1   **Domains of transmission and association of community, school, and household sanitation**

2   **with soil-transmitted helminth infections among children in coastal Kenya**

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Abstract

21

22 Introduction - Few studies have simultaneously examined the role of sanitation conditions at

23 the home, school, and community on soil-transmitted helminth (STH) infection. We examined

24 the contribution of each domain that children inhabit (home, village, and school) and

25 estimated the association of sanitation in each domain with STH infection.

26 Methods - Using data from 4,104 children from Kwale County, Kenya, who reported attending

27 school, we used logistic regression models with cross-classified random effects to calculate

28 measures of general contextual effects and estimate associations of village, school, and

29 household sanitation with STH infection.

30 Findings - We found reported use of a sanitation facility by households was associated with

31 reduced prevalence of hookworm infection but not with reduced prevalence of *T. trichiura*

32 infection. School sanitation coverage > 3 toilets per 100 pupils was associated with lower

33 prevalence of hookworm infection. School sanitation was not associated with *T. trichiura*

34 infection. Village sanitation coverage > 81% was associated with reduced prevalence of *T.*

35 *trichiura* infection, but no protective association was detected for hookworm infection.

36 General contextual effects represented by residual heterogeneity between village and school

37 domains had comparable impact upon likelihood of hookworm and *T. trichiura* infection as

38 sanitation coverage in either of these domains.

39 Conclusion - Findings support the importance of providing good sanitation facilities to support

40 mass drug administration in reducing the burden of STH infection in children.

Author Summary

Infection by whipworm and hookworm results from either ingestion of eggs or larvae or through skin exposure to larvae. These eggs and larvae develop in suitable soils contaminated with openly-deposited human faeces. Safe disposal of faeces should reduce transmission of these soil-transmitted helminths (STH), yet evidence of the impact of sanitation on STH transmission remains limited. We used data collected during a large, community-wide survey to measure prevalence of STH infections in coastal Kenya in 2015 to examine the relationship between sanitation conditions at home, school, and village and the presence of STH infection among 4,104 children who reported attending schools. We found that sanitation access at home and school sanitation coverage, but not the overall level of village sanitation coverage, was protective against hookworm infection. In contrast, only high village sanitation coverage, but not home or school sanitation, was protective against whipworm infection. Current STH control strategies emphasise periodic deworming through mass drug administration (MDA) of at-risk populations, including school-age children. Our findings highlight the need for continued efforts, alongside MDA, to extend access to good sanitation facilities at homes, schools, and across communities.

Introduction

In 2016, it was estimated that world-wide more than 1.5 billion people were infected with at least one species of soil-transmitted helminth (STH)(1). Infection by roundworm, *Ascaris lumbricoides*, and whipworm, *Trichuris trichiura*, results from ingestion of embryonated eggs, and the hookworms, *Necator americanus* and *Ancylostoma duodenale*, infect humans through skin exposure to or ingestion of larvae (*A. duodenale)* that develop in warm, moist soils from eggs in openly-deposited human faeces (2, 3). Preventing human contact with excreta through consistent safe disposal of faeces should reduce STH transmission, yet evidence of the impact of sanitation on STH remains limited (4-6). The concept of private and public domains of transmission for STH has been described previously (7, 8), but to our knowledge few studies have simultaneously examined the role of sanitation conditions at the home, school, and community on STH infection (9-11).

Multilevel statistical models provide a means to estimate effects of individual factors, using measures of association. They can simultaneously assess general contextual effects upon individual health outcomes, using measures of within-unit clustering and between-unit heterogeneity (12, 13). Such models provide a useful complement to mathematical modelling of transmission dynamics for examining specific effects and possible areas for intervention (14). Identifying effects of sanitation within each of the domains that a child inhabits will contribute to evidence for the prioritization of sanitation promotion activities alongside the regular deworming of at-risk populations, including school-aged children, recommended by the World Health Organization (15, 16).

4

80

81   Employing multilevel modelling, we investigate the relative importance of household, village

82   and school domains and estimate the association of sanitation in each domain on STH

83   infection among Kenyan children who attend school.

84

85   **Methods**

86   *Study Population*

87

88   The study took place in Kwale County on the south Kenyan coast. Data were collected during

89   a cross-sectional parasitological survey conducted between March-May 2015 as the baseline

90   for TUMIKIA, a randomised, controlled trial to evaluate the impact and cost-effectiveness of

91   school-based versus community-wide deworming on STH transmission (NCT02397772,

92   www.clinicaltrials.gov).

93

94   Study design, baseline findings, and impact have been described previously (17, 18) (Halliday

95   KE, Oswald WE, Mcharo C, Beaumont E, Gichuki PM, Kepha S, et al. Community-level

96   epidemiology of soil-transmitted helminths in the context of school-based deworming:

97   Baseline results of a cluster randomised trial on the coast of Kenya. In Press). For the baseline

98   survey, 225 households were randomly selected within 120 community units (CUs) of

99   approximately 1000 households comprising 2 to 7 villages. Among consenting households, a

100   structured questionnaire was conducted with the head of household or primary caregiver to

101   collect information on demographics, ownership of key assets, and sanitation, hygiene, and

102   water conditions. One household member (aged ≥ 2 years) was randomly selected to provide

103   a stool sample. A questionnaire was then conducted with individuals who provided samples

104   or their caregiver to collect information on deworming within the last year and observe their

105   footwear. School facility surveys were conducted across Kwale County in June 2015 and July

106   2016. During visits, student enrolment was recorded from school registers, and sanitation

107   conditions were assessed using structured observations. All data were collected on

108   smartphones running the Android operating system (Google, Mountain View, CA, USA) using

109   SurveyCTO (Dobility, Inc., Cambridge, MA, USA). Records from school and household surveys

110   were linked based on the school each child reported attending. Geographic coordinates

111   (based on WGS84 datum) were systematically collected at each household and school using

112   the smartphones' global positioning systems. Missing coordinates for 4 schools were obtained

113   from Google Maps (Google, Mountain View, CA, USA). Children were excluded *a priori* if they

114   lived in villages or attended schools in semi-arid areas unsuitable for STH transmission

115   (Halliday KE, Oswald WE, Mcharo C, Beaumont E, Gichuki PM, Kepha S, et al. Community-level

116   epidemiology of soil-transmitted helminths in the context of school-based deworming:

117   Baseline results of a cluster randomised trial on the coast of Kenya. In Press). Children were

118   eligible if they were sampled in the 2015 TUMIKIA baseline parasitological survey, aged 5 to

119   14 years, and reported attending school.

120

121   *STH infection*

122

123   Kato-Katz microscopy was used to enumerate STH eggs (*A. lumbricoides*, *T. trichiura*, and

124   hookworm) per gram of stool. For both hookworm and *T. trichiura*, our outcome was a

125   dichotomous indicator for the presence of > 0 eggs in stool samples (i.e. prevalence). *A.*

126   *lumbricoides* was not examined in detail since few cases were detected. STH infection was also

127   classified based on categories of infection intensity (19), and frequencies were tabulated

128   across categories of household, community, and school sanitation as detailed below.

129

130   *Sanitation measures*

131

132   The measure for household sanitation access was combined from reported use of a toilet

133   facility on or off the household's compound. Using all households sampled per village for the

134   TUMIKIA baseline survey, this measure of household sanitation was aggregated for village

135   sanitation coverage, as the percentage of households with reported access to sanitation.

136   During structured observations at schools, the number of latrines considered usable (not

137   assigned to teachers, locked, or with full pits) was quantified, excluding urinals, for both girls

138   and boys. School sanitation coverage was calculated as the number of usable toilets per

139   enrolled pupil, in contrast to the indicator of students per toilet (20). Village and school

140   sanitation coverage were categorised based on estimated quartiles to explore possible non-

141   linear relationships during modelling.

142

143   *Covariates*

144

145   Information on covariate specification and creation of household socioeconomic status

146   measure is described elsewhere (Halliday KE, Oswald WE, Mcharo C, Beaumont E, Gichuki PM,

147   Kepha S, et al. Community-level epidemiology of soil-transmitted helminths in the context of

148   school-based deworming: Baseline results of a cluster randomised trial on the coast of Kenya.

149   In Press). One school surveyed in 2015 was missing total enrolment, so 2016 enrolment was

150   used. For 51 schools attended by children for which we had no 2015 data, enrolment and

151   sanitation conditions from the 2016 survey were used. Environmental and sociodemographic

152   conditions hypothesized to influence STH transmission and sanitation coverage were

153   assembled in a geographic information system using ArcGIS 10.5 (ESRI, Redlands, CA, USA),

154   and values were extracted for each school and household (Halliday KE, Oswald WE, Mcharo C,

155   Beaumont E, Gichuki PM, Kepha S, et al. Community-level epidemiology of soil-transmitted

156   helminths in the context of school-based deworming: Baseline results of a cluster randomised

157   trial on the coast of Kenya. In Press). We aggregated mean continuous and mode categorical

158   values per village, using all households sampled per village.

159

160   *Ethical Approval*

161

162   The TUMIKIA trial protocol was approved by the Kenya Medical Research Institute and

163   National Ethics Review Committee (SSC Number 2826) and the London School of Hygiene &

164   Tropical Medicine (LSHTM) Ethics Committee (7177). Written informed consent was sought

8

165   from the household head or adult answering the household-level questionnaire and from the

166   individual selected to provide the stool sample and complete the individual-level

167   questionnaire. Parental consent was sought for individuals aged 2 to 17 years and written

168   assent was additionally obtained from children aged 13 to 17 years. All information and

169   consent procedures were conducted in Kiswahili.

170

171   *Statistical analyses*

172

173   We estimated associations between sanitation conditions in the domains of interest and

174   presence of hookworm and *T. trichiura* infection, separately, using logistic regression models

175   with cross-classified (non-nested) random effects to account for membership of children

176   within village of residence and school attended.

177

178   We fit a series of generalised mixed models (with logit link), excluding observations with

179   missing outcome or covariate information, which assumes the probability of having complete

180   data is independent of the outcome after adjusting for included covariates. First, we fit an

181   intercept-only model containing school- and village-specific random effects to quantify

182   between school and between village variation in STH infection. Next, we fit models with fixed

183   effects for sanitation conditions in each domain separately and then together in a combined

184   unadjusted model. Finally, we fit a model containing all sanitation effects, adjusting for

185   potential confounders. Confounders were selected based on existing knowledge and encoding

9

186   possible causal relationships in directed acyclic graphs. We then implemented d-separation in

187   DAGitty to identify minimal sufficient sets of available covariates to control to estimate effects

188   of sanitation on both hookworm (S2 Supporting Information) and *T. trichiura* infections (S3

189   Supporting Information)(21, 22). Estimation used Hamiltonian Monte Carlo sampling to

190   improve mixing and reduce auto-correlation (23). We conducted a sensitivity analysis

191   excluding outliers in and missingness of distance from child's home to reported school

192   attended.

193

194   We report prevalence odds ratios (PORs) with 95% credible intervals (CIs) as fixed effects for

195   sanitation in each domain. We also calculated measures to quantify general contextual effects

196   on individual infection (13). Proportion of total observed individual variation in the outcome

197   attributable to between-school and between-village variation, or intraclass correlation

198   coefficient (ICC), was calculated using the latent variable method. This method converts

199   individual variance to the logistic scale from the probability scale and assumes an underlying

200   continuous propensity for infection following a logistic distribution with individual variance of

201    $\pi^2/3$ (24). We calculated median odds ratios (MORs), as measures of residual heterogeneity

202   on the odd ratio scale. MORs are always greater than or equal to 1 (MOR = 1 if there is no

203   variation between areas) and interpreted as the median value of the odds ratios between

204   comparable individuals drawn randomly from high and low risk areas. MORs are useful as they

205   measure how much individual infection is determined by domain membership and are directly

206   comparable to fixed effects (24). The ICC is recommended, however, for estimating general

207   contextual effects as a measure of clustering that incorporates both between- and within-area

10

208   variance (12). We calculated 80% interval odds ratios (80% IORs) for village and school

209   sanitation fixed effects. This measure does not reflect the estimate's precision but instead is

210   recommended to consider residual variation in the interpretation of fixed effects (25). A wider

211   interval indicates greater unexplained between-area variation, and the inclusion of 1 indicates

212   between-area variance is large compared to the specific fixed effect. Analyses were conducted

213   in Stata 15 (StataCorp LP, College Station, TX, USA) and in R 3.5 (r-project.org) using the 'brms'

214   package.

215

216   **Results**

217   Of 6,066 school-aged children with matched samples in the survey, 602 (10%) reported not

218   attending school, and 688 (11%) reported attending school but resided in a village or were

219   linked to a school in a semi-arid area (Figure 1). Among these excluded children, prevalence

220   of infection was 3% (22/688), < 1% (4/688), and 0% (0/688) for hookworm, *T. trichiura* and *A.*

221   *lumbricoides*, respectively. Of 4,776 eligible children, the school reported to be attended was

222   identified for 4,243 children (89%) and school survey data was available for 4,163 children

223   (87%). Eligible children without school information were younger, more often being boys, less

224   likely to have been dewormed, and less poor (S4 Table). Data were available for 4,104 eligible

225   children (86%).

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┌─────────────────────────────┐
│   TUMIKIA baseline survey   │
│        (n=19,684)           │
└─────────────────────────────┘
              │        ┌──────────────────────────────────────────────┐
              │        │ • Not aged 5-14 (n=13,618)                    │
              │───────▶│ • Reported not attending school (n=602)       │
              │        │ • Village in semi-arid area (n=656)           │
              │        │ • School in semi-arid area (n=32)             │
              ▼        └──────────────────────────────────────────────┘
┌─────────────────────────────┐
│ School-attending children   │
│      aged 5-14              │
│        (n=4,776)            │
└─────────────────────────────┘
              │        ┌──────────────────────────────────────────────┐
              │───────▶│ • School attended not identified (n=533), 11% │
              │        └──────────────────────────────────────────────┘
              │                 ┌──────────────────────────────────────┐
              │                 │      TUMIKIA school surveys          │
              │                 │ • Surveyed 2015 (n=439)              │
              │                 │ • Surveyed 2016 (n=32)               │
              │                 └──────────────────────────────────────┘
              │        ┌──────────────────────────────────────────────┐
              │───────▶│ • School (n=17) not surveyed (n=80), 2%       │
              ▼        └──────────────────────────────────────────────┘
┌─────────────────────────────┐
│   Linked to school survey   │
│      (n=4,163), 87%         │
└─────────────────────────────┘
              │        ┌──────────────────────────────────────────────┐
              │───────▶│ • Missing outcome information (n=4), <1%      │
              │        │ • Missing covariate information (n=55), 1%    │
              ▼        └──────────────────────────────────────────────┘
┌─────────────────────────────┐
│       Complete data         │
│      (n=4,104), 86%         │
└─────────────────────────────┘
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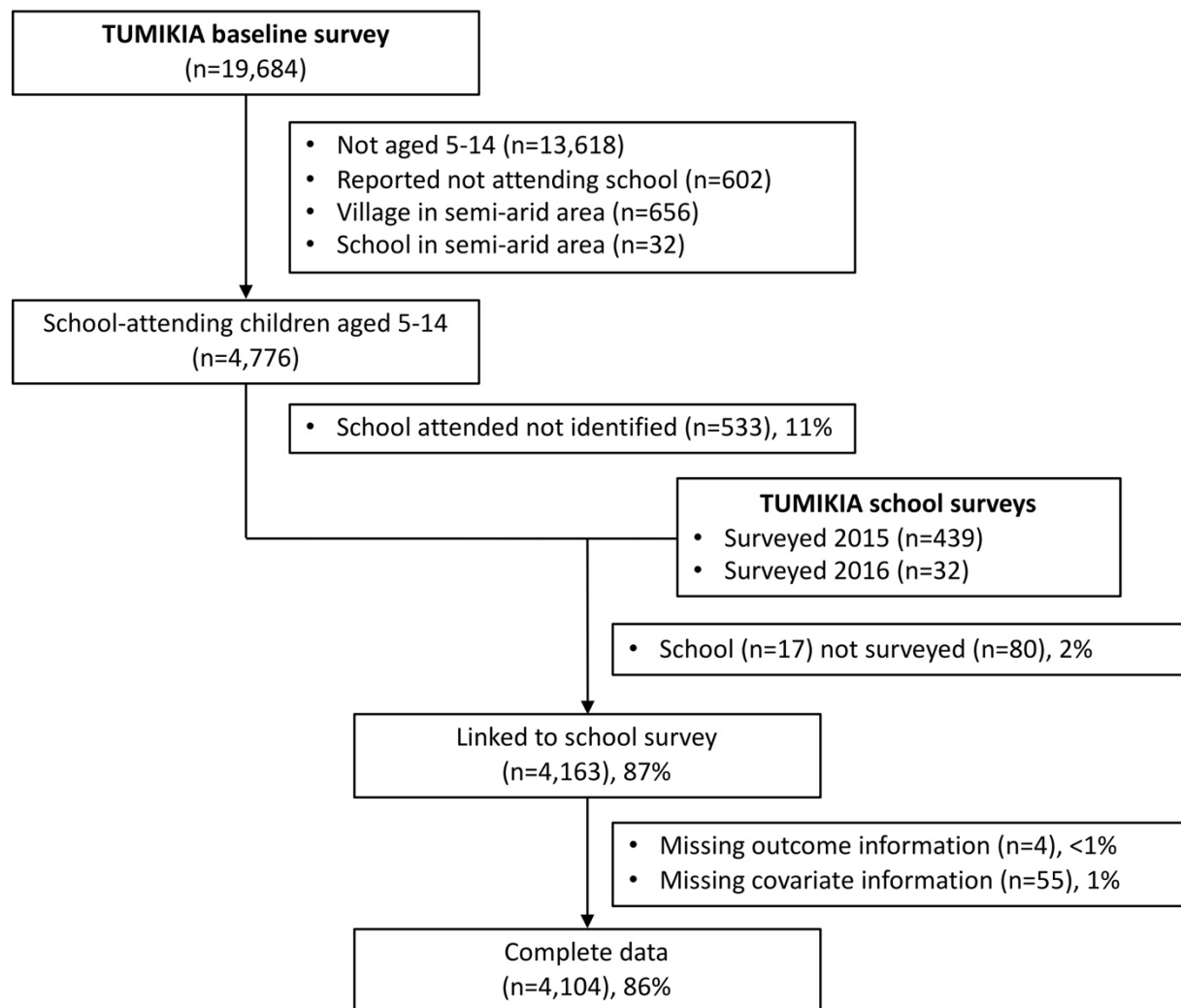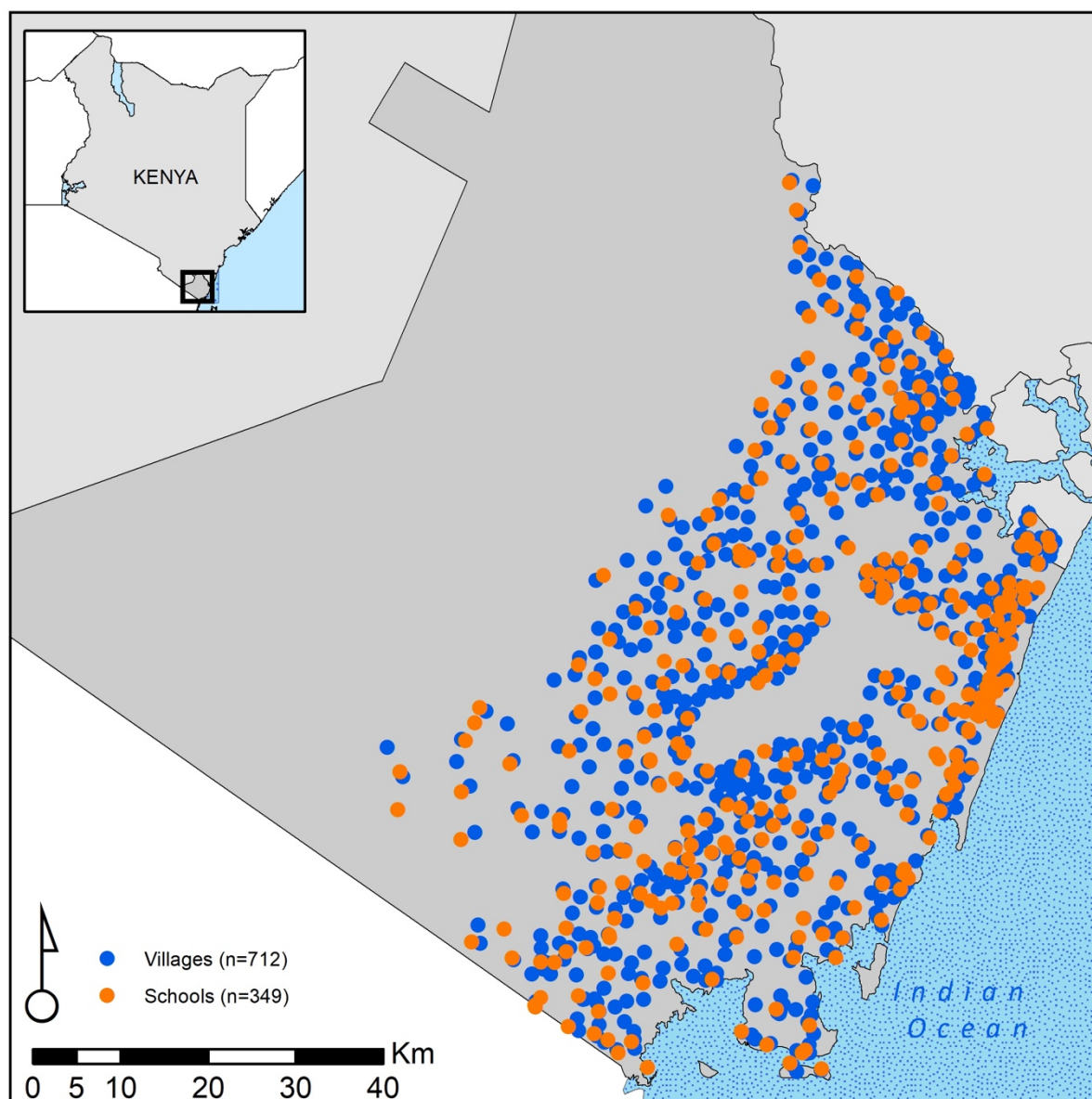
226

227   Figure 1. Flow chart of participants in the TUMIKIA baseline survey who were included in the

228   current analysis. Eligible sample included children aged 5-14 years who reported attending

229   school and not residing in villages or attending schools in semi-arid areas. The proportion of

230   eligible subjects with complete data is 86% (4,104/4,776).

231

232   Participants resided in 712 villages (median sampled per village 4, range 1, 38) and reported

233   attending 349 schools (median sampled per school 9, Range 1, 49) (Figure 2). Figure 3

234   describes the structure of the data. In half of all villages, resident children reported attending

12

235   the same school (range 1 to 8 schools per village). Included schools enrolled children from 1

236   up to 13 villages. Table 1 describes individual, household, and village characteristics of

237   included children.

238

239   Figure 2. Village of residence and attended schools among 4,104 school-attending children

240   aged 5-14 years in Kwale County, Kenya, 2015.

13

Village	School
n = 712	n = 349
Median schools attended per village = 1	Median villages enrolled per school = 3
(IQR 1, 2)	(IQR 2, 5)

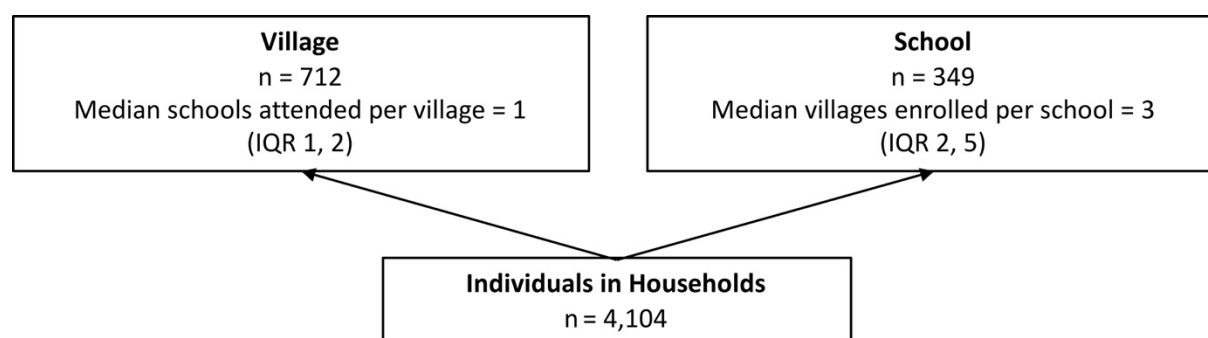**Individuals in Households**
n = 4,104

Figure 3. Diagram for the classification model of individuals, villages, and schools.

Table 1. Summary characteristics for 4,104 school-attending children in coastal Kenya, 2015

Characteristics	No. or Mean	% or SD
Individual level (n=4104)		
Age (years)	9.46	2.65
Being girls	2,129	51.88
Observed wearing shoes	1,443	35.16
Reported deworming in past year	2,219	54.07
Reported household access to toilet	2,255	54.95
Reported improved water source	2,216	54.00
Missing	13	0.32
Time to fetch water, < 30 min	3,344	81.48
Missing	14	0.34
Covered floor	833	20.30

14

Household wealth quintile		
Most poor, 1	1,190	29.00
2	2,158	52.58
Least poor, 3	756	18.42
Distance to school (km) (n=3906)	2.25	5.82
Village level (n=712)		
Proportion reporting toilet access	0.53	0.31
Urbanization		
Rural	545	76.54
Periurban	141	19.80
Urban	26	3.65
Aridity index		
Dry sub-humid (> 0.5--0.65)	284	39.89
Humid (> 0.65)	428	60.11
Soil sand content ≥ 62%	256	35.96
School level (n=349)		
Usable toilets per pupil	0.03	0.02
Pupils per usable toilet	57.79	47.35
Total enrolment	479.47	270.67
Urbanization		

15

Rural	234	67.05
Periurban	84	24.07
Urban	31	8.88
Aridity index		
Dry sub-humid (> 0.5--0.65)	130	37.25
Humid (> 0.65)	219	62.75
Soil sand content ≥ 62%	126	36.10

245

246 Overall prevalence of any detected infection was 17.8% and 6.0% for hookworm and *T.*

247 *trichiura*, respectively, and most infections were classified as light (Table 2). Comparing

248 median odds ratios in tables 3 and 4, school attended had greater impact than village of

249 residence upon hookworm infection (School MOR 2.73, 95% CI 2.50, 2.98; Village MOR 2.09,

250 95% CI 1.74, 2.38). School and village membership had comparable impacts on *T. trichiura*

251 infection (School MOR 2.92, 95% CI 2.40, 3.43; Village MOR 2.78, 95% CI 2.28, 3.29). Calculated

252 ICC showed similar results. Including measures for sanitation in household, school, and village

253 domains in separate models did not meaningfully change measures of variance and

254 heterogeneity (S5 Table). Including all domain sanitation measures in the same model, we saw

255 no change in calculated MOR and ICC values for hookworm or *T. trichiura* (Tables 3 and 4).

256 Adjusting for potential confounders, residual heterogeneity between schools decreased for *T.*

257 *trichiura* and, to a lesser extent, hookworm infection, but residual heterogeneity between

258 villages was unchanged.

259

Table 2. Intensity and any presence of STH infections by household, school, and village sanitation conditions among 4,104 school-attending children in coastal Kenya, 2015.

Infection			N	None %	Light %	Moderate %	Heavy %	Any %
						Intensity		
Hookworm	Overall		4,104	82.21	16.91	0.56	0.32	17.79
	Household sanitation access							
		Y	2,255	84.12	15.25	0.40	0.22	15.88
		N	1,849	79.88	18.93	0.76	0.43	20.12
	School sanitation coverage (per 100)							
		< 1.49	1,182	81.30	17.77	0.68	0.25	18.70
		1.49 - 2.17	1,181	80.10	19.14	0.68	0.08	19.90
		2.18 - 3.13	1,077	83.84	15.51	0.46	0.19	16.16
		> 3.13	664	84.94	13.70	0.30	1.05	15.06
	Village sanitation coverage							

	≤ 0.25	792	83.59	15.53	0.63	0.25	16.41
	0.26 - 0.54	1,123	82.37	16.92	0.53	0.18	17.63
	0.54 - 0.81	1,130	77.88	20.71	0.88	0.53	22.12
	> 0.81	1,059	85.65	13.88	0.19	0.28	14.35
T. trichiura	Overall		4,104	94.05	5.43	0.49	0.02	5.95
	Household sanitation access							
	Y	2,255	94.10	5.54	0.35	0.00	5.90
	N	1,849	94.00	5.30	0.65	0.05	6.00
	School sanitation coverage (per 100)							
	< 1.49	1,182	92.89	6.35	0.68	0.08	7.11
	1.49 - 2.17	1,181	95.17	4.40	0.42	0.00	4.83
	2.18 - 3.13	1,077	94.15	5.48	0.37	0.00	5.85
	> 3.13	664	93.98	5.57	0.45	0.00	6.02
	Village sanitation coverage							
	≤ 0.25	792	94.19	4.80	1.01	0.00	5.81
	0.26 - 0.54	1,123	94.57	5.08	0.36	0.00	5.43

	0.54 - 0.81	1,130	93.27	6.28	0.35	0.09	6.73
	> 0.81	1,059	94.24	5.38	0.38	0.00	5.76
A. lumbricoides	Overall	4,104	99.32	0.41	0.24	0.02	0.68

262 Hookworm intensity categories (epg=eggs per gram): none 0 epg; light <2,000 epg; moderate

263 2,000-<4,000 epg; heavy ≥4,000 epg

264 *T. trichiura* intensity categories (epg=eggs per gram): none 0 epg; light <1,000 epg; moderate

265 1,000-<10,000 epg; heavy ≥10,000 epg

266 *A. lumbricoides* intensity categories (epg=eggs per gram): none 0 epg; light <5,000 epg;

267 moderate 5,000-<50,000 epg; heavy ≥50,000 epg

268

269 **Table 3. Sanitation and contextual effects on presence of hookworm infection among 4,104**

270 **school-attending children in coastal Kenya**

	Intercept-Only		Unadjusted		Adjusted[1]		
Fixed Effects	POR	(95% CI)	POR	(95% CI)	POR	(95% CI)	80% IOR
Household							
Sanitation access	--	--	0.63	(0.51, 0.79)	0.76	(0.61, 0.95)	--

School sanitation coverage (per 100)							
1.49 - 2.17	--	--	0.89	(0.55, 1.42)	0.79	(0.51, 1.21)	(0.14, 4.52)
2.18 - 3.13	--	--	0.86	(0.54, 1.36)	0.64	(0.40, 0.98)	(0.11, 3.66)
> 3.13	--	--	0.58	(0.35, 0.98)	0.51	(0.31, 0.83)	(0.09, 2.94)
Village sanitation coverage							
0.26 - 0.54	--	--	1.28	(0.89, 1.86)	1.40	(0.96, 2.08)	(0.33, 6.06)
0.54 - 0.81	--	--	1.52	(1.01, 2.29)	1.86	(1.22, 2.86)	(0.43, 8.01)
> 0.81	--	--	1.21	(0.75, 1.92)	1.40	(0.86, 2.34)	(0.33, 6.06)
Contextual Effects							
School							
Variance	1.11	(0.92, 1.31)	1.12	(0.93, 1.32)	0.93	(0.74, 1.14)	--
Median Odds Ratio	2.73	(2.50, 2.98)	2.74	(2.51, 2.99)	2.51	(2.27, 2.77)	--
ICC	0.22	(0.20, 0.24)	0.22	(0.20, 0.24)	0.19	(0.17, 0.21)	--
Village							
Variance	0.60	(0.34, 0.83)	0.61	(0.34, 0.85)	0.65	(0.41, 0.89)	--
Median Odds Ratio	2.09	(1.74, 2.38)	2.11	(1.74, 2.41)	2.16	(1.84, 2.46)	--
ICC	0.12	(0.07, 0.15)	0.12	(0.07, 0.16)	0.13	(0.09, 0.17)	--

271 POR = Prevalence Odds Ratio; CI = Credible Interval; IOR = Interval Odds Ratio; ICC =

272 Intraclass Correlation Coefficient

273 [1]Adjusted for age (centred at 9), being female, reported deworming in past year, observed

274 shoe-wearing, household floor covered, village high soil sand content, village aridity index

275 (scaled 100x), village urban/periurban/rural, school high soil sand content, school aridity

276 index (scaled 100x), school urban/periurban/rural

277

278 **Table 4. Sanitation and contextual effects on presence of _T. trichiura_ infection among 4,104**

279 **school-attending children in coastal Kenya**

Fixed Effects	Intercept-Only		Unadjusted		Adjusted[1]		
	POR	(95% CI)	POR	(95% CI)	POR	(95% CI)	80% IOR
Household							
Sanitation access	--	--	0.95	(0.66, 1.38)	1.00	(0.68, 1.46)	--
School sanitation coverage (per 100)							
1.49 - 2.17	--	--	0.75	(0.36, 1.51)	1.23	(0.70, 2.23)	(0.29, 5.26)
2.18 - 3.13	--	--	0.85	(0.42, 1.70)	1.07	(0.60, 1.93)	(0.25, 4.57)
> 3.13	--	--	0.81	(0.36, 1.73)	1.06	(0.56, 1.95)	(0.25, 4.53)

Village sanitation coverage							
0.26 - 0.54	--	--	1.00	(0.51, 1.92)	0.59	(0.30, 1.15)	(0.09, 4.05)
0.54 - 0.81	--	--	1.57	(0.79, 3.16)	0.82	(0.41, 1.62)	(0.12, 5.57)
> 0.81	--	--	0.84	(0.37, 1.90)	0.30	(0.14, 0.68)	(0.04, 2.07)
Contextual Effects							
School							
Variance	1.26	(0.84, 1.67)	1.34	(0.92, 1.78)	0.64	(0.11, 1.10)	--
Median Odds Ratio	2.92	(2.40, 3.43)	3.02	(2.50, 3.57)	2.14	(1.37, 2.72)	--
ICC	0.22	(0.17, 0.26)	0.23	(0.18, 0.27)	0.13	(0.03, 0.19)	--
Village							
Variance	1.15	(0.75, 1.56)	1.17	(0.77, 1.59)	1.12	(0.75, 1.51)	--
Median Odds Ratio	2.78	(2.28, 3.29)	2.81	(2.31, 3.33)	2.74	(2.28, 3.23)	--
ICC	0.20	(0.15, 0.24)	0.20	(0.15, 0.24)	0.22	(0.18, 0.26)	--

280 POR = Prevalence Odds Ratio; CI = Credible Interval; IOR = Interval Odds Ratio; ICC =

281 Intraclass Correlation Coefficient

282 [1]Adjusted for household SES category, village high soil sand content, village aridity index

283 (scaled 100x), village urban/periurban/rural, school high soil sand content, school aridity

284 index (scaled 100x), school urban/periurban/rural

285

286 Reported presence of household sanitation access reduced odds of hookworm infection by

287 37%, compared to no household sanitation access (POR 0.63, 95% CI 0.51, 0.79), among

288 children in villages and schools with similar sanitation conditions. Adjusting for potential

289 confounders, this association was attenuated towards null (POR 0.76, 95% CI 0.61, 0.95).

290 School sanitation coverage in the two highest quartiles (> 2.17 toilets per 100 students) was

291 associated with lower hookworm prevalence, compared to the lowest coverage quartile (<

292 1.49 toilets per 100 students), adjusting for potential confounders and household and village

293 sanitation (POR 0.64, 95% CI 0.40, 0.98; POR 0.51, 95% CI 0.31, 0.83). No evidence of

294 association of household or school sanitation with *T. trichiura* infection was detected. Children

295 in villages where 54 to 81% of households had sanitation access, compared to children in

296 villages with ≤ 25% sanitation coverage, had 1.86 times the odds of hookworm infection (POR

297 1.86, 95% CI 1.22, 2.86). Children in villages where > 81% of households had sanitation access,

298 compared to children in villages with ≤ 25% sanitation coverage, had 70% lower odds of *T.*

299 *trichiura* infection (POR 0.30, 95% CI 0.14, 0.68). Results were robust to the exclusion of 199

300 children without household coordinates and 197 reporting attending a school > 6.5 km from

301 their house.

302

303 Calculated 80% IORs from adjusted models for hookworm and *T. trichiura* were wide and

304 included one for both village and school sanitation measures, indicating sanitation was less

305   important for explaining individual infection, compared to residual variation between these

306   domain levels. For example, comparing children with identical characteristics but drawn from

307   either a village with sanitation coverage ≤ 25% or a village with sanitation coverage > 81%,

308   odds of *T. trichiura* infection will be between 0.04 and 2.07 in 80% of such comparisons.

309

310   **Discussion**

311   In this analysis of baseline data from the TUMIKIA trial, we found notable differences between

312   two species of STH in the relationship between sanitation availability and prevalence of

313   infection within different domains among school-attending children in coastal Kenya.

314   Reported use of a sanitation facility by households was associated with reduced prevalence

315   of hookworm infection but was not associated with reduced prevalence of *T. trichiura*

316   infection. Meanwhile, village sanitation coverage > 81% was associated with reduced

317   prevalence of *T. trichiura* infection, but no protective association was detected for hookworm

318   infection. School sanitation coverage > 3.13 toilets per 100 pupils was associated with lower

319   prevalence of hookworm infection. This coverage level, corresponding to a pupil:toilet ratio

320   of 32:1, supports the minimum ratios (25:1 for girls and 35:1 for boys) currently recommended

321   by the Kenyan government (26). School sanitation was not associated with *T. trichiura*

322   infection, however. We found that general contextual effects, represented by residual

323   heterogeneity between village and school domains, had comparable impact upon likelihood

324   of hookworm and *T. trichiura* infection as sanitation coverage in either of these domains.

325

326   Three published meta-analyses record considerable heterogeneity in estimates of the effect

327   of sanitation access on hookworm and *T. trichiura* infection. Ziegelbauer et al. found that

328   sanitation was protective against both hookworm and *T. trichiura* infection (5). Strunz et al.

329   found no association of sanitation access with hookworm infection, but it was protective

330   against *T. trichiura* (4). Freeman et al., in the most recent review, found no association of

331   sanitation access with *T. trichiura* infection but sanitation access was protective against

332   hookworm (6). Our findings for household and school sanitation are consistent with these

333   latter results, while adjusting for village and school sanitation coverage plus potential

334   confounders and conditional on village and school membership. Freeman et al. concluded

335   that the lack of an association of sanitation access with *T. trichiura* may result from sanitation's

336   expected long-term impact on infection compared to a shorter-term impact on reinfection (6).

337   Our findings would support this conclusion. Albendazole, the medication used for Kenya's

338   National School-Based Deworming Programme (NSBDP), is less effective against *T. trichiura*,

339   compared to hookworm and *A. lumbricoides* (27). Observed associations of household and

340   school sanitation with lower hookworm prevalence in this population of school-attending

341   children could reflect impacts of sanitation in these domains on reinfection, following school-

342   based deworming, rather than a reduction in infection, which might only be observable for *T.*

343   *trichiura* over a longer time period.

344

345   The meta-analyses described above did not distinguish between sanitation access at home or

346   at school. We estimated the independent effects of sanitation access at both the household

347   and school on STH infection. We also expanded upon previous work to estimate the effect of

348   village sanitation coverage (9, 10). The protective association of village sanitation coverage

349 against *T. trichiura* may reflect longer-term impacts of sanitation and a possible community-

350 wide (herd) effect at access levels > 80%, independent of household sanitation access and

351 other factors. In contrast, we found no consistent pattern between village sanitation coverage

352 and hookworm infection. We may not have observed an association because many of the

353 included villages with the lowest sanitation coverage were also in the most arid environments,

354 limiting their suitability for transmission.

355

356 Our results clearly show the large contextual effects of village and school domains relative to

357 the estimated fixed effects. The 80% IOR does not indicate precision but provides an interval

358 around our estimated village and school sanitation effects that incorporates unexplained

359 variability between these domains. This result, coupled with the calculated ICCs and MORs,

360 indicates that sanitation coverage in these domains is not a strong predictor of hookworm or

361 *T. trichiura* infection in this setting, though some protective associations were observed.

362 Others have also reported that village membership alone has a large impact on the likelihood

363 of hookworm or *T. trichiura* infection (28), and that heterogeneity of prevalence is associated

364 with multiple environmental and socioeconomic factors (29). Adjusting for potential

365 individual, village and school level confounders in our models did not meaningfully explain

366 further heterogeneity in hookworm infection between villages or schools but did explain some

367 heterogeneity in *T. trichiura* infection between schools.

368

369 Though our general contextual effects indicate that village is a relevant context for analysis,

370 the representativeness of village measures is a limitation of the current study. We aggregated

371 village measures from all households sampled for the baseline survey. Because sampling for

372 TUMIKIA was based on CUs, the number of units sampled per village varied. We assumed that

373 included units were representative, but our sample may not have adequately characterised

374 village conditions. Village membership was based on an administrative rather than geographic

375 grouping, so it may also not represent sanitation conditions in the area surrounding study

376 households. While useful for implementation purposes, village may not be the most suitable

377 scale at which to assess community-wide sanitation effects. Future studies could use varying

378 spatial buffers with complete household samples to examine community-wide effects of

379 sanitation coverage on STH infection and identify target thresholds (30). Our household

380 sanitation measure was based on a reported measure and may not reflect actual consistent

381 usage and faeces disposal by household members or faecal contamination levels in the area.

382 Our outcome measure was based on a single stool sample, which may also have

383 underestimated prevalence (31).

384

385 In the current study, sanitation conditions, as measured, explained little of the heterogeneity

386 in transmission between villages and schools. Further studies should examine the role of

387 sanitation in different domains against STH infections within the context of school- and

388 community-based mass drug administration. We found evidence of a protective effect of

389 sanitation access at the household against hookworm infection and a sanitation coverage

390 threshold at which a community-wide effect against *T. trichiura* was observed. We also found

391 evidence in support of current school sanitation coverage guidelines towards the control of

392 hookworm infection. In summary, our findings highlight the need for continued efforts,

393 alongside mass drug administration, to extend access to good sanitation facilities at homes,

394 schools, and across communities.

395 **Data sharing statement**

396 Individual participant data (after de-identification) that underlie the results reported in this

397 paper will be made available on LSHTM Data Compass. The data will be available at the time

398 of publication and researchers can request access through the Data Compass portal. Requests

399 for release of the data will be reviewed by the relevant institutional review boards.

400

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492

493 **Supporting Information Legends**

494 **S1 Checklist. STROBE Checklist**

495 **S2 Supporting Information. Sanitation and hookworm infection model code (dagitty.net)**

496 **S3 Supporting Information. Sanitation and *Trichuris trichiura* infection model code**

497 **(dagitty.net)**

498   **S4 Table. Characteristics of school-attending children in non-arid areas by linked to school**

499   **survey information status**

500   **S5 Table. Unadjusted sanitation exposures and contextual effects on presence of hookworm**

501   **and *T. trichiura* infection among 4104 school-attending children in coastal Kenya**