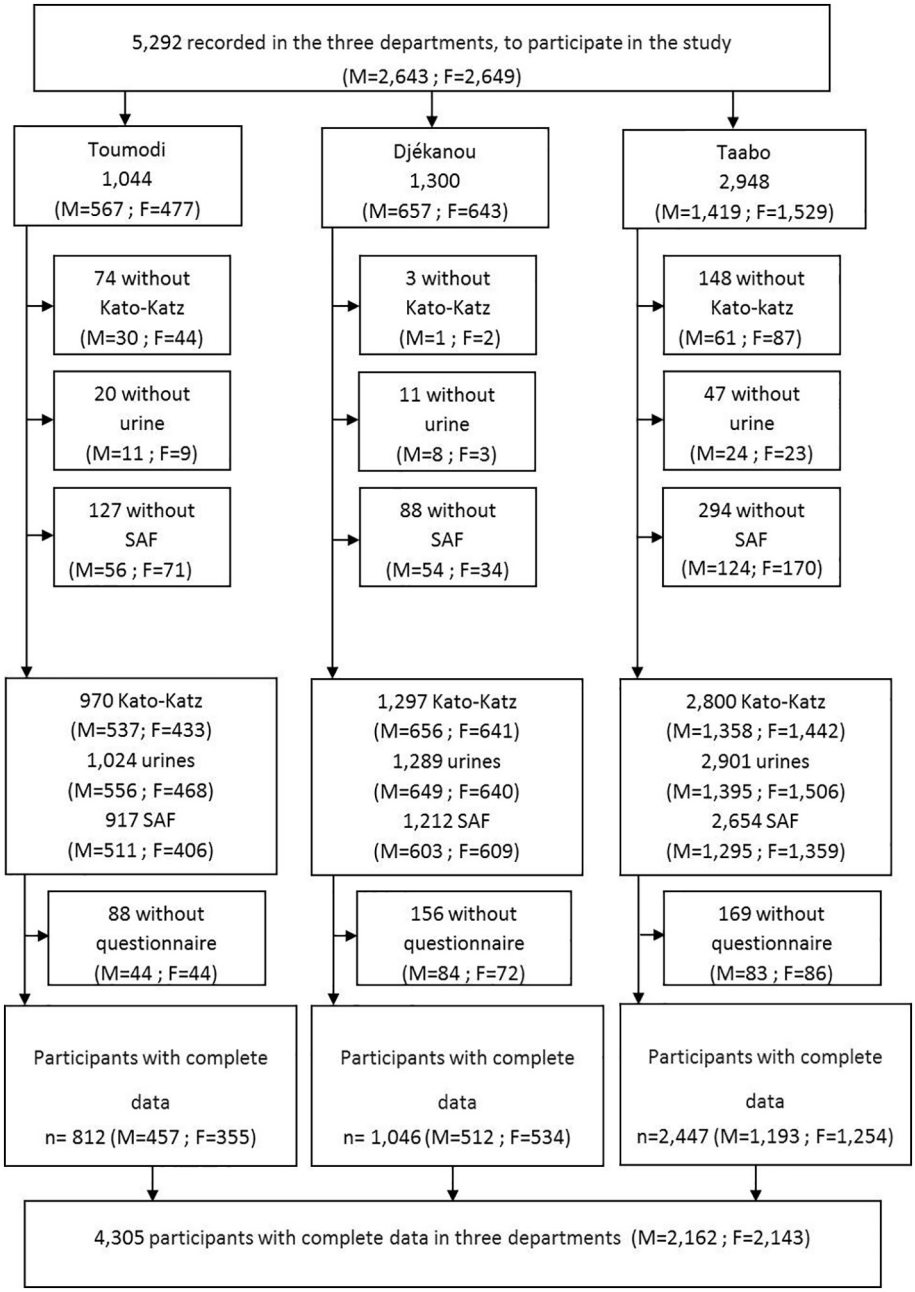

Fig. 2. Flow chart detailing the participation of individuals (F = female, M = male) in the parasitological and questionnaire survey and final sample used for analysis. The cross-sectional study was carried in August and September 2014 in 56 communities of three departments in south-central Côte d'Ivoire.

concentration method was employed and samples examined for helminths and intestinal protozoa by experienced laboratory technicians (Utzinger et al., 2010). The number of species-specific helminth eggs was recorded, whereas intestinal protozoa cysts and trophozoites were recorded semi-quantitatively based on occurrence per slide or field of views at a magnification of x400 or x500 (Utzinger et al., 2010).

2.5. Questionnaire survey

A questionnaire was administered to all selected households on the same day as stool and urine samples were collected. The questionnaire was readily adapted from an instrument previously used in a pilot study conducted in the same setting (Schmidlin et al., 2013). It aimed at household heads and included questions on demographic factors (e.g. age, sex, ethnicity and education), socioeconomic indicators (e.g. possession of household assets) and reported or observed WASH indicators (e.g. sources of water for household use, open defecation, use of latrines and waste disposal near the house).

2.6. Statistical analysis

Parasitological data were double-entered in Microsoft Excel and cross-checked in EpiInfo version 3.5.4 (Centers for Disease Control and Prevention; Atlanta, USA). Questionnaire data were collected using open data kit (ODK). Note that ODK is an open source software for electronic data collection (http://opendatakit.org/) that we operated on mobile Android devices. Data were uploaded daily on a server. Statistical analyses were performed with STATA version 11.0 (Stata Corporation; College Station, USA).

For each study participant, the arithmetic mean of the number of species-specific helminth egg counts was calculated based on the duplicate Kato-Katz thick smear readings. At the community level, the geometric mean egg counts were calculated. Helminth infection intensities were classified according to WHO guidelines, as follows: for *S. mansoni* infection three categories were used, light infection (1–99 EPG), moderate infection (100–399 EPG) and heavy infection (≥400 EPG); for STH, light, moderate and heavy infections were 1–1,999 EPG, 2,000–3,999 EPG and ≥4,000 EPG for hookworm; 1–4,999 EPG, 5,000–49,999 EPG and ≥50,000 EPG for *A. lumbricoides*; and 1–999 EPG, 1,000–9,999 EPG and ≥10,000 EPG for *T. trichiura* (WHO, 2002). *S. haematobium* infection was categorised into light (1–49 eggs/10 ml of urine) and heavy (≥50 eggs/10 ml of urine) intensity (WHO, 2002).

Participants were stratified into six age groups (< 5, 5–9, 10–14, 15–19, 20–24 and ≥25 years). The socioeconomic index was calculated using principal component analysis (PCA) via an asset-based approach and stratified into wealth quartiles (most poor, very poor, poor and least poor) (Filmer and Pritchett, 2001). Univariate analysis (x^2 and Fisher's exact test, as appropriate) was used for comparison between groups. Significant associations between parasite infections, sociodemographic factors and WASH indicators (e.g. use of latrine, open defecation and water sources) were assessed by multivariable logistic regression. Models were adjusted for parasite species, age, sex, ethnicity and wealth quartiles. For all statistical analyses, a p-value below 0.05 was considered as significant.

3. Results

3.1. Characteristics of the study population

A total of 4,305 participants (2,162 males and 2,143 females) had complete parasitological and questionnaire data, and hence, were included for all subsequent analyses (Fig. 2). There were 339 (7.9%) preschool-aged children (< 5 years), 3,183 (73.9%) school-aged children (5–15 years) and 783 (18.2%) adolescents and adults (> 15 years). The majority (2,447) of participants lived in the Taabo department, while 1,046 and 812 participants were from the Djékanou and Toumodi departments, respectively.

3.2. Parasite infections

The prevalence of species-specific helminth and intestinal protozoa infection is shown in Table 1. Individual helminth infections were generally low (< 5%), except for hookworm that showed a prevalence of 35.3% in Djékanou and 34.2% in Toumodi departments, respectively. In Taabo department, the overall hookworm prevalence was 10.9%. We noted a few hot spots of schistosomiasis with prevalences above 20% and up to 43% in some villages of Toumodi and Taabo departments.

The prevalences of intestinal protozoa infections were similar between the three departments, varying from 1.0% to 42.4%, depending on the species. The most common intestinal protozoa were non-pathogenic species, *Entamoeba coli* and *Endolimax nana*, with overall prevalences of 40.2% and 19.6%, respectively. *Giardia intestinalis* had a prevalence of about 13% in all three departments.

3.3. Intensity of infection

Helminth infection intensities were quite similar in the three departments. However, a marked difference was observed for hookworm infection, where a considerably lower infection intensity was observed in the Taabo department (1.6 EPG, 95% confidence interval (CI): 1.5–1.7 EPG), compared to Toumodi (5.1 EPG, 95% CI: 4.3–6.0 EPG) and Djékanou (5.8 EPG, 95% CI: 4.9–6.7 EPG). In terms of intensity categories, helminth infections were primarily of light intensity in all three departments (Table 2). Regarding pathogenic intestinal protozoa, almost all *Entamoeba histolytica/E. dispar*-infected participants had a light or moderate intensity infection, while one-third of the *G. intestinalis*-positive participants were heavily infected.

Table 1
Prevalence of helminth and intestinal protozoa infections in three departments, south-central Côte d'Ivoire in August and September 2014.

Parasite species	Department					
	Toumodi (n = 812)		Djékanou (n = 1,046)		Taabo (n = 2,447)	
	Infected	% (95% CI[a])	Infected	% (95% CI[a])	Infected	% (95% CI[a])
Helminths						
Schistosoma haematobium	57	7.0 (5.4–9.0)	23	2.2 (1.4–3.3)	82	3.4 (2.7–4.1)
Schistosoma mansoni	18	2.2 (1.3–3.5)	8	0.8 (0.3–1.5)	94	3.8 (3.1–4.7)
Hookworm	278	34.2 (31.0–37.6)	369	35.3 (32.4–38.3)	266	10.9 (9.7–12.2)
Trichuris trichiura	4	0.5 (0.1–1.3)	13	1.2 (0.7–2.1)	51	2.1 (1.6–2.7)
Ascaris lumbricoides	3	0.4 (0.1–1.1)	1	0.1 (0.0–0.5)	8	0.3 (0.1–0.6)
Intestinal protozoa						
Entamoeba coli	331	40.8 (37.4–44.2)	443	42.4 (39.3–45.4)	955	39.0 (37.1–41.0)
Endolimax nana	179	22.0 (19.2–25.1)	223	21.3 (18.9–24.0)	440	18.0 (16.5–19.6)
Giardia intestinalis	105	12.9 (10.7–15.4)	139	13.3 (11.3–15.5)	320	13.1 (11.8–14.5)
Blastocystis hominis	74	9.1 (7.2–11.3)	93	8.9 (7.2–10.8)	231	9.4 (8.3–10.7)
Iodamoeba bütschlii	68	8.4 (6.6–10.5)	75	7.2 (5.7–8.9)	211	8.6 (7.5–9.8)
Entamoeba histolytica/E. dispar	46	5.7 (4.2–7.5)	45	4.3 (3.2–5.7)	149	6.1 (5.2–7.1)
Chilomastix mesnili	42	5.2 (3.8–6.9)	52	5.0 (3.7–6.5)	113	4.6 (3.8–5.5)
Entamoeba hartmanni	8	1.0 (0.4–1.9)	18	1.7 (1.0–2.7)	46	1.9 (1.4–2.5)

[a] Confidence interval.

Table 2
Helminth and intestinal protozoa infection intensities, stratified by study departments, from August to September 2014.

Parasite species	Department								
	Toumodi (n = 812)			Djékanou (n = 1,046)			Taabo (n = 2,447)		
	Light (%)	Moderate (%)	Heavy (%)	Light (%)	Moderate (%)	Heavy (%)	Light (%)	Moderate (%)	Heavy (%)
Helminths									
Schistosoma haematobium	45 (78.9)	N/A[a]	12 (21.1)	20 (87.0)	N/A[a]	3 (13.0)	64 (78.0)	N/A[a]	18 (22.0)
Schistosoma mansoni	9 (50.0)	6 (33.3)	3 (16.7)	8 (100)	0	0	60 (63.8)	19 (20.2)	15 (16.0)
Hookworm	269 (96.8)	6 (2.2)	3 (1.1)	347 (94.0)	10 (2.7)	12 (3.3)	260 (97.7)	5 (1.9)	1 (0.4)
Trichuris trichiura	2 (50.0)	2 (50.0)	0	12 (92.3)	1 (7.7)	0	38 (74.5)	9 (17.6)	4 (7.8)
Ascaris lumbricoides	3 (100)	0	0	1 (100)	0	0	5 (62.5)	3 (37.5)	0
Intestinal protozoa									
Entamoeba coli	116 (35.0)	167 (50.5)	48 (14.5)	181(40.9)	173 (39.1)	89 (20.1)	320 (33.5)	458 (48.0)	177 (18.5)
Endolimax nana	79 (44.1)	79 (44.1)	21 (11.7)	110 (49.3)	99 (44.4)	14 (6.3)	216 (49.1)	172 (39.1)	52 (11.8)
Giardia intestinalis	27 (25.7)	45 (42.9)	33 (31.4)	32 (23.0)	61 (43.9)	46 (33.1)	73 (22.8)	147 (45.9)	100 (31.3)
Blastocystis hominis	21 (28.4)	38 (51.4)	15 (20.3)	39 (41.9)	42 (45.2)	12 (12.9)	75 (32.5)	117 (50.6)	39 (16.0)
Iodamoeba bütschlii	29 (42.6)	27 (39.7)	12 (17.6)	22 (29.3)	35 (46.7)	18 (24.0)	69 (32.7)	99 (46.9)	43 (20.4)
Entamoeba histolytica/E. dispar	22 (47.8)	21 (45.7)	3 (6.5)	28 (62.2)	16 (35.6)	1 (2.2)	68 (45.6)	71 (47.7)	10 (6.7)
Chilomastix mesnili	16 (38.1)	19 (45.2)	7 (16.7)	18 (34.6)	28 (53.8)	6 (11.5)	49 (43.4)	46 (40.7)	18 (15.9)
Entamoeba hartmanni	3 (37.5)	5 (62.5)	0	7 (38.9)	8 (44.4)	3 (16.7)	21 (45.7)	20 (43.5)	5 (10.9)

Helminth infection intensity categories are based on eggs per gram of stool (EPG) and 10 ml of urine for *S. haematobium* and defined according to World Health Organization guidelines (WHO, 2002). Intestinal protozoa infection intensities were recorded based on a semi-quantitative method distinguishing between light (1-5 cysts or trophozoites per slide); moderate (1 cyst or trophozoite per observation field at a magnification of ×400 or 500); and heavy (more than 1 cyst or trophozoite per observation field at a magnification of ×400 or 500) (Utzinger et al., 2010).

[a] Not applicable

3.4. Parasite infection status, stratified by age and sex

Figs. 3 and 4 show the prevalence of intestinal protozoa and helminth infections, stratified by age groups and sex in the three departments. Males were significantly more often infected with hookworm ($x^2 = 83.42$; $p < 0.001$) and *T. trichiura* ($x^2 = 7.04$; $p = 0.008$) than females. We found the same pattern with *G. intestinalis* ($x^2 = 15.63$; $p < 0.001$). In contrast, females were more likely to be infected with *E. coli* than males (42.0% *versus* 38.3%; $x^2 = 6.28$; $p = 0.012$) and *E. nana* (21.6% *versus* 17.5%; $x^2 = 11.36$; $p = 0.001$). In all three departments, males were significantly more infected with hookworm compared to females ($p < 0.001$ for all three departments). More detailed information pertaining to parasite infection frequencies, stratified by sex, are provided in the Appendix Table A.1.

Regarding age, significant differences were found for hookworm ($x^2 = 134.47$; $p < 0.001$), *S. mansoni* ($x^2 = 16.17$; $p = 0.006$), *S. haematobium* ($x^2 = 16.17$; $p = 0.006$) and seven intestinal protozoa species (*G. intestinalis*, *E. histolytica/E. dispar*, *E. coli*, *E. nana*, *Entamoeba hartmanni*, *Iodamoeba bütschlii* and *Blastocystis hominis*) diagnosed with an ether concentration method using SAF-fixed stool samples. Participants aged 15–19 years showed the highest infection prevalence for hookworm and *S. haematobium*. Further details pertaining to parasite infection frequencies, stratified by age group, are presented in the Appendix Table A.2.

3.5. Associations between parasite infections, sociodemographic factors and WASH indicators

All significant associations ($p < 0.05$) between parasite infections, sociodemographic factors and WASH indicators, as determined by logistic regression analyses, are presented in Tables 3 and 4. Our results showed that being infected with *S. mansoni* and *S. haematobium* was significantly associated with ethnic groups. In terms of relationships between parasite infections and WASH, the multivariable models revealed a positive association between hookworm and open defecation (OR = 1.28; $p = 0.014$). Furthermore, *E. coli* was negatively associated with tap water use (OR = 0.66; $p = 0.032$). *G. intestinalis* was statistically positively associated with household's waste disposal occurring near the household (OR = 1.32; $p = 0.010$).

4. Discussion

We present the baseline epidemiological situation of helminthiases (STH and schistosomiasis) and intestinal protozoa infection among more than 4,000 individuals before the implementation of a cluster-randomised trial in three departments of south-central Côte d'Ivoire. The most prevalent intestinal helminth infection was hookworm (913 among 4,305 individuals infected; 21.2%). While more than a third of the study population in Toumodi and Djékanou were infected with hookworm, the respective prevalence in Taabo was considerably lower (10.9%). This observation might be explained by prior interventions in Taabo, in the frame of research and control targeting neglected tropical diseases. This includes annual treatment with albendazole plus ivermectin for the control/elimination of lymphatic filariasis, IEC and CLTS conducted by researchers and the Taabo HDSS staff (Fürst et al., 2012; Glinz et al., 2017; Hürlimann et al., 2014; Hürlimann et al., 2018; Lo et al., 2017; Righetti et al., 2013; Schmidlin et al., 2013). Of note, control/elimination activities for lymphatic filariasis, schistosomiasis and STH by the Ministry of Health in Côte d'Ivoire are currently ongoing in all three departments.

Males, particularly those aged 15–19 years, were most commonly infected with hookworm. Life style of adolescents and young adults put them at risk of becoming infected with helminths trough professional activities. Indeed, in the study area, cocoa farming is a main economic activity of the local population (Bassa et al., 2016; Hürlimann et al., 2018). It is important to note that control of STH currently focuses on school-aged children, as they are at highest risk of morbidity. Hence, control is mainly done through the education platform or might be combined with vaccination campaigns for infants (Anon, 2016). It follows that individuals aged

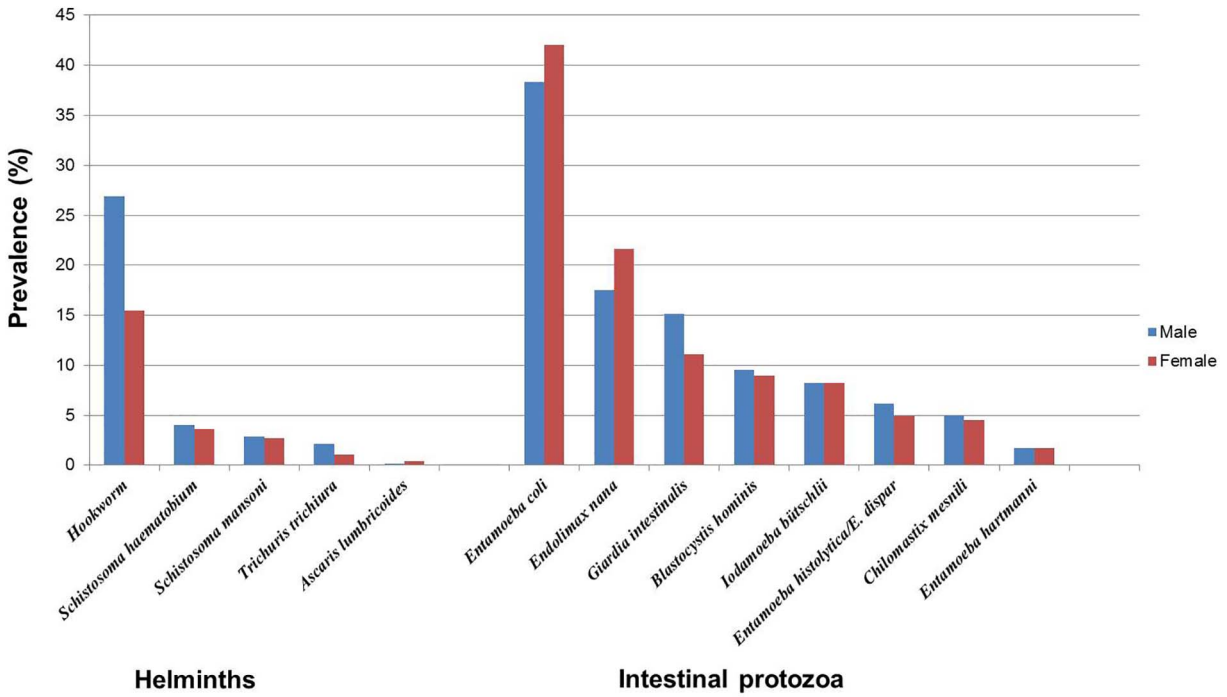

Fig. 3. Prevalence of investigated parasites in 4,305 community members, stratified by sex. The cross-sectional study was carried in August and September 2014 in 56 communities of three departments in south-central Côte d'Ivoire.

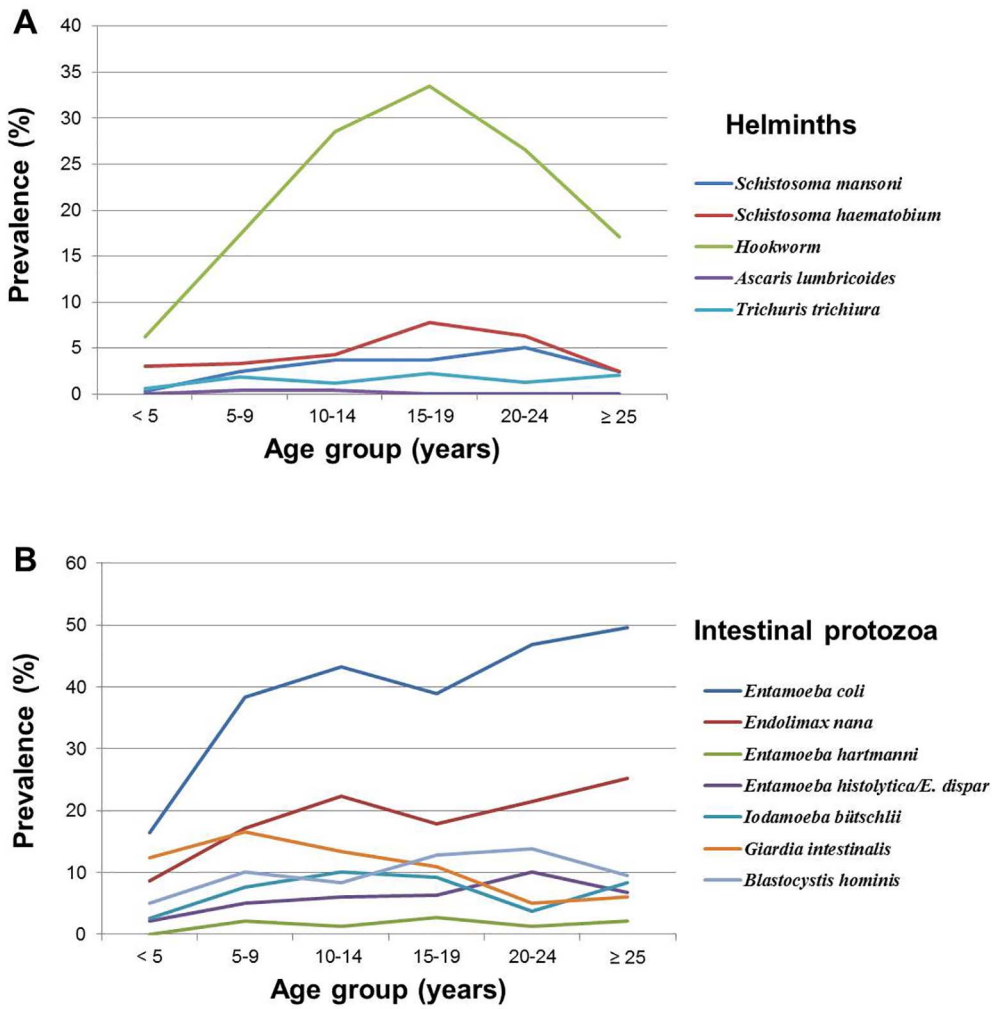

Fig. 4. Age-prevalence curves of helminths (A) and intestinal protozoa (B) infections of the study population (n = 4,305). The cross-sectional study was carried in August and September 2014 in 56 communities of three departments in central Côte d'Ivoire.

15 years and above are neglected by preventive chemotherapy campaigns. There is a pressing need to address this issue, particularly in view of equity, cost-effectiveness and aspirations to move from morbidity control to elimination (Lo et al., 2016; Lo et al., 2017).

Schistosomiasis was observed in all three departments with a prevalence of up to 40% in some focal areas. Interestingly, we noted an increase in the overall prevalence of *S. mansoni* from 1.3% in 2013 (Schmidlin et al., 2013) to 3.8% in the current study (2014/2015) in the Taabo department. The occurrence of *S. mansoni* in the study area is quite recent and appears to expand as we observed new foci (Fürst et al., 2012; N'Goran et al., 1997). For instance, a high prevalence was observed in Ahouaty (43.1%) and a moderate prevalence in N'Denou (20.9%), two neighbouring localities, downstream from Lake Taabo in close proximity to the Bandama River. In contrast to the increase of *S. mansoni*, it seems that *S. haematobium* is well under control; while a high prevalence was observed in the early 1990s in villages around Lake Taabo (73%) and in the late 1990s in Taabo village (up to 90%) (N'Goran et al., 2001), we now found an overall prevalence of 3.4%. It is conceivable that preventive chemotherapy with praziquantel, coupled with IEC and social and economic development, explains this decline. Yet, the fact that *S. mansoni* foci emerged might as well indicate a change in the intermediate host snail population ecology with *Biomphalaria pfeifferi* becoming the predominant snail species (Southgate, 1997).

The prevalence of intestinal protozoa infection was similar in all three departments. Pathogenic intestinal protozoa were observed at comparable levels as in previous studies (Hürlimann et al., 2014). *G. intestinalis* remains the predominant pathogenic intestinal protozoon with an overall prevalence above 10% in all three departments. Meanwhile, non-pathogenic intestinal protozoa species, namely *E. coli* and *E. nana*, showed the highest prevalence, corroborating previous studies conducted in different parts of Côte d'Ivoire (Coulibaly et al., 2012; Ouattara et al., 2010; Traoré et al., 2011). Although these are non-pathogenic protozoa, it highlights the high faecal contamination of the community surroundings (Savichtcheva and Okabe, 2006).

The lack of clean water and improved sanitation, is an impediment for transmission interruption of intestinal parasite infections in the surveyed communities (Schmidlin et al., 2013). Multivariable logistic regression analyses revealed significant associations between parasite infections and hygiene indicators, after adjusting for sex, age, ethnicity and wealth quartiles. For example, we found a

Table 3
Significant associations between helminth infections, socio-demographic factors and WASH indicators in study participants (n = 4,305) from 56 communities of three departments in south-central Côte d'Ivoire, from August to September 2014.

Parasite	Association	OR[b] (95% CI[a])	*p*-value[c]
Schistosomasis			
Schistosoma mansoni			
	10–14 years	9.59 (1.30–70.93)	0.027
	15–19 years	12.45 (1.50–103.26)	0.020
	20–24 years	21.18 (2.19–205.23)	0.008
	Ethnics group from Mali (Dioula/Bozoh/Kadô)	35.11 (7.35–167.81)	< 0.001
	Ethnics group from Burkina Faso (Mossi/Groussi/Tronka)	4.79 (1.81–12.64)	0.002
	Poor	2.84 (1.30–6.20)	0.009
	Least poor	8.52 (4.11–17.69)	< 0.001
	Well	3.44 (1.85–6.40)	< 0.001
	River	0.27 (0.11–0.66)	0.004
Schistosoma haematobium			
	15–19 years	3.14 (1.32–7.47)	0.010
	Ethnics group from Mali (Dioula/Bozoh/Kadô)	4.01 (1.38–11.69)	0.011
	Pump	0.39 (0.22–0.70)	0.001
	Tap water	0.16 (0.04–0.72)	0.017
Soil-transmitted helminthiasis (STH)			
Hookworm			
	Schistosoma haematobium	1.73 (1.18–2.54)	0.005
	Trichuris trichiura	2.30 (1.34–3.92)	0.002
	Ascaris lumbricoides	4.57 (1.30–16.05)	0.018
	Entamoeba coli	1.20 (1.01–1.42)	0.033
	Female	0.49 (0.41–0.57)	< 0.001
	5–9 years	3.15 (1.96–5.04)	< 0.001
	10–14 years	6.27 (3.93–10.02)	< 0.001
	15–19 years	7.43 (4.33–12.77)	< 0.001
	20-24 years	6.33 (3.17–12.65)	< 0.001
	≥ 25 years	3.49 (2.11–5.76)	< 0.001
	Ethnics group from Mali (Dioula/Bozoh/Kadô)	0.40 (0.20–0.80)	0.009
	Ethnics group from Burkina Faso (Mossi/Groussi/Tronka)	0.34 (0.20–0.58)	< 0.001
	Least poor	0.52 (0.40–0.68)	< 0.001
	Tap water	0.37 (0.20–0.68)	0.001
	Pump	1.34 (1.01–1.78)	0.040
	River	0.57 (0.42–0.74)	< 0.001
	Latrine	0.77 (0.61–0.97)	0.028
	Open defecation	1.28 (1.05–1.55)	0.014
Ascaris lumbricoides			
	Giardia intestinalis	4.84 (1.34–17.55)	0.016

Reference group of explanatories: intestinal parasites = non-infected; sex = male, age group = < 5; ethnic group = local ethnic group (Baoulé); wealth quartile = most poor; source of water for household = not use; use of latrine = no; open defecation = no.

[a] Confidence interval.

[b] Adjusted odds ratio (all models are adjusted for other parasite species, sex, age, ethnicity and wealth quartiles).

[c] Only significant categories at 0.05 levels are shown.

positive association between hookworm infection and open defecation. Open defecation is a common practice in the surveyed communities (Schmidlin et al., 2013) and a major risk factor in the spread of intestinal parasites, particularly hookworm (Esrey et al., 1991; Fewtrell et al., 2005; Vercruysse et al., 2001). Furthermore, we found that the use of tap water at home is associated with lower odds of *S. haematobium*, hookworm and *E. coli*. These findings are consistent with a previous study carried out in southern Côte d'Ivoire that revealed that regular consumption of tap water is associated with a lower odds of *E. histolytica/E. dispar*, *E. coli* and *E. nana* (Ouattara et al., 2010). Finally, the disposal of waste near the household was associated with a higher odds of *G. intestinalis*. Lack of appropriate hygiene conditions leads to a contaminated environment, which contributes to the spread of parasites via the faecal-oral route. In particular, it has been suggested that flies and cockroaches can carry intestinal protozoa cysts, bacteria and viruses from faeces in the environment to food (Pai et al., 2003). Furthermore, some authors have shown that *G. intestinalis* is a parasite of rats (Reedyk and Scott, 2001) and garbage dumps near and around the villages are places where rats proliferate. Rats could thus contaminate these places with their faeces containing *G. intestinalis* cysts, whereas flies and cockroaches would, in turn, contaminate the food.

In the current epidemiological baseline survey, we used a comprehensive approach to assess risk factors of parasite infections through parasitological examinations and a household questionnaire. We employed four different diagnostic techniques to identify and quantify helminths and intestinal protozoa among people of all age groups. This is of relevance, since co-infections are frequent in rural settings, but studies mostly focus on single or restricted groups of parasites (e.g. STH or schistosomiasis) in specific age group (e.g. school-aged children).

There are, however, some limitations of the study that are offered for discussion. Although we used duplicate Kato-Katz thick

Table 4
Significant associations between intestinal protozoa infections, socio-demographic factors and WASH indicators in study participants (n = 4,305) from 56 communities of three departments in south-central Côte d'Ivoire, from August to September 2014.

Parasite	Association	OR[b] (95% CI[a])	*p*-value[c]
Entamoeba coli			
	Endolimax nana	3.18 (2.69–3.75)	< 0.001
	Giardia intestinalis	0.80 (0.65–0.98)	0.031
	Entamoeba histolytica/dispar	2.25 (1.70–3.00)	< 0.001
	Blastocystis hominis	1.32 (1.05–1.64)	0.016
	Chilomastix mesnili	5.41 (3.81–7.68)	< 0.001
	Iodamoeba bütschlii	2.60 (2.04–3.31)	< 0.001
	Female	1.16 (1.01–1.32)	0.034
	5–9 years	2.71 (1.96–3.74)	< 0.001
	10–14 years	3.04 (2.20–4.20)	< 0.001
	15–19 years	2.56 (1.68–3.90)	< 0.001
	20–24 years	3.39 (1.93–5.97)	< 0.001
	≥ 25 years	3.89 (2.75–5.49)	< 0.001
	Ethnics group from North Côte d'Ivoire (Senoufo/Tagbana/Lobi)	0.44 (0.24–0.81)	0.009
	Pump	0.76 (0.60–0.95)	0.016
	Tap water	0.66 (0.45–0.97)	0.032
Giardia lamblia			
	Endolimax nana	0.62 (0.47–0.82)	0.001
	Female	0.74 (0.61–0.89)	0.001
	5–9 years	1.46 (1.02–2.09)	0.037
	≥ 25 years	0.52 (0.33–0.84)	0.007
	Disposal of garbage near home	1.32 (1.07–1.63)	0.010
Entamoeba histolytica/E. dispar			
	Ascaris lumbricoides	5.67 (1.14–28.19)	0.034
	Female	0.74 (0.56–0.97)	0.030
	10–14 years	2.57 (1.16–5.69)	0.020
	15–19 years	2.90 (1.13–7.43)	0.026
	20–24 years	5.10 (1.75–14.85)	0.003
	≥ 25 years	2.77 (1.21–6.32)	0.016
	Ethnics group from North Côte d'Ivoire (Senoufo/Tagbana/Lobi)	3.00 (1.29–7.00)	0.011

Reference group of explanatories: intestinal parasites = non-infected; sex = male; age group = < 5; ethnic group = local ethnic group (Baoulé); wealth quartile = most poor; source of water for household = non-use; disposition of garbage near the household = no.

[a] Confidence interval.

[b] Adjusted odds ratio (all models are adjusted for other parasite species, sex, age, ethnicity and wealth quartiles).

[c] Only significant categories at 0.05 levels are shown.

smears, we only collected one stool sample from each participant, thus, the true parasite prevalence is higher due to day-to-day variation in helminth egg output and intestinal protozoa cyst and trophozoite output (Booth et al., 2003; Knopp et al., 2008). In future studies, more sensitive diagnostic tools such as the FLOTAC technique (Coulibaly et al., 2016; Cringoli et al., 2010), molecular diagnosis (e.g. polymerase chain reaction (PCR) (Verweij et al., 2007)) should be envisaged, particularly in view of future shifts from morbidity control to transmission interruption of schistosomiasis and STH. Furthermore, our questionnaire was administered at the household level. Some questions pertaining to hygiene practices might have yielded more specific information if asked at the individual level.

Our results confirm that lack of appropriate sanitation facilities is associated with helminth and intestinal protozoa infections. Integrated control approaches that couple ongoing control and elimination efforts through preventive chemotherapy with improved sanitation and health education have the potential to sustainably control and eliminate these diseases. Of note, in the past, ordnidazole, secnidazole and tinidazole have been identified as drug candidates allowing treatment of amoebiasis (amoebic dysentery) and/or giardiasis with a single oral application. Such a treatment scheme holds promise for cost-effective control, particularly if integrated with ongoing STH and schistosomiasis control and elimination strategies. However, the evidence-base, particularly the safety and efficacy of these is insufficient (Escobedo and Cimerman, 2007). Other drugs, such as nitaxozanide, have been tested in the field but results were disappointing against major pathogenic intestinal protozoa (Speich et al., 2013). Furthermore, potential drug interactions with currently used drugs against schistosomiasis and STH would need to be evaluated in detail.

Data from this study will serve as a baseline reference to assess the effect of a package of interventions, including preventive chemotherapy, CLTS and health education on helminth and intestinal protozoa infections and diarrhoea incidence. Results and experiences from our subsequent cluster-randomised trial will be important for the national control programmes targeting neglected tropical diseases and might influence public health actions elsewhere in sub-Saharan Africa.

Conflict of interest

There is no conflict of interest.

Appendix Table A.1
Prevalence (%) of parasitic infections by sex in the three departments.

Parasite species	Total	Toumodi		*P*	Total	Djékanou		*P*	Total	Taabo		*P*
		m	f			m	f			m	f	
Helminths												
Schistosoma haematobium	57 (7.0)	37 (8.1)	20 (5.6)	0.173	23 (2.2)	12 (2.3)	11 (2.1)	0.754	82 (3.4)	37 (3.1)	45 (3.6)	0.503
Schistosoma mansoni	18 (2.2)	15 (3.3)	3 (0.8)	0.019[a]	8 (0.8)	2 (0.4)	6 (1.1)	0.174	94 (3.8)	46 (3.9)	48 (3.8)	0.971
Hookworm	278 (34.2)	181 (39.6)	97 (27.3)	< 0.001[a]	369 (35.2)	223 (43.6)	146 (27.3)	< 0.001[a]	266 (10.9)	177 (14.8)	89 (7.1)	< 0.001[a]
Trichuris trichiura	4 (0.5)	1 (0.2)	3 (0.8)	0.206	13 (1.2)	8 (1.6)	5 (0.9)	0.361	51 (2.1)	36 (3.0)	15 (1.2)	0.002[a]
Ascaris lumbricoides	3 (0.4)	1 (0.2)	2 (0.6)	0.422	1(0.1)	0 (0.0)	1 (0.2)	0.327	8 (0.3)	3 (0.3)	5 (0.4)	0.524
Intestinal protozoa												
Entamoeba coli	331 (40.8)	179 (39.2)	152 (42.8)	0.294	443 (42.4)	204 (39.8)	239 (44.8)	0.108	955 (39.0)	445 (37.3)	510 (40.7)	0.088
Endolimax nana	179 (22.0)	87 (19.0)	92 (25.9)	0.019[a]	223 (21.3)	94 (18.9)	126 (23.6)	0.066	440 (18.0)	195 (16.3)	245 (19.5)	0.040[a]
Giardia lamblia	105 (13.0)	66 (14.4)	39 (11.0)	0.145	139 (13.3)	83 (16.2)	56 (10.5)	0.006[a]	320 (13.1)	178 (14.9)	142 (11.3)	0.008
Blastocystis hominis	74 (9.1)	45 (9.2)	29 (8.2)	0.410	93 (8.9)	41 (8.1)	52 (9.7)	0.326	231 (9.4)	119 (10.0)	112 (8.9)	0.378
Iodamoeba bütschlii	68 (8.4)	38 (8.3)	30 (8.5)	0.945	75 (7.2)	40 (7.8)	35 (6.6)	0.430	211 (8.6)	100 (8.4)	111 (8.9)	0.679
Entamoeba histolytica/dispar	46 (5.7)	32 (7.0)	14 (3.9)	0.061	45 (4.3)	22 (4.3)	23 (4.3)	0.993	149 (6.1)	81 (6.8)	68 (5.4)	0.158
Chilomastix mesnili	42 (5.2)	27 (5.9)	15 (4.2)	0.283	52 (5.0)	21 (4.1)	31 (5.8)	0.205	113 (4.6)	61 (5.1)	52 (4.1)	0.255
Entamoeba hartmanni	8 (1.0)	3 (0.7)	5 (1.4)	0.282	18 (1.7)	8 (1.6)	10 (1.9)	0.700	46 (1.9)	25 (2.1)	21 (1.7)	0.443

Toumodi (n = 812; m = 457, f = 355), Djékanou (n = 1046; m = 512, f = 534), Taabo (n = 2,447; m = 1,193, f = 1,254) m: male, f: female.
[a] Pearson's X^2 test.

Appendix Table A.2
Prevalence (%) of parasitic infections by age in the three departments.

Parasite species	Total	Toumodi							Total	Djékanou		
		< 5 years	5–9 years	10–14 years	15–19 years	20-24 years	≥ 25 years	*p*		< 5 years	5–9 years	10–14 years
Helminths												
Schistosoma haematobium	57 (7.0)	3 (6.8)	17 (6.2)	27 (8.1)	4 (8.9)	1 (14.3)	5 (4.7)	0.767	23 (2.2)	1 (1.1)	5 (1.3)	13 (3.6)
Schistosoma mansoni	18 (2.2)	0 (0.0)	2 (0.7)	9 (2.7)	3 (6.7)	0 (0.0)	4 (3.8)	0.086	8 (0.8)	1 (1.1)	2 (0.5)	3 (0.8)
Hookworm	278 (34.2)	4 (9.1)	77 (27.9)	137 (41.0)	23 (51.1)	3 (42.9)	34 (32.1)	< 0.0013[a]	369 (35.3)	8 (8.9)	115 (29.6)	175 (49.0)
Trichuris trichiura	4 (0.5)	0 (0.0)	1 (0.4)	2 (0.6)	1 (2.2)	0 (0.0)	0 (0.0)	0.594	13 (1.2)	2 (2.2)	7 (1.8)	2 (0.6)
Ascaris lumbricoides	3 (0.4)	0 (0.0)	2 (0.7)	1 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0.884	1 (0.1)	0 (0.0)	1 (0.3)	0 (0.0)
Intestinal protozoa												
Entamoeba coli	331 (40.7)	8 (18.2)	102 (37.0)	143 (42.8)	17 (37.8)	4 (57.1)	57 (53.8)	0.001[a]	443 (42.4)	11 (12.2)	157 (40.4)	177 (49.6)
Endolima x *nana*	179 (22.0)	8 (18.2)	42 (15.2)	82 (24.6)	11 (24.4)	0 (0.0)	36 (34.0)	0.001[a]	223 (21.3)	4 (4.4)	81 (20.8)	96 (26.9)
Giardia lamblia	105 (12.9)	5 (11.4)	42 (15.2)	50 (15.0)	5 (11.1)	0 (0.0)	3 (2.8)	0.020[a]	139 (13.3)	11 (12.2)	66 (17.0)	45 (12.6)
Blastocystis hominis	74 (9.1)	2 (4.6)	27 (9.8)	29 (8.7)	3 (6.7)	1 (14.3)	12 (11.3)	0.775	93 (8.9)	3 (3.3)	39 (10.0)	32 (9.0)
Iodamoeba bütschlii	68 (8.4)	3 (6.8)	22 (8.0)	33 (9.9)	4 (8.9)	0 (0.0)	6 (5.7)	0.722	75 (7.2)	1 (1.1)	25 (6.4)	35 (9.8)
Entamoeba histolytica/dispar	46 (5.7)	1 (2.3)	11 (4.0)	19 (5.7)	3 (6.7)	2 (28.6)	10 (9.4)	0.032[a]	45 (4.3)	1 (1.1)	14 (3.6)	18 (5.0)
Chilomastix mesnili	42 (5.1)	0 (0.0)	11 (4.0)	22 (6.6)	3 (6.7)	0 (0.0)	6 (5.7)	0.393	52 (5.0)	2 (2.2)	16 (4.1)	17 (4.8)
Entamoeba hartmanni	8 (1.0)	0 (0.0)	3 (1.1)	3 (0.9)	1 (2.2)	0 (0.0)	1 (0.9)	0.938	18 (1.7)	0 (0.0)	10 (2.6)	3 (0.8)

Parasite species	Djékanou				Total	Taabo						
	15–19 years	20–24 years	≥ 25 years	*p*		< 5 years	5–9 years	10–14 years	15-19 years	20–24 years	≥ 25 years	*p*
Helminths												
Schistosoma haematobium	4 (6.3)	0 (0.0)	0 (0.0)	0.018[a]	82 (3.4)	6 (2.9)	29 (3.2)	24 (3.1)	9 (8.3)	4 (7.6)	10 (2.5)	0.032[a]
Schistosoma mansoni	1 (1.6)	1 (5.3)	0 (0.0)	0.215	94 (3.8)	0 (0.0)	33 (3.7)	43(5.5)	4 (3.7)	3(5.7)	11 (2.8)	0.008[a]
Hookworm	33 (51.6)	7 (36.8)	31 (24.4)	< 0.001[a]	266 (10.9)	9 (4.4)	78 (8.7)	108 (13.8)	17 (15.6)	11 (20.8)	43 (10.8)	< 0.001[a]
Trichuris trichiura	0 (0.0)	0 (0.0)	2 (1.6)	0.521	51 (2.1)	0 (0.0)	21 (2.3)	14 (1.8)	4 (3.7)	1 (1.9)	11 (2.8)	0.202
Ascaris lumbricoides	0 (0.0)	0 (0.0)	0 (0.0)	0.890	8 (0.3)	0 (0.0)	3 (0.3)	5 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)	0.435
Intestinal protozoa												
Entamoeba coli	27 (42.2)	10 (52.6)	61 (48.0)	< 0.001[a]	955 (39.0)	37 (18.1)	341 (37.9)	318 (40.6)	41 (37.6)	23 (43.4)	195 (49.0)	< 0.001[a]
Endolima x *nana*	12 (18.8)	5 (26.3)	25 (19.7)	< 0.001[a]	440 (18.0)	17 (8.3)	146 (16.2)	151 (19.3)	16 (14.7)	12 (22.7)	98 (24.6)	< 0.001[a]
Giardia lamblia	5 (7.8)	2 (10.5)	10 (7.9)	0.080	320 (13.1)	26 (12.7)	151 (16.8)	102 (13.0)	14 (12.8)	2 (3.8)	25 (6.3)	< 0.001[a]
Blastocystis hominis	7 (10.9)	4 (21.1)	8 (6.3)	0.113	231(9.4)	12 (5.9)	92 (10.2)	63 (8.1)	18 (16.5)	6 (11.3)	40 (10.1)	0.031[a]
Iodamoeba bütschlii	6 (9.4)	0 (0.0)	8 (6.3)	0.050	211 (8.6)	5 (2.4)	73 (8.1)	81 (10.3)	10 (9.1)	3 (5.7)	39 (9.8)	0.013[a]
Entamoeba histolytica/dispar	5 (7.8)	0 (0.0)	7 (5.5)	0.270	149 (6.1)	5 (2.4)	53 (5.9)	53 (6.8)	6 (5.5)	6 (11.3)	26 (6.5)	0.145
Chilomastix mesnili	4 (6.3)	2 (10.5)	11 (8.7)	0.206	113 (4.6)	8 (3.9)	45 (5.0)	33 (4.2)	3 (2.8)	2 (3.8)	22 (5.5)	0.772
Entamoeba hartmanni	2 (3.1)	0 (0.0)	3 (2.4)	0.282	46 (1.9)	0 (0.0)	19 (2.1)	13 (1.7)	3 (2.8)	1 (1.9)	10 (2.5)	0.335

Toumodi (n = 812; > 5 years = 44, 5–9 years = 276, 10–14 years = 334, 15–19 years = 45, 20–24 years = 7, ≥25 years = 106), Djékanou (n = 1,046; < 5 years = 90, 5–9 years = 389, 10–14 years = 357, 15–19 years = 64, 20–24 years = 19, ≥25 years = 127), Taabo (n = 2,447; < 5 years = 205, 5–9 years = 899, 10–14 years = 783, 15–19 years = 109, 20–24 years = 53, ≥25 years = 398).

[a] Pearson's X^2 test.

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