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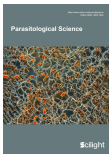

Article

Enteric Parasitic Infections and Associated Risk Factors among Symptomatic Children Attending Two Outpatient Health Facilities in Kiambu County, Kenya

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Abstract: Enteric parasitic infections continue to contribute substantially to childhood morbidity and nutritional problems in Kenya, yet limited information is available on their prevalence and associated risk factors among children living in urban informal settlements. This cross-sectional study assessed the prevalence and risk factors of enteric parasitic infections among children aged 10 years and below in Kiambu County, Kenya. Participants comprised 550 children recruited from Kiandutu Health Centre and Thika Level 5 Hospital. Stool samples underwent direct microscopic examination, formal-ether concentration, and Modified Ziehl-Neelsen staining. Demographic and risk-factor data were collected using structured questionnaires and analyzed in STATA version 14.0 ($p \leq 0.05$). The overall prevalence of enteric parasitic infections was 36.7%, and it was significantly higher at Kiandutu Health Centre compared to Thika Level 5 Hospital. Protozoan infections (34.2%) were more common than helminth infections (5.3%). Protozoa detected included *Entamoeba histolytica/E. dispar/E. moshkovskii* complex, *Giardia lamblia*, *Entamoeba coli*, *Blastocystis* species, *Iodamoeba buetschlii*, *Cryptosporidium* species, and *Chilomastix mesnili*. Helminths identified were *Hymenolepis nana*, *Trichuris trichiura*, and *Ascaris lumbricoides*. Overall enteric parasitic infection was associated with older age (72–131 months: AOR = 2.73, 95% CI: 1.50–4.98, $p = 0.001$), lower parental income (AOR = 1.24, 95% CI: 1.08–1.43, $p = 0.002$), lowest income level ≤ Kshs. 5000 (AOR = 3.20, 95% CI: 1.61–6.39, $p = 0.001$), and untrimmed fingernails (AOR = 1.89, 95% CI: 1.31–2.73, $p = 0.001$). These findings highlight the need for targeted water, sanitation, hygiene, and health education interventions to reduce enteric parasite transmission among vulnerable Kenyan children.

Keywords: enteric parasites; protozoa; helminths; children; Kiambu county; Kenya

1. Introduction

Enteric parasites continue to pose a substantial health burden among children in low- and middle-income countries (LMICs). Globally, enteric parasitic infections affect billions of people and contribute substantially to morbidity, particularly among children living in resource-limited settings [1]. Approximately 835 million children reside in regions with high parasite transmission rates, with sub-Saharan Africa (SSA), Asia, and Latin America being the most affected due to inadequate water supply, poor sanitation, rapid population growth, and socio-economic challenges [2,3].

Diarrheal diseases affect approximately 1.7 billion people each year, resulting in around 760,000 deaths among children younger than five years [4]. Protozoan parasites, including *Cryptosporidium* spp., *Giardia lamblia* and *Entamoeba histolytica* are the primary contributors to enteric infections and are responsible for a significant global disease burden, with the greatest impact observed in low-income regions, particularly across sub-Saharan Africa and Asia [5,6]. Protozoa are transmitted predominantly via the fecal—oral route through contact with infected hosts or consumption of contaminated food and water [5]. Similarly, soil-transmitted helminths such as hookworms, *Trichuris trichiura*, and *Ascaris lumbricoides* are acquired through exposure to contaminated soil, either by ingestion of infective eggs or by penetration of the skin by larval stages. These infections are particularly prevalent where sanitation and hygiene practices are inadequate [7]. Children bear a greater burden because their immune system is still developing and increased exposure to unhygienic conditions [8]. These infections have severe consequences beyond diarrhea, including malnutrition, impaired cognitive development, stunted growth, anemia, and increased mortality risk [9].

Kenya introduced the National School-Based Deworming Programme (NSBDP) in 2012 as a public health strategy to control soil-transmitted helminth (STH) and schistosomiasis infections. The programme aimed to reduce moderate-to-heavy infections to less than 1%, thereby bringing these diseases below the threshold of a public health problem [10]. Over a five-year period (2012–2017), infection prevalence declined markedly from 32.3% at baseline to 16.4% at midterm and 13.5% at endline representing an overall 58.2% reduction [11]. Despite this progress, evidence indicates that mass drug administration (MDA) alone, without complementary water, sanitation, and hygiene (WASH) interventions, may not sufficiently lower intestinal parasite prevalence to levels recommended by the World Health Organization (WHO) [12]. This limitation is reflected in the persistently high prevalence of protozoan infections reported in several regions of Kenya. Recent studies have documented enteric parasite infection rates ranging from 12.6% to 54% [13–17]. This substantial variation in infection rates highlights the continued public health burden posed by enteric parasites in the country.

Enteric parasitic infections in children have been linked to several interacting risk factors, including water, sanitation and hygiene (WASH), socioeconomic conditions, environmental exposures, and behavioral practices [18]. WASH-related determinants such as inadequate hand hygiene, lack of soap use before eating, untrimmed fingernails, poor sanitation, and the use of contaminated or untreated water for washing vegetables or drinking have consistently been associated with increased infection risk in endemic settings [18–20]. Socioeconomic factors including poverty, unemployment, low maternal education, and large or overcrowded households may increase vulnerability by limiting access to safe water, adequate sanitation, and healthy living environments [19,21,22]. Environmental exposures such as agricultural activities, contact with livestock or free-ranging animals, unsanitary household environments, and the presence of houseflies have been linked to a higher likelihood of enteric parasitic infection [18,23]. Behavioral practices including consumption of raw or undercooked foods, eating street food, walking barefoot, swimming in unprotected water bodies, and other poor personal hygiene habits also increase the likelihood of infection [20,21,24]. Together, these domains highlight the multifactorial determinants of intestinal parasitic infections and underscore the need for integrated public health interventions addressing sanitation, hygiene, environmental conditions, and social determinants of health.

Similar patterns are observed in Kenya, where enteric parasitic infections among children are influenced by interacting WASH, socioeconomic, environmental, and behavioral factors. WASH-related determinants such as the use of untreated or contaminated water, inadequate hand hygiene, untrimmed fingernails, poor household sanitation, and unclean living environments have been consistently associated with increased infection risk [13,25,26]. Socioeconomic factors, including poverty, overcrowded informal settlements, low parental education, and poor housing conditions, further increase vulnerability by limiting access to improved sanitation, safe water, and health services [26,27]. Environmental exposures, such as living in households with earthen floors, close contact with domestic animals, and frequent interaction with contaminated surroundings, also contribute to transmission [26,27]. Behavioral practices including walking barefoot, consumption of improperly washed raw vegetables, and inadequate food-handling practices further elevate infection risk [13,25,27]. In addition, demographic and health-related characteristics, including younger age, male sex, and immunosuppression, particularly related to HIV infection, have been reported to increase susceptibility to enteric parasitic infections among Kenyan children [13,15,28]. The rapid growth of urban areas in Kenya has contributed to the proliferation of informal settlements where overcrowding, inadequate waste disposal, limited access to safe water, and poor sanitation are common. Such conditions create favorable environments for enteric parasite transmission, placing children at particularly high risk of infection [15,26,27,29]. Kiandutu informal settlement in Thika town, Kiambu County represents one such setting, where rapid population growth and poor living conditions may facilitate the transmission of enteric parasitic infections.

Despite the persistent burden of enteric parasitic infections in Kenyan, especially among children, few studies have examined how socioeconomic, environmental, behavioral, and WASH factors interact to increase

vulnerability, especially in urban informal settlements. Existing evidence on these risk factors remains limited and often fragmented, hindering the design of effective and targeted public health interventions. Moreover, recent data on the prevalence and drivers of these infections among young children in densely populated, resource-constrained settings like Kiambu are lacking [16]. This study aimed to assess the prevalence of enteric parasitic infections and determine the major risk factors among children under 10 years residing in an urban informal settlement in Kiambu, Kenya, with the goal of informing context-appropriate preventive and control measures.

2. Materials and Methods

2.1. Study Design and Study Site

This cross-sectional study was conducted from July to December 2021 among children aged 10 years and younger residing in Kiandutu informal settlement. Eligible participants were children who sought healthcare at Kiandutu Health Centre (KHC) or Thika Level 5 Hospital (TH), both situated in Thika town, Kiambu County, Kenya (Figure 1). KHC is a primary healthcare facility serving predominantly residents of the Kiandutu informal settlement, a densely populated urban slum characterized by socioeconomic challenges, limited sanitation infrastructure, and potential environmental conditions that may facilitate intestinal parasite transmission. In contrast, TH is a Level 5 hospital that provides healthcare services to a broad and socioeconomically diverse population from Thika and the surrounding areas, including individuals from varied socioeconomic backgrounds. The inclusion of both sites provided an opportunity to assess intestinal parasite infections among children from populations with differing environmental and socioeconomic exposures. Thika is an important commercial and industrial centre in Kiambu County, located approximately 42 km northeast of Nairobi, the capital city of Kenya. The town is one of the country's rapidly expanding socioeconomic and industrial centres, with a population of approximately 279,429 and an area of 1960 km^2 at an elevation of 1631 m above sea level [30].

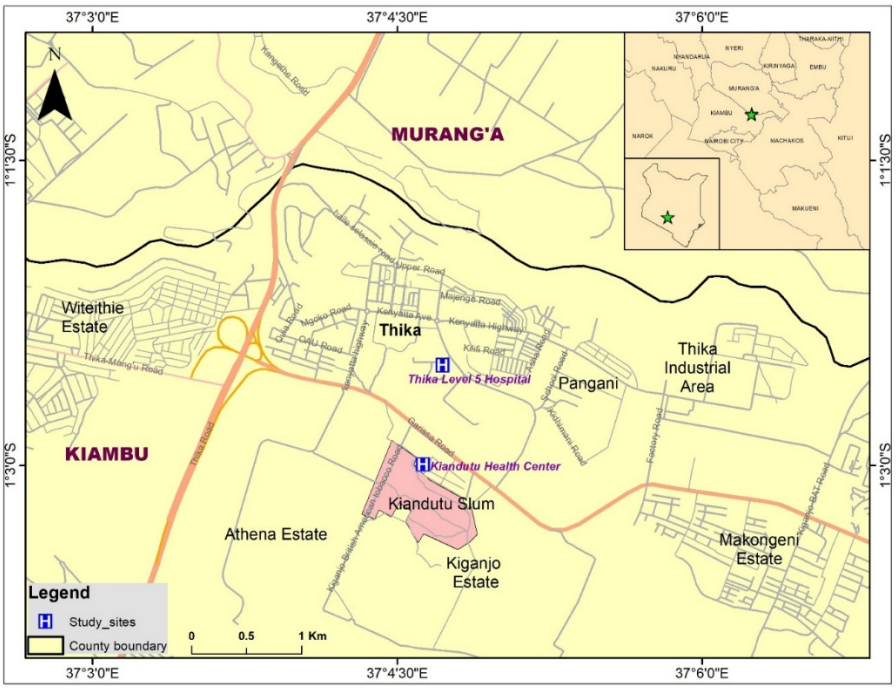

Figure 1. A map showing the two sampling areas Kiandutu Health Centre and Thika Level 5 Hospital and Kiandutu Informal Settlement in Kiambu County, Kenya.

Several informal settlements are located within Thika, including Kiandutu, which has an estimated population of about 50,000 residents.

2.2. Study Population and Recruitment

The sample size was determined using the modified Fisher's formula [31]: $n = z^2pq/d^2$, where $z = 1.96$ for 95% confidence, $p = 0.5$ estimated prevalence and $d = 0.05$ margin of error, giving $n = 385$. To ensure adequate statistical power, and enhance the applicability of the findings to Kenya and similar settings, the sample size was increased by 40% to 539. Ultimately, 550 children aged 10 years or younger who sought medical care at either

KHC or TH were enrolled (330 from KHC and 220 from TH). All enrolled children were symptomatic at presentation, with reported symptoms including abdominal pain or discomfort, vomiting, and diarrhea. The symptom profile varied among participants, with some children presenting with a single symptom and others with multiple concurrent symptoms. Participants who had received systemic antihelminthic or antiprotozoal treatment within one month prior to screening were excluded to avoid misclassification bias resulting from recent therapy reducing detectable parasite loads [32]. Treatment history was verified through parent or guardian self-report at the time of recruitment.

Children presenting with gastrointestinal symptoms were referred by the attending clinicians to the respective institutional laboratories for routine stool examination alongside other diagnostic investigations. Following provision of verbal and written informed consent by their parents or guardians, eligible children were enrolled consecutively until the required sample size was attained.

2.3. Data Collection and Stool Specimen Processing

A structured questionnaire was administered to obtain socio-demographic information and evaluate maternal or guardian knowledge of factors associated with the transmission of enteric parasitic infections. Parents or guardians who accompanied the participating children and voluntarily consented to the interview provided information on household hygiene and sanitation practices through an open-ended questionnaire.

Fresh stool specimens, approximately 5–30 g in quantity, were obtained from each enrolled child. Parents or guardians of the participants were provided with clear instructions on proper stool sample collection to ensure sample quality and minimize contamination. Each specimen container was assigned a unique identification code generated during participant recruitment at the respective healthcare facility. The collected stool specimens were preserved in 10% formal-saline for subsequent parasitological examination and transported to the Centre for Microbiology Research (CMR), Kenya Medical Research Institute (KEMRI), for further processing. Upon receipt, the specimens underwent macroscopic examination to assess their gross fecal characteristics. Parasites were concentrated from the preserved stool specimens using the formal-ether concentration technique following the procedure described by Cheesbrough [33]. The concentrated sediment was used to prepare two thin smears on separate microscope slides. For detection of cysts and ova, one smear was mixed with a drop of iodine and examined using the wet-mount method under 10× and 40× objectives. The second smear was subjected to modified Ziehl-Neelsen (MZN) staining according to the method described by Casemore [34], and examined under the 100× oil-immersion objective for *Cryptosporidium* spp. oocysts. Findings from both microscopic examinations were communicated to the participating healthcare facilities to support patient management. The microscopic examination was conducted independently by two technologists, who resolved any discrepancies through mutual agreement.

2.4. Data Analysis

Data was entered into a structured Microsoft Excel spreadsheet by trained research assistants. To minimize entry errors, Excel's built-in data validation features were applied prior to entry, including drop-down lists for categorical variables, range restrictions for numeric fields, predefined date formats, and consistency checks. Additionally, a random sample (approximately 20%) of entries was independently verified against the original data collection forms. Prevalence was determined based on the proportion of positive cases overall and at each healthcare facility. To identify factors associated with parasitic infection prior to adjustment for confounding, the crude association between parasitic infection and each independent categorical variable was assessed using Pearson's χ^2 or Fisher's exact tests, as appropriate based on the expected cell frequencies. The strength of the observed associations was quantified using crude odds ratios (ORs) with corresponding 95% confidence intervals (CIs).

Variables demonstrating a bivariate association with parasitic infection at $p < 0.1$ were selected for inclusion in the multivariable model, together with age and gender, to identify independent associations while accounting for potential confounding. A binary logistic regression model was fitted using a stepwise approach incorporating both backward and forward conditional selection, with a variable entry threshold of $p < 0.1$. Age and gender were retained in the model a priori as key potential confounders. Three multivariable logistic regression models were constructed: one for parasitic infections (all infected/550 children), the second for protozoan infections (children with protozoa/550), and the third for helminth infections (children with helminths/550). Adjusted odds ratios (AORs) and corresponding 95% confidence intervals (CIs) were derived by exponentiating the regression coefficients. Statistical significance was evaluated using a two-sided $p < 0.05$ threshold. All analyses were performed using STATA version 14. Model diagnostics, including assessments of multicollinearity, goodness-of-fit, and interaction effects, showed no major violations.

2.5. Ethical Approval

Ethical approval for the research was granted by the Kenya Medical Research Institute Scientific and Ethical Review Unit (KEMRI SERU; approval no. KEMRI/SERU/CMR/P00/4187). The required research permit was obtained from the National Commission for Science, Technology and Innovation (NACOSTI; permit no. NACOSTI/P/21/11500), with authorization also secured from Kiambu County, Thika Level 5 Hospital, and Kiandutu Health Centre. Written and verbal informed consent was obtained from the parents or guardians before the children were enrolled.

3. Results

3.1. Demographic Information

A total of 550 children participated, of whom 330 were recruited from Kiandutu Health Centre (KHC) and 220 from Thika Level 5 Hospital (TH). Females accounted for 272 (49.5%) participants, while males comprised 278 (50.5%). The participants ranged in age from 3 months to 10 years and were categorized into three age groups: 3–35 months (infants and toddlers), 36–71 months (preschool-aged children), and 72–131 months (school-aged children). Preschool-aged children formed the largest proportion of participants (266/550; 48.4%), followed by school-aged children (200/550; 36.4%) and infants and toddlers (84/550; 15.3%) (Table 1).

3.2. Prevalence of Enteric Parasites

Of the 550 stool specimens examined microscopically for enteric parasites, 202 (36.7%, 95% CI: 32.7–40.9) tested positive for enteric parasites. Infection prevalence differed significantly between the two healthcare facilities, with higher prevalence recorded at Kiandutu Health Centre (45.8%, 95% CI: 40.3–51.3) compared with Thika Level 5 Hospital (23.2%, 95% CI: 17.8–29.3) ($\chi^2 = 28.95$, $p < 0.001$). Protozoan infections were detected in 188 samples (34.2%, 95% CI: 30.2–38.3), while helminth infections were identified in 29 samples (5.3%, 95% CI: 3.7–7.7) (Table 1). A total of ten genera of enteric parasites were identified. Among the protozoa, the detected species included *Entamoeba histolytica/E. dispar/E. moshkovskii* complex (163; 29.6%, 95% CI: 25.8–33.6), *Entamoeba coli* (58; 10.5%, 95% CI: 8.1–13.4), *Giardia lamblia* (80; 14.5%, 95% CI: 11.7–17.8), *Cryptosporidium* spp. (7; 1.3%, 95% CI: 0.5–2.6), *Iodamoeba buetschlii* (13; 2.4%, 95% CI: 1.3–4.0), *Blastocystis* spp. (18; 3.3%, 95% CI: 2.0–5.1), and *Chilomastix mesnili* (3; 0.5%, 95% CI: 0.1–1.6). The helminths identified were *Hymenolepis nana* (24; 4.4%, 95% CI: 2.5–6.0), *Trichuris trichiura* (4; 0.7%, 95% CI: 0.2–1.8), and *Ascaris lumbricoides* (3; 0.5%, 95% CI: 0.1–1.6) (Table 1). Data on the genotypic characterization of *G. lamblia*, *E. histolytica/E. dispar/E. moshkovskii* complex and *Cryptosporidium* spp. has been published in a separate manuscript [35].

3.3. Parasitic Coinfections

Out of the 550 study participants, 125 (22.7%, 95% CI: 18.2–25.1) were infected with more than one enteric parasite. Kiandutu Health Centre reported a significantly higher rate of co-infection, with 96 of 330 participants (29.1%, 95% CI: 24.2–34.3) affected, compared to Thika Level 5 Hospital, where 29 of 220 participants (13.2%, 95% CI: 9.0–18.4) had co-infections ($\chi^2 = 19.02$, $p < 0.001$). Additionally, 118 of the 550 participants (21.5%, 95% CI: 18.2–25.1) had protozoan co-infections, most commonly involving *E. histolytica/E. dispar/E. moshkovskii* complex, *G. lamblia*, and *E. coli*. No helminth-helminth co-infections were reported; however, 15 participants (2.7%, 95% CI: 1.6–4.5) had protozoa-helminth co-infections (Table 2).

Co-infection prevalence increased significantly across the age groups. ($\chi^2 = 22.93$, $p < 0.001$), ranging from 10.7% (95% CI: 5.6–19.4) among infants and toddlers to 18.4% (95% CI: 14.2–23.6) among preschoolers and 33.5% (95% CI: 27.3–40.4) among school-aged children. In contrast, a significant reduction was observed with higher parental monthly income ($\chi^2 = 14.93$, $p = 0.005$). The prevalence of co-infections declined progressively with increasing parental income from 27.7% (95% CI: 22.4–33.7) among children whose parents earned less than Kshs. 5000, to 23.0% (95% CI: 16.7–30.8) for those earning Kshs. 5001–10,000, 23.9% (95% CI: 15.1–35.6) for Kshs. 10,001–15,000, 17.7% (95% CI: 8.0–34.4) for Kshs. 15,001–20,000, and 5.9% (95% CI: 2.2–14.8) among those whose parents earned above Kshs. 20,000. Children who wore shoes had a significantly lower prevalence of multiple parasitic co-infections ($\chi^2 = 5.44$, $p = 0.020$), 20.5% (95% CI: 16.9–24.6) compared to 30.6% (95% CI: 23.0–39.4) among those who did not. Similarly, children who consumed uncleaned or raw fruits and vegetables had a significantly higher prevalence of co-infections ($\chi^2 = 4.19$, $p = 0.041$), 24.2% (95% CI: 20.6–28.3) compared to 12.7% (95% CI: 6.4–23.5) among those who did not.

Table 1. Prevalence of enteric parasites and their association with age and sex in children aged 10 years and below attending Kiandutu Health Centre and Thika Level 5 Hospital, Kiambu County, Kenya.

Enteric Parasitic Infections	Overall (n = 550) (%)	KHC (n = 330) (%)	TH (n = 220) (%)	Prevalence *p* Value	Gender		Gender *p* Value	Age in Months			Age *p* Value
					Male (n = 278)	Female (n = 272)		3–35 (n = 84)	36–71 (n = 266)	72–131 (n = 200)	
All parasitic infections	202 (36.7)	151 (45.8)	51 (23.2)	$x^2 = 28.95$ $p < 0.001$ *	103 (37.1)	99 (36.4)	$x^2 = 0.03$ $p = 0.874$	19 (22.6)	89 (33.5)	94 (47.0)	$x^2 = 17.50$ $p < 0.001$ *
Protozoa	188 (34.2)	140 (42.4)	48 (21.8)	$x^2 = 24.91$ $p < 0.001$ *	95 (34.2)	93 (34.2)	$x^2 = 0.00$ $p = 0.996$	18 (21.4)	80 (30.1)	90 (45.0)	$x^2 = 18.47$ $p < 0.001$ *
Entamoeba histolytica/E. dispar/E. moshkovskii complex	163 (29.6)	125 (37.9)	38 (17.3)	$x^2 = 26.88$ $p < 0.001$ *	87 (31.3)	76 (27.9)	$x^2 = 0.74$ $p = 0.389$	13 (15.5)	64 (24.1)	86 (43.0)	$x^2 = 29.17$ $p < 0.001$ *
Entamoeba coli	58 (10.5)	46 (13.9)	12 (5.5)	$x^2 = 10.07$ $p = 0.002$ *	29 (10.4)	29 (10.7)	$x^2 = 0.01$ $p = 0.930$	4 (4.8)	21 (7.9)	33 (16.5)	$x^2 = 12.48$ $p = 0.002$ *
Giardia lamblia	80 (14.5)	61 (18.5)	19 (8.6)	$x^2 = 10.30$ $p = 0.001$ *	42 (15.1)	38 (14.0)	$x^2 = 0.14$ $p = 0.705$	7 (8.3)	37 (13.9)	36 (18.0)	$x^2 = 4.62$ $p = 0.100$
Cryptosporidium spp.	7 (1.3)	1 (0.3)	6 (2.7)	$x^2 = 6.17$ $p = 0.013$ *	3 (1.1)	4 (1.5)	$x^2 = 0.17$ $p = 0.682$	3 (3.6)	4 (1.5)	0 (0)	$x^2 = 6.22$ $p = 0.045$ *
Iodamoeba buetschlii	13 (2.4)	12 (3.6)	1 (0.5)	$x^2 = 5.79$ $p = 0.016$ *	6 (2.2)	7 (2.6)	$x^2 = 0.10$ $p = 0.749$	1 (1.2)	2 (0.8)	10 (5.0)	$x^2 = 9.31$ $p = 0.010$ *
Blastocystis spp.	18 (3.3)	8 (2.4)	10 (4.6)	$x^2 = 1.88$ $p = 0.171$	8 (2.9)	10 (3.7)	$x^2 = 0.28$ $p = 0.599$	4 (4.8)	7 (2.7)	7 (3.5)	$x^2 = 0.93$ $p = 0.627$
Chilomastix mesnili	3 (0.5)	2 (0.6)	1 (0.5)	$x^2 = 0.06$ $p = 0.813$	3 (1.1)	0 (0)	$x^2 = 2.95$ $p = 0.086$	1 (0.7)	1 (0.7)	1 (0.5)	$x^2 = 0.79$ $p = 0.674$
Helminths	29 (5.3)	26 (7.9)	3 (1.4)	$x^2 = 11.22$ $p = 0.001$ *	14 (5.0)	15 (5.5)	$x^2 = 0.06$ $p = 0.802$	0 (0)	16 (6.0)	13(6.5)	$x^2 = 5.57$ $p = 0.062$
Hymenolepis nana	24 (4.4)	22 (6.7)	2 (0.9)	$x^2 = 10.49$ $p = 0.001$ *	10 (3.6)	14 (5.2)	$x^2 = 0.79$ $p = 0.374$	0 (0)	13 (4.9)	11 (5.5)	$x^2 = 4.38$ $p = 0.112$
Trichuris trichiura	4 (0.7)	3 (0.9)	1 (0.5)	$x^2 = 0.38$ $p = 0.539$	2 (0.7)	2 (0.7)	$x^2 = 0.00$ $p = 0.983$	0 (0)	2 (0.8)	2 (1.0)	$x^2 = 0.81$ $p = 0.666$
Ascaris lumbricoides	3 (0.5)	3 (0.9)	0 (0)	$x^2 = 2.01$ $p = 0.156$	2 (0.7)	1 (0.4)	$x^2 = 0.31$ $p = 0.575$	0 (0)	2 (0.8)	1 (0.5)	$x^2 = 0.69$ $p = 0.709$

* Significant *p* value.

Table 2. Enteric parasitic coinfections in children 10 years and below attending Kiandutu Health Centre and Thika level 5 Hospital in Kiambu County, Kenya.

Enteric Parasitic Coinfections	No. of Coinfections (n)
Protozoa	
Entamoeba histolytica, E. dispar/E. moshkovskii complex + *Giardia lamblia*	38
E. histolytica, E. dispar/E. moshkovskii complex + *Entamoeba coli*	29
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *G. lamblia*	15
E. histolytica, E. dispar/E. moshkovskii complex + *Blastocystis* spp.	6
E. histolytica, E. dispar/E. moshkovskii complex + *Iodamoeba buetschlii*	5
E. histolytica, E. dispar/E. moshkovskii complex + *G. lamblia* + *Blastocystis* spp.	3
E. histolytica, E. dispar/E. moshkovskii complex + *G. lamblia* + *I. buetschlii*	2
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *Blastocystis* spp.	2
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *G. lamblia* + *Blastocystis* spp.	2
G. lamblia + *Cryptosporidium* spp.	1

Table 2. *Cont*.

Enteric Parasitic Coinfections	No. of Coinfections (n)
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *I. buetschlii*	1
E. histolytica, E. dispar/E. moshkovskii complex + *G. Lamblia* + *Chilomastix mesnili*	1
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *G. lamblia* + *I. buetschlii*	1
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *C. mesnili*	1
E. histolytica, E. dispar/E. moshkovskii complex + *C. mesnili*	1
Protozoa + helminth coinfections	
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *Hymenolepis nana*	4
E. histolytica, E. dispar/E. moshkovskii complex + *G. lamblia* + *H. nana*	3
G. lamblia + *H. nana*	3
E. histolytica, E. dispar/E. moshkovskii complex + *H. nana*	2
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *G. lamblia* + *I. buetschlii* + *H. nana*	1
E. histolytica, E. dispar/E. moshkovskii complex + *I. buetschlii* + *H. nana*	1
E. histolytica, E. dispar/E. moshkovskii complex + *E. coli* + *I. buetschlii* + *H. nana*	1
E. histolytica, E. dispar/E. moshkovskii complex + *A. lumbricoides*	1
E. histolytica, E. dispar/E. moshkovskii complex +*E. coli* + *A. lumbricoides*	1

3.4. Risk Factors Associated with Enteric Parasitic Infections

In multivariable logistic regression analysis, children in the older age groups showed progressively higher odds of overall enteric parasitic infection, *E. histolytica/E. dispar/E. moshkovskii* complex infection, and *E. coli* infection compared with the reference age group (3–35 months). However, statistically significant associations were observed only among children aged 72–131 months. Specifically, children aged 72–131 months had significantly higher odds of overall enteric parasitic infection (AOR = 2.73, 95% CI: 1.50–4.98, $p = 0.001$), *E. histolytica/E. dispar/E. moshkovskii* complex infection (AOR = 3.79, 95% CI: 1.93–7.41, $p < 0.001$), and *E. coli* infection (AOR = 3.34, 95% CI: 1.12–9.98, $p = 0.031$). Although children aged 36–71 months also demonstrated increased odds of overall enteric parasitic infection (AOR = 1.51, 95% CI: 0.84–2.72, $p = 0.168$), *E. histolytica/E. dispar/E. moshkovskii* complex infection (AOR = 1.51, 95% CI: 0.77–2.95, $p = 0.231$), and *E. coli* infection (AOR = 1.41, 95% CI: 0.46–4.31, $p = 0.550$), these associations were not statistically significant. When age group was additionally modeled as an ordinal variable, each increase from one age category to the next was associated with significantly higher odds of overall enteric parasitic infection (AOR = 1.70, 95% CI: 1.29–2.24, $p < 0.001$), *E. histolytica/E. dispar/E. moshkovskii* complex infection (AOR = 2.15, 95% CI: 1.59–2.91, $p < 0.001$), and *E. coli* infection (AOR = 2.08, 95% CI: 1.30–3.32, $p = 0.002$).

Compared with children from households in the highest income category (≥ Kshs. 20,000), those with lower parental or guardian income generally had greater odds of overall enteric parasitic infection, as well as infection with the *E. histolytica/E. dispar/E. moshkovskii* complex, *E. coli*, and *G. lamblia*. For overall enteric parasitic infection, significantly increased odds were observed among households earning Kshs. 10,001–15,000 (AOR = 2.84, 95% CI: 1.26–6.42, $p = 0.012$), Kshs. 5001–10,000 (AOR = 2.28, 95% CI: 1.09–4.73, $p = 0.028$), and ≤ Kshs. 5000 (AOR = 3.20, 95% CI: 1.61–6.39, $p = 0.001$), while households earning Kshs. 15,001–20,000 showed increased but non-significant odds (AOR = 2.22, 95% CI: 0.85–5.80, $p = 0.103$). A comparable trend was observed for *E. histolytica/E. dispar/E. moshkovskii* complex infection, where significant associations were identified among households earning Kshs. 10,001–15,000 (AOR = 2.94, 95% CI: 1.20–7.24, $p = 0.019$), Kshs. 5001–10,000 (AOR = 2.50, 95% CI: 1.11–5.65, $p = 0.028$), and ≤ Kshs. 5000 (AOR = 3.29, 95% CI: 1.51–7.13, $p = 0.003$), whereas the Kshs. 15,001–20,000 category remained non-significant (AOR = 2.00, 95% CI: 0.69–5.76, $p = 0.200$). In contrast, for *E. coli* and *G. lamblia* infections, statistically significant associations were observed only among households earning ≤ Kshs. 5000, with AORs of 10.3 (95% CI: 1.37–77.97, $p = 0.024$) and 3.38 (95% CI: 1.16–9.83, $p = 0.026$), respectively, while the remaining lower-income categories showed elevated but non-significant odds. When income category was additionally modeled as an ordinal variable, each decrease in income category was associated with significantly increased odds of overall parasitic infection (AOR = 1.24, 95% CI: 1.08–1.43, $p = 0.002$), *E. histolytica/E. dispar/E. moshkovskii* complex infection (AOR = 1.25, 95% CI: 1.07–1.46, $p = 0.004$), *E. coli* infection (AOR = 1.54, 95% CI: 1.17–2.04, $p = 0.002$), and *G. lamblia* infection (AOR = 1.30, 95% CI: 1.06–1.60, $p = 0.012$).

Untrimmed fingernails were significantly associated with a higher prevalence of overall parasitic infections, protozoan infections, *E. histolytica/E. dispar/E. moshkovskii* complex, *E. coli* and *G. lamblia* infections (AOR = 1.89, 95% CI: 1.31–2.73, $p = 0.001$; 1.79, 95% CI: 1.23–2.60, $p = 0.002$; 1.93, 95% CI: 1.31–2.85, $p = 0.001$; 2.70, 95% CI: 1.53–4.77, $p = 0.001$ and 1.66, 95% CI: 1.02–2.71, $p = 0.040$, respectively) (Table 3). After adjusting for potential confounders in the multivariable logistic regression model, no statistically significant associations were observed with gender, parental education level, handwashing with soap and water, wearing shoes, consumption of raw fruits and vegetables, drinking unboiled water, open defecation, type of toilet facility (improved, unimproved, shared, or overflowing), eating a balanced diet, meal frequency, or keeping pets/animals (Table 3).

Table 3. Potential risk factors associated with transmission of enteric parasitic infections in children 10 years and below attending Kiandutu Health Centre and Thika level 5 Hospital in Kiambu County, Kenya.

Variable	Participants (n)	Infected (%)	COR (95% CI)	*p* Value	AOR (95% CI)	*p* Value
Age in months						
3–35	84	19 (22.6)	1.0 (Reference)		1.0 (Reference)	
36–71	266	89 (33.5)	1.71 (0.97–3.03)	0.066	1.51 (0.84–2.72)	0.168
72–131	200	94 (47)	3.04 (1.70–5.43)	<0.001 *	2.73 (1.50–4.98)	0.001 *
Gender						
Male	278	103 (37.1)	1.0 (Reference)		1.0 (Reference)	
Female	272	99 (36.4)	1.03 (0.73–1.45)	0.874	1.11 (0.77–1.59)	0.569
Education level of parent						
Tertiary	132	39 (29.6)	1.0 (Reference)			
Secondary	260	96 (36.9)	1.12 (0.18–6.90)	0.902		
Primary	153	65 (42.5)	0.89 (0.15–5.40)	0.897		
Non-formal	5	2 (40)	0.61 (0.10–3.77)	0.592		
Monthly income of parents (Kshs)						
≥20,000	68	12 (17.6)	1.0 (Reference)		1.0 (Reference)	
15,001–20,000	34	13 (38.2)	2.89 (1.14–7.33)	0.026 *	2.22 (0.85–5.80)	0.103
10,001–15,000	67	27 (40.3)	3.15 (1.43–6.95)	0.005 *	2.84 (1.26–6.42)	0.012 *
5001–10,000	139	50 (35.9)	2.65 (1.30–5.41)	0.007 *	2.28 (1.09–4.73)	0.028 *
≤5000	242	100 (41.3)	3.26 (1.66–6.40)	0.001 *	3.20 (1.61–6.39)	0.001 *
Hand washing before eating						
Always	150	48 (32)	1.0 (Reference)			
Most times	195	83 (42.6)	0.88 (0.56–1.38)	0.579		
Sometimes	4	1 (25)	0.62 (0.06–6.11)	0.685		
No	201	70 (34.8)	1.39 (0.92–2.08)	0.114		
Hand washing after visiting the toilet						
Always	188	67 (35.6)	1.0 (Reference)			
Most times	179	74 (41.3)	1.10 (0.72–1.69)	0.668		
No	182	61 (33.5)	1.40 (0.91–2.14)	0.125		
Hand washing using soap and water						
Yes	370	132 (35.7)	1.0 (Reference)			
No	180	70 (38.9)	1.13 (0.78–1.63)	0.507		
Shoe wearing						
Yes	429	150 (35)	1.0 (Reference)			
No	121	52 (43)	0.71 (0.47–1.08)	0.107		
Eating uncleaned fruits/raw vegetables						
No	63	16 (25.4)	1.0 (Reference)		1.0 (Reference)	
Yes	487	186 (38.2)	1.81 (1.00–3.28)	0.052	1.47 (0.78–2.79)	0.234
Drinking boiled water						
Yes	127	34 (26.8)	1.0 (Reference)		1.0 (Reference)	
No	423	168 (39.7)	0.54 (0.34–0.83)	0.006 *	0.72 (0.44–1.16)	0.175
Open defecation						
No	439	153 (34.9)	1.0 (Reference)			
Yes	111	49 (44.1)	1.48 (0.97–2.26)	0.071		
Unimproved toilets						
No	328	112 (34.2)	1.0 (Reference)			
Yes	222	90 (40.5)	1.32 (0.93–1.88)	0.117		

Table 3. *Cont.*

Variable	Participants (n)	Infected (%)	COR (95% CI)	*p* Value	AOR (95% CI)	*p* Value
Improved toilets						
Yes	345	119 (34.5)	1.0 (Reference)			
No	205	83 (40.5)	0.78 (0.54–1.11)	0.159		
Shared toilets						
No	265	92 (34.7)	1.0 (Reference)			
Yes	285	110 (38.6)	1.18 (0.83–1.67)	0.346		
Overflowing toilets						
No	479	181 (37.8)	1.0 (Reference)			
Yes	71	21 (29.6)	0.69 (0.40–1.19)	0.182		
Fingernail status						
Trimmed	352	108 (30.7)	1.0 (Reference)		1.0 (Reference)	
Untrimmed	198	94 (47.5)	2.04 (1.43–2.92)	<0.001 *	1.89 (1.31–2.73)	0.001 *
Balanced diet						
Yes	341	125 (36.7)	1.0 (Reference)			
No	209	77 (36.8)	0.99 (0.69–1.42)	0.965		
Meal frequency per day						
≥3	481	176 (36.6)	1.0 (Reference)			
≤3	69	26 (37.7)	0.95 (0.57–1.61)	0.860		
Keeping pets/ animals						
No	309	109 (35.3)	1.0 (Reference)			
Yes	241	93 (38.6)	1.15 (0.81–1.63)	0.424		

* Significant *p* value.

4. Discussion

Epidemiological studies on enteric parasitic infections in children are critical for guiding effective intervention strategies. This study assessed the burden of enteric parasitic infections and examined the factors associated with their occurrence among children aged 10 years or younger in Kiambu County, Kenya. Enteric parasitic infections affected more than one-third (36.7%) of the children aged ≤10 years studied in Kiambu County, highlighting their continued public health significance within this population. This prevalence is broadly consistent with reports from other settings in Kenya [13,14,17,25–27,36] and similar endemic regions [37,38], reflecting the continued influence of environmental and socioeconomic conditions that facilitate parasite transmission. The elevated prevalence may partly reflect the environmental and socioeconomic challenges characteristic of informal urban settlements, where overcrowding, inadequate sanitation infrastructure, insufficient access to safe water, and inappropriate waste disposal are common. These factors create favorable environments for the transmission of enteric parasites, particularly among young children who are more vulnerable due to frequent environmental exposure and developing hygiene practices [18].

Infection occurrence varied considerably by study site, affecting nearly half of the children attending Kiandutu Health Centre (45.8%) compared with approximately one-quarter of those attending Thika Level 5 Hospital (23.2%). This difference likely reflects the environmental and socioeconomic conditions typical of informal settlements, as reported in other similar settings [15,26,27,29]. Protozoan infections constituted the majority of enteric parasitic infections in this study, a pattern consistent with reports from other Kenyan settings [25,27]. The predominance of protozoa likely reflects continued exposure to contaminated water, food, and inadequate hygiene practices in densely populated environments [5].

Seven protozoan species were identified, including *E. histolytica/E. dispar/E. moshkovskii* complex, *E. coli*, *G. lamblia, Blastocystis* spp., *I. buetschlii, Cryptosporidium* spp., and *C. mesnili*. The *E. histolytica/E. dispar/E. moshkovskii* complex was the most prevalent enteric parasite identified by microscopy, with an overall prevalence of 29.6%. The higher occurrence observed among children attending Kiandutu Health Centre compared with Thika Level 5 Hospital likely reflects differences in environmental and sanitation conditions typical of informal settlements. Comparable findings have been documented in other parts of Kenya, highlighting the contribution of local environmental conditions and hygiene-related behaviors to the continued transmission of enteric parasitic infections. [13–15]. Entamoeba histolytica causes amoebiasis, which can result in amoebic dysentery and, in severe cases, liver abscess [39,40]. Globally amoebiasis affects approximately 50 million people and about 100,000 of them succumb to the infection annually [1]. Although microscopy detected a relatively high prevalence of the *E. histolytica/E. dispar/E. moshkovskii* complex (29.6%), PCR analysis confirmed that only 3.3% of these cases were attributable to the pathogenic species *E. histolytica*. This finding demonstrates the challenges associated with relying on microscopy to differentiate morphologically indistinguishable *Entamoeba* spp. and emphasizes the value of molecular methods for reliable species-level identification and accurate epidemiological assessment [35].

Giardia lamblia was detected in 14.5% of children, consistent with previously reported prevalence ranges in Kenya (4.2–44.7%) [15,36,41], suggesting ongoing transmission in the study population. *Giardia lamblia* causes giardiasis, an intestinal infection that may present with watery diarrhea, epigastric discomfort, nausea, vomiting, malabsorption, and subsequent weight loss [40]. Globally, it is responsible for approximately 280 million diarrheal cases each year [42]. In children, untreated giardiasis can impair growth, development, and overall health [43]. The presence of both *G. lamblia* and the *E. histolytica/E. dispar/E. moshkovskii* complex suggests persistent exposure to contaminated environments in densely populated settings. Protozoan cysts are environmentally resilient and can survive in contaminated water or surfaces, increasing the risk of infection in settings where safe water supplies and adequate sanitation are lacking [5,44].

Other protozoan parasites detected included *Entamoeba coli* (10.5%), *Blastocystis* spp. (3.3%), *Iodamoeba buetschlii* (2.4%), *Cryptosporidium* spp. (1.3%), and *Chilomastix mesnili* (0.5%). Although most of these organisms are considered non-pathogenic or opportunistic commensals, their presence indicates exposure to contaminated environments and ongoing faecal-oral transmission within the community. In particular, *E. coli*, a non-pathogenic intestinal protozoan, is commonly used as an indicator of poor sanitation and hygiene conditions [45,46]. Accurate differentiation of *E. coli* from the *E. histolytica/E. dispar/E. moshkovskii* complex is important due to their overlapping morphological characteristics, as only *E. histolytica* is pathogenic and misidentification may lead to unnecessary treatment [45,46].

Blastocystis spp. was detected in 3.3% of children. Although its pathogenicity remains debated, increasing evidence suggests that *Blastocystis* spp. may influence gut health, particularly when co-occurring with other enteric pathogens, and has been associated with gastrointestinal symptoms and impaired growth in children [47,48]. The detection of *Blastocystis* spp. indicates exposure to contaminated environments in the study population. However,

its epidemiology and clinical significance remain insufficiently characterized in many low- and middle-income countries, including Kenya, highlighting the need for further investigation in these settings [49].

Cryptosporidium spp. was detected in 1.3% of children, which is lower than prevalence rates of up to 30% previously reported among Kenyan children [14,15]. Infection is primarily acquired through consumption of food or water contaminated with oocysts, with transmission facilitated by inadequate sanitation infrastructure and the use of unsafe water sources [5,50]. Although the prevalence was low, infections were predominantly observed among children under 60 months of age, a group particularly vulnerable due to immature immune systems [51,52]. This observation agrees with evidence from an informal settlement in Nairobi, Kenya, where children aged two years and younger were found to have the greatest burden of *Cryptosporidium* spp. infection [15]. *Cryptosporidium* spp. is an important cause of diarrheal disease, particularly among immunocompromised individuals, and has been linked to growth impairment, neurocognitive deficits, and malnutrition in young children [53].

Helminth infections were detected in 5.3% of the children, representing a lower prevalence than protozoan infections but exceeding the 1.2% prevalence previously documented in Kenya [27]. Three helminth species were identified: *H. nana*, *T. trichiura*, and *A. lumbricoides* with *H. nana* being the most common (4.4%). This prevalence is higher than earlier Kenyan estimates (0.5–3.6%) [13–15,17] but lower than the 17% reported among children living in informal settlements in Thika, Kenya [16]. *Hymenolepis nana* infection is more common among children than adults in developing countries. [54,55]. Infections were observed primarily among children older than 36 months, which may reflect increased environmental exposure associated with greater mobility and exploratory behavior at this age.

Trichuris trichiura was detected in 0.7% of cases, a prevalence generally consistent with previous Kenyan reports ranging from 0.13% to 1.2% [14,15,17,27,36], although slightly lower than the 3.9% reported among children in the Kibera informal settlement [26]. *Ascaris lumbricoides* was detected at a prevalence of 0.5%, which falls within the lower range of previously reported Kenyan estimates (0.4–9.1%) [13–15,17,27,36,56]. However, substantially higher prevalence has been documented among children in some Kenyan informal settlements, including Kibera and Thika [16,26]. The comparatively lower occurrence of helminth infections may be partly attributable to the implementation of Kenya's National School-Based Deworming Programme (NSBDP), introduced in 2012, which has substantially reduced the burden of soil-transmitted helminths among children [10,11,57]. Environmental and behavioral factors typical of urban settings, such as increased footwear use and environmental conditions less favorable for helminth egg survival (e.g., low humidity and limited moisture), may contribute to reduced transmission. This pattern is consistent with studies reporting lower soil-transmitted helminth prevalence in peri-urban and urban areas [15,27]. However, the continued detection of helminths suggests persistent environmental exposure and underscores the need to sustain deworming programmes alongside improvements in water, sanitation, and hygiene (WASH), particularly in densely populated informal settlements.

Polyparasitism was observed in 22.7% of participants, predominantly involving protozoa–protozoa coinfections. The most frequent combinations included the *E. histolytica/E. dispar/E. moshkovskii* complex, *E. coli*, and *G. lamblia*, likely reflecting shared faecal-oral transmission pathways. Coinfections were more common among older children and were significantly higher at Kiandutu Health Centre, suggesting increased exposure associated with crowded living conditions and limited access to safe water and sanitation in informal settlements. These findings reflect the broader drivers of enteric parasitic transmission in low- and middle-income countries, including overcrowding, inadequate water and sanitation infrastructure, poor hygiene practices, and limited economic resources, particularly in informal settlements [15,29,58].

The odds of enteric parasitic infections increased with age, with school-aged children showing significantly higher odds of infection, while pre-school children showed a non-significant higher odd compared with infants and toddlers. Previous research has likewise demonstrated higher infection risk among older children compared to younger age groups [13]. The pattern likely reflects increased mobility, environmental exposure, and greater interaction with contaminated surroundings as children grow older. Protozoan infections, particularly the *E. histolytica/E. dispar/E. moshkovskii* complex and *E. coli*, also showed a clear age-related increase. This pattern is consistent with studies from Kenya and Ethiopia, which attribute higher infection rates among older children to increased exposure to contaminated environments and poor hygiene practices [17,59,60]. The observed findings underscore the need for focused hygiene education and preventive interventions among school-aged children in informal settlements.

Children from low-income households exhibited significantly higher odds of overall enteric parasitic infections and *E. histolytica/E. dispar/E. moshkovskii* complex infection, while significantly higher odds of *E. coli* and *G. lamblia* infections were observed mainly among households earning ≤ Kshs. 5000. This pattern is consistent with previous findings linking low income to increased prevalence of enteric infections in Kenya [26]. This association likely reflects socioeconomic conditions that increase exposure to infection, such as household

overcrowding, poor housing conditions, and limited access to adequate sanitation and hygiene In informal settlement settings, low household income may therefore contribute to environments that facilitate fecal-oral transmission [27]. These findings highlight the importance of addressing socioeconomic inequalities alongside improvements in water, sanitation and hygiene (WASH) to reduce the burden of enteric parasitic infections among vulnerable children.

Inadequate personal hygiene, such as untrimmed fingernails that can harbor infectious stages, was associated with a greater likelihood of enteric parasitic infection, particularly protozoa, consistent with findings from Kenya and Ethiopia [13,37]. This finding highlights the role of poor hygiene practices in facilitating fecal-oral transmission. These results underscore the importance of improving water, sanitation, and hygiene (WASH) practices as part of efforts to limit enteric parasite transmission in informal settlement settings.

5. Limitations

First, this cross-sectional, hospital-based study conducted in two facilities in Kiambu County limits causal inference and generalizability beyond similar urban informal settings. Second, the microscopy-based diagnostic approach may have underestimated low-intensity infections and could not differentiate pathogenic from morphologically similar parasite species. Third, because participants were symptomatic children seeking healthcare, the reported prevalence rates may not reflect the broader community, including asymptomatic children. Additionally, potential selection bias and limited generalizability may exist; therefore, the findings should be interpreted within the context of symptomatic children attending healthcare facilities rather than as population-level estimates. Fourth, questionnaire-based data are subject to recall and social desirability bias, particularly regarding hygiene and sanitation practices. Fifth, the six-month sampling period precluded assessment of potential seasonal variations in infection patterns. Sixth, due to its cross-sectional design and single-time-point interaction with participants, we did not collect information on duration of residence in the study area or migration history; therefore, we could not determine whether multi-species parasite infections were acquired before settlement or during residence in the study area. Finally, unmeasured confounders, including nutritional status, prior deworming, antimicrobial use, and household water quality, may have influenced the observed associations.

Future studies should incorporate additional context-specific questionnaire variables, including duration of residence, migration history, and detailed environmental and sanitation characteristics, to better characterize factors influencing intestinal parasite transmission in rapidly expanding informal settlements.

6. Conclusions

The study demonstrates that enteric parasitic infections remain a substantial health burden among children aged below 10 years in Kiambu County, Kenya. Protozoan infections were predominantly attributed to the *Entamoeba histolytica/E. dispar/E. moshkovskii* complex and *Giardia lamblia*, whereas helminth infections occurred at considerably lower frequencies. Increasing age, untrimmed fingernails, and low parental income showed significant associations with infection, particularly in children residing in informal settlements. The findings underscore the importance of implementing focused interventions addressing the identified risk factors, including hygiene education for children, promotion of regular nail trimming, and improved access to sanitation and healthcare services for low-income households to reduce infection risk in urban informal settlements.

Author Contributions

L.K.M.: Conceptualization, methodology, validation, formal analysis, investigation, original draft writing, review and editing, and visualization. M.M.: Methodology, review and editing, and supervision. S.M.: Methodology, review and editing, and supervision. M.M.M.: Investigation. T.I.: Investigation. B.N.: Formal analysis. E.M.: Methodology, validation, investigation, and review and editing. C.M.: Methodology, validation, review and editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the Kenya Medical Research Institute, Scientific and Ethical Review Unit (KEMRI SERU- KEMRI/SERU/CMR/P00/4187 on 10 June 2021).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

Data will be accessible upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used ChatGPT to improve readability and language. After using ChatGPT, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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