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Detection and Transmission Dynamics of Intestinal Schistosomiasis among Primary School Pupils in Tharaka Nithi County in the Mt. Kenya Highlands

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ABSTRACT

Emerging infections cause considerable public health problems to humanity worldwide. The presence of Biomphalaria spp vector snails, the compatibility of the snails with schistosomes, and the prevalence of intestinal schistosomiasis infection in school-going children were determined. The study sought to determine the presence and transmission dynamics of schistosomiasis in Tharaka Nithi, an emerging schistosomiasis transmission focus in the Mt. Kenya highlands. The Epidemiological Triangle Model (ETM), which sheds light on the transmission of infectious diseases, served as the foundation for this study. A cross-sectional study design was used. The study targeted 178 students in grades 1–8 from the two primary schools in Tharaka Nithi located along the catchment area of Mukothima and Thanantu rivers. The number of study participants was determined using the Cochran formula. Study participants were selected randomly from the class register while ensuring equal numbers of boys and girls to avoid bias in results. The stool samples collected from the participants were processed using Kato Katz's quantitative screening technique for helminths and formal ether concentration technique for intestinal protozoa. Biomphalaria snails were collected and identified based on morphology. Snails were also bred and experimentally infected with a laboratory strain of Schistosoma mansoni and passed to the F5 generation to check the compatibility with the Schistosoma mansoni parasite. The overall mean snail parasite infection rate was 23.51% with a positivity of 19.38% in Mukothima River compared to 27.64% in Thanantu River. Although none of the field sampled snails were found infected with S. mansoni, pupils tested were found to be infected with the parasite with a positivity rate of 15.5%. Other parasites detected included Ascaris lumbricoides with a prevalence rate of 9.23% and Entamoeba histolytica with a prevalence of 8.48%. Results from the snail susceptibility experiment showed that the snails supported the development of S. mansoni to full patency, indicating the potential to support the schistosomiasis transmission cycle. Despite not finding any field-sampled snails infected with S. mansoni, the demonstrated compatibility of the snails with the parasite and the finding of infection in school children suggests that transmission is a possibility. Schistosomiasis prevention strategies including deworming programs, school and community environment sanitation, and latrines provision are highly recommended to prevent further spread of the disease.

Keywords: Biomphalaria Spp**,** Detection, Intestinal Schistosomiasis, Transmission Dynamics

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I. INTRODUCTION

One of the most common neglected tropical diseases (NTDs) and a persistent public health concern in approximately 77 countries that are developing in the tropics and subtropics is a parasitic infection an infection caused by parasite brought on by digenetic blood trematode worms of the Schistosomatidae family (Deol et al., 2019). Around 700 million people globally are thought to be at risk of infection, out of an estimated 240 million affected individuals (Ansha et al., 2020). Sub-Saharan Africa accounts for about 90% of cases of this illness, and the disease causes nearly 300,000 fatalities there each year (Deol et al., 2019). Hematuria, urinary retention, bladder wall pathological conditions, water retention, and the potential for carcinoma of the squamous cell are the hallmarks of urogenital parasitic infection which is brought on by S. haematobium (Rite et al., 2020). Adults who contract the virus may develop vaginal ulcers and other lesions that impair their reproductive health and lead to infertility and sexual dysfunction (Wubet & Damtie, 2020).

Conversely, intestinal schistosomiasis resulting from *S. mansoni* causes symptoms such as hematemesis, per portal liver fibrosis, portal hypertension, bloody diarrhea, and intestine ulcers (Swai et al., 2006). Chronic infections can also lead to hepatomegaly. These diseases cause immense harm to humanity and have been present in the course of human history (Bhutta et al., 2014). Most of these diseases require favorable conditions for the interaction of vectors, pathogens, climate conditions, and susceptible human hosts, thus for the disease to occur, all confounders must be favorable (Savi et al., 2021). Climate change can affect pathogens directly, by influencing their survival, reproduction, and life cycle, or indirectly, by affecting their habitat, environment, and competitors of pathogens, via altering the contact patterns of pathogens and their intermediate hosts. In addition, human activities like irrigation and the construction of dams in developing countries often result in the introduction of new vector-borne infectious diseases in an area and cause steady transmission amplification (Kibret et al., 2016). It has been demonstrated that ecological modifications with water resource expansion and an influx of human population in a new non-endemic area can cause an influx of schistosomiasis (Chala & Torben, 2018). Higher temperatures result in faster development and replication of pathogens transmitted by vectors in the environment (McCreesh et al., 2015).

According to (Perez-Saez et al., 2015), human movement is identified as a key factor influencing pathogen invasion success and the overall distribution of disease burden at regional sizes in Burkina Faso. Average distances between human settlements and bodies of water that serve as ecosystems for an intermediate host of the parasite account for the effects of resource development related to water resources. The persistence of infection, particularly when reinfection occurs at the highest level of worm load, may be caused by worm-burden variability (Vilches et al., 2021) A schistosomiasis control program was started in the Gambia in 2015. Bathing, playing, and swimming in bodies of water reduce the risk of contracting *S. haematobium*, suggesting that children's actual water contact behavior may be underreported (Joof et al., 2021). Due to their higher likelihood of coming into contact with these freshwater sources, school-age children are more susceptible to contracting schistosomiasis (Lo et al., 2022).

For mapping and field diagnosis of Schistosomiasis, the World Health Organization recommends using the urine filtration technique to identify eggs of *S. haematobium* in urine and the Kato-Katz thick smear method to identify eggs of *S. mansoni* in stool. To detect blood in the urine, or haematuria, which is an excellent sign of S. haematobium infection, urine dipsticks are frequently used in conjunction with the filtration approach (Kisavi, 2015). A neglected tropical disease (NTD) control campaign for schistosomiasis was started in Kenya by the Ministry of Health. To effectively direct this control program, however, there was a dearth of up-to-date, thorough data regarding the frequency and endemicity of schistosomiasis across the nation. The high frequency of contact with contaminated water in an endemic area is mostly responsible for the disease's dissemination among school-age children, aged 10 to 15. After that, as adults, this prevalence declines with reduced exposure to contaminated water.

1.1 Statement of the Problem

Approximately 700 million people worldwide are at risk of contracting schistosomiasis, one of the most common neglected tropical diseases (NTDs), which continues to be a public health concern in many poor countries in the tropics and subtropics (Zeleke et al., 2021). Nearly 300,000 people in Africa die from schistosomiasis each year, with sub-Saharan Africa accounting for over 90% of cases. School-age children have the highest rates of schistosomiasis morbidity and prevalence (Thiam et al., 2022). Schoolchildren are most affected by schistosomiasis prevalence and morbidity (Bethony et al., 2006) which has detrimental effects on academic achievement as well as social and economic development in endemic areas. In addition, no research has ever been done on the prevalence of schistosomiasis among primary school students and related risk factors in Tharaka Nithi areas in the Mt. Kenya highlands. In light of the previously mentioned, this study developed the detection and transmission dynamics of intestinal schistosomiasis among Primary School Pupils in Tharaka in the Mt. Kenya highlands. This study further evaluated the prevalence and related risk factors of schistosomiasis in the selected regions. There is a need for more current and comprehensive information on the endemicity of schistosomiasis to effectively guide control strategies. Because such knowledge is essential to identifying and putting into practice effective control measures, this makes intervention and control measures more challenging. In light of this, the current study's objectives were to map the distribution of the schistosomiasis parasite vector, ascertain the rates of schistosomiasis parasite infection, and describe the dynamics of disease transmission within the study regions.

1.2 Research Objectives

i. To map the distribution of schistosomiasis parasite vector in Tharaka Nithi areas.
ii. To determine schistosomiasis parasite infection rates and characterize disease transmission dynamics in the study areas.
iii. To investigate the prevalence of schistosomiasis infections among populations inhabiting in the study areas.
iv. To evaluate the role of environmental and climate change on schistosomiasis transmission in the study areas.

II. LITERATURE REVIEW

2.1 Theoretical Model

The Epidemiological Triangle Model (ETM), which sheds light on the transmission of infectious diseases, served as the foundation for this study. The triangle is composed of three corners, or vertices: the environment, or those outside variables that either cause or permit the spread of the disease, the host, or organism, that harbors the disease, and the agent, or microbe that produces the disease.

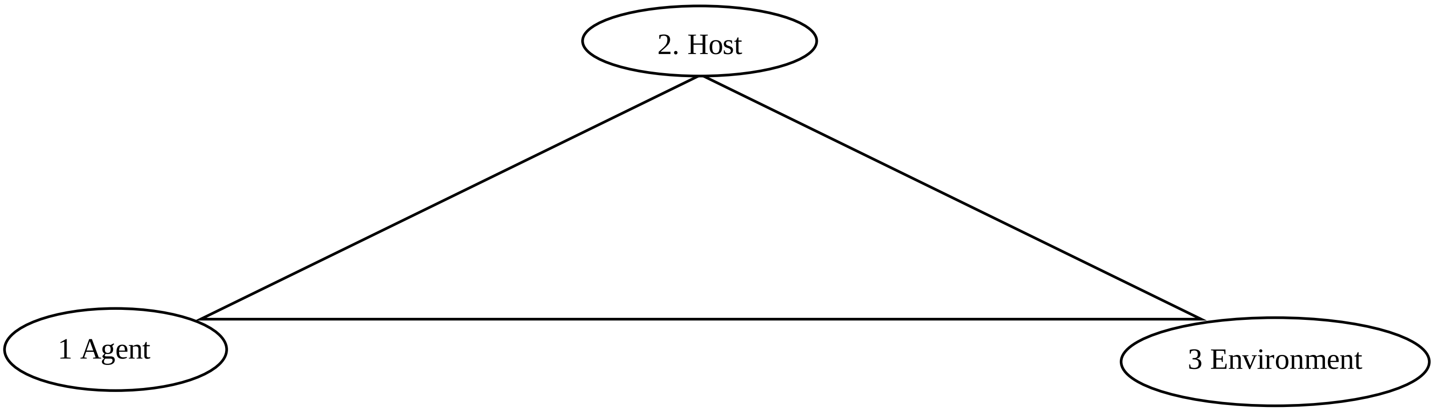


Figure 1
Epidemiological Triangle Model
Source: (Author, 2024)

Vertex 1 states that the agent is what causes the illness. The agent in most epidemiological studies of infectious diseases is a microbe, which is a creature that is too small to be seen with the human eye. Vertex 2 denotes the host, which is an organism that has been exposed to and is harboring a disease. Typically, this organism is an animal or human. Both the diseased organism and any animal carrier, such as insects or worms, that may or may not become ill, might be considered the host. The disease does take residence in the host, even though the host may or may not be aware that it has the disease or exhibits any symptoms of illness. The favorable external circumstances and surroundings that either promote or permit the disease to spread are referred to as the environment in vertex 3. To understand the causes and transmission of both established and newly emerging diseases, the epidemiological triangle is an excellent place to start.

2.2 Empirical Review

2.2.1 Transmission of Schistosomiasis

Schistosomiasis is usually transmitted by unsanitary and adverse environmental conditions, which frequently impact persons in low-income socioeconomic situations (Calasans et al., 2018). Intestinal schistosomiasis, caused by *S. mansoni, S. japonicum, S. mekongi, S. guineenis*, and *S. intercalatum*, and urogenital schistosomiasis, caused by *S. haematobium*, are the two main forms of the disease. *S. mansoni* and *S. haematobium* are the most common and, perhaps, the most significant from the perspective of public health among the Schistosoma species that cause human schistosomiasis. Kenya is home to both of these species, which are obligately dependent on freshwater planorbid snails for transmission *(S. mansoni* depends on snails of the genus Biomphalaria, specifically *B. pfeifferi, B. sudanica,* and *B. choanomphala*).

S. haematobium is dependent on Bulinus snails, specifically *B. nasutus, B. globossus,* and *B. africanus* (Mitta et al., 2017). Temperatures have been observed to have an impact on the transmission of schistosomiasis by vector snails, along with other environmental factors such as the presence or lack of vegetation near water bodies, seasonal patterns of rainfall, water contact behavior, and sanitation (Stensgaard et al., 2013). According to (Mwakitalu et al., 2014), there has been an upward tendency in the years before 2015 in the spread of disease foci in peri-urban and urban areas. Rapid and unplanned urbanization combined with rural-to-urban migration in low- and middle-income countries seems to encourage this kind of phenomenon (Klohe et al., 2021). More recently, research found that the widespread disease schistosomiasis, which is associated with urban areas, posed a serious threat to public health (Kappagoda & Ioannidis, 2014). The primary method of preventing helminthic infections is mass drug administration (MDA) to at-risk population segments periodically. Significant benefits have been demonstrated for this strategy, although long-term dedication is required (Mwandawiro et al., 2019).

2.2.2 Prevalence and Vectors of Schistosomiasis

The data from a prior study carried out in 2015 in four regions of The Gambia, where ten schools were randomly selected from each region, were used by (Joof et al., 2021) A total of 25 boys and 25 girls (7–14 years old) from each school had urine and stool samples taken. Using urine filtration, dipstick, and Kato-Katz procedures, the infections caused by *Schistosoma haematobium* in the urinary system and *Schistosoma mansoni* in the intestinal system were investigated. The total prevalence of urinary schistosomiasis was 10.2%, whereas the prevalence of intestinal schistosomiasis was 0.3% among the schoolchildren in the sample. One student was infected with *S. haematobium* in every school sampled in CRR, 50% of schools in URR, and just one school in LRR each had an infection. There was no significant difference in the infection rate between age groups ($\chi^2 = 0.882$, df = 2, $p = 0.643$), however, *S. haematobium* infection was considerably greater in boys ($\chi^2 = 4.440$, df = 1, $p = 0.035$). A risk factor for *S. haematobium* infection was male gender. It was discovered that bathing, playing, and swimming in water bodies reduced the chance of contracting *S. haematobium*, suggesting that children's actual water contact behavior may have been underreported.

Sakubita et al. (2019) carried out research in Zambia to find out the incidence of urinary schistosomiasis in the Mpongwe district and the risk factors linked with the disease in school-age children. Interviews were conducted with 390 (100%) students from 15 schools, ages 5 to 14. Of these, 206 (52.8%) were female and 184 (47.2%) were male. The four positive instances, representing 1% of the total, were all male and the study participants' median age was 12 (IQR 7, 14). The prevalence of urinary schistosomiasis was one percent at the time. Recurrence of schistosomiasis was linked to contracting new infections. The lower prevalence rate could have been caused by widespread medication administration.

Schistosoma is extremely prevalent in Tanzania (Mwakitalu et al., 2014), in places where it is most endemic, prevalence can range from 80%. In the previous 30 years, very few systematic reviews have been conducted to report the prevalence of parasitic diseases in poor nations. Tanzania (63.5%) and Zimbabwe (50%) have been shown to have significant levels of *Schistosoma mansoni* infection, while the prevalence in other nations has generally been around 30%. In a different study conducted in Tanzania, 5952 students from 36 schools were enlisted and their stool and urine specimens were analysed. Of the 5952 students, 898 (15.1%) tested positive for *Schistosoma mansoni*, whereas 519 (8.9%) tested positive for *S. haematobium.*

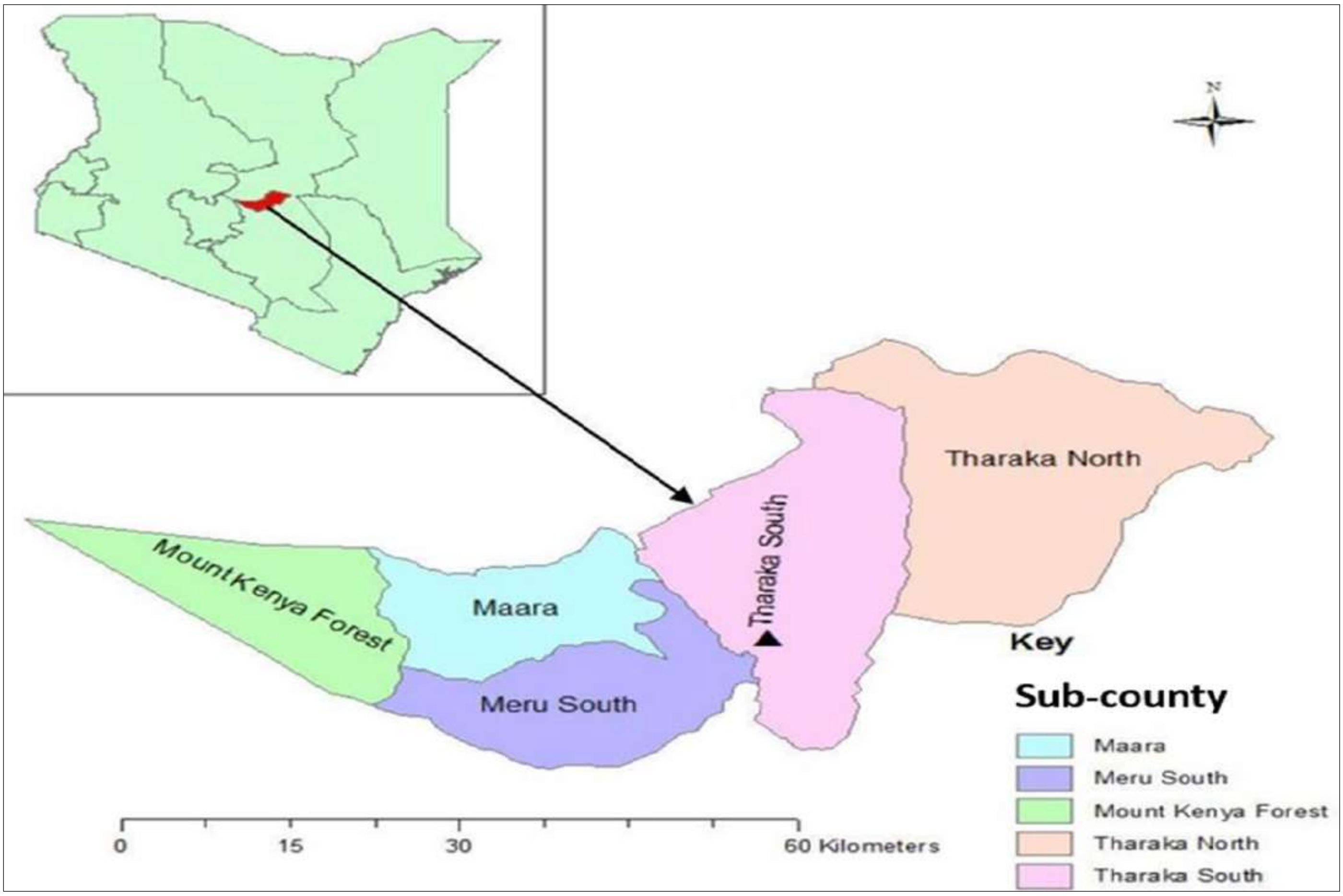
In Kenya, Kisavi (2015) investigated the risk variables for STH infections in 394 students in school, ages 5 to 10, from certain schools in the Kikumini sub-location of Machakos County. The children's stool samples were taken to check for STH infection. 38.6% of people (152/394) had at least one STH infection overall. *A. lumbricoides*, hookworms, and *T. trichiura* were the most common STHs, with a prevalence of 25.9% (102/394), 10.4% (41/394), and 2.3% (9/394), respectively. One hundred and forty-four children developed one or more STH infections. Of the children, 77.42% (96/124) had a single illness, while 22.58% (28) had two infections. The stool samples did not exhibit triple infection.

According to the reviewed studies, children who attended schools near open bodies of water were more likely to become infected. Furthermore, in many sub-Saharan African nations, the ongoing transmission of schistosomiasis is also a result of ecological changes brought about by human-caused reservoir and dam construction, irrigation systems, and electricity generation (Jourdan et al., 2018), socioeconomic variables that contribute to the ongoing spread of the crippling illness in sub-Saharan nations include the lack of drinkable water for residential use, inadequate sanitation and hygiene, and poverty in the workplace (Gryseels et al., 2006), Farming and fishing are two occupations that increase the danger of the disease spreading.

III. METHODOLOGY

3.1 Study Site

This study was in Tharaka-Nithi County in Kenya (Figure 1). It covers an area of 2609 km² with an average altitude of approximately 1200 meters above sea level and as of the 2019 census, a population of 393,177 (Kenya National Bureau of Statistics [KNBS], 2019. It lies between 0°18′S and 38°0′E with physical features including hills and several rivers that flow from Mt. Kenya and Nyambene Hills. The study area was in Tharaka North, and the rivers of interest were the Thanantu River and Mukothima River, with coordinates; Thanantu River 00 º 04′ 08″ S, 037º 56′ 021″E, Alt 756m while Mukothima River 00º 07′ 27″S, 037º 56′ 034″E, Alt 798m. The study participants' schools were Mukothima Primary School GPS coordinates 00º 00. 359'N, 037º 56. 084 E and Thanantu primary school GPS coordinates 00 º 00. 0136'N, 037º 942'E. The average annual rainfall received in the county ranges between 200 and 800mm, and the main economic activity is non-mechanized subsistence farming.



Template 1

Map of Tharaka Nithi County, Kenya

Source: https://tharakanithi.go.ke

3.2 Study Design

This was a cross-sectional study. Parasitological screening and malacological surveys were carried out in 2 schools and 2 rivers respectively in Tharaka Nithi County, Kenya.

3.3 Study Population

The study population comprised 178 students in grades 1–8 from the two primary schools in Tharaka Nithi located along the catchment area of Mukothima and Thanantu rivers. Study participants were selected randomly from the class register while ensuring equal numbers of boys and girls to avoid bias in results, 130 pupils provided complete data and were thus used for this study.

3.4 Limitations of the Study

A cross-sectional study design cannot give a conclusive picture of the infection rate as the study participants' exposure and outcome are done only once. Financial constraints also affected the sample collection and manipulation.

3.5 Sample Size Calculation.

The number of study participants was determined using the Cochran formulae as described by (Mezui-Mbeng, 2015)

$$n_o = \frac{z^2pq}{e^2}$$

Where

n_o -sample size,

Z^2 is the abscissa of the normal curve which cuts off an area α at the tails.

(1 – α) equals the desired confidence level, e.g., 95%).

e the desired level of precision,

p -population's estimated proportion of a given attribute. (13.5%) (Mwandawiro et al., 2019) national-wide geo-helminths proposition.

q is 1-p.

$$=\frac{1.96^2 * 0.135(1-0.135)}{0.05^2}$$

=177.64

=178

3.6 Snails Survey

Snails from the Mukothima and Thanantu rivers were collected using standard scooping techniques as described by (Takougang et al., 2008). Snails collected were identified up to species level, based on shell morphological characteristics using standard taxonomic keys (Goodfriend, 1986).The snails of interest (*B. pfeifferi)* were screened to determine their infection status as previously described (Mutuku et al., 2014). Briefly, each of the snails was placed into an individual well of a plastic 24-well culture plate containing about 1ml of aged de-chlorinated water and placed in indirect sunlight for cercariae shedding and subsequently examined under a dissecting microscope. Cercariae were then identified using the standard identification key. The screening process was repeated after four weeks to determine snails that could have been harboring pre-patent infection during the time of collection.

3.7 Laboratory Breeding of Snails

Snails that did not shed any cercariae were used to breed F1 generation in the laboratory using the methods described by (Mutuku et al., 2017) and were used in subsequent susceptibility studies. The snails were maintained in plastic aquaria measuring 60cm long x 30cm wide x 15cm deep in the laboratory at an ambient temperature of 25-28^{o}C by use of an electric heater. The snails were fed with partially boiled lettuce and aeration of the aquaria was provided by use of an air pump with plastic aeration tubes, and water was changed once a week.

3.7.1 Exposure of Mice to *S. Mansoni* Cercariae

The cercariae that the F1 snails produced were used to expose mice (25 cercariae per mouse) using the ring technique as described (Colley et al., 2014) or passaging. The exposed mice were maintained in the laboratory for 8 weeks after which they were perfused, and ova harvested from the liver using nested sieves as previously described (Chelkeba et al., 2022; Lee et al., 2013)The harvested ova were then hatched into miracidia by exposing them to indirect light (Wanlop et al., 2022) and the miracidia were used to infect the F2 generation snails. This process was repeated up to the F5 generation.

3.7.2 Exposure of Snails to *S. Mansoni* Miracidia

Schistosoma mansoni miracidia obtained from laboratory-maintained mice were used to infect the F1 generation snails. The snails were exposed to 5 miracidia each in a 24-well culture plate for 6 hours. The exposed snails were maintained in the laboratory at an ambient temperature of 25-28℃ as previously described (Thiam et al., 2022).

3.8 Parasitological Stool Screening Survey

Stool samples collected were screened for *S. mansoni* and other geo-helminths using the Kato Katz technique and for protozoa using the formal ether concentration method. S *mansoni* and other geo-helminths using the Kato Katz technique and for protozoa using the formal ether concentration method.

3.9 Ethical Considerations

This study was approved by the Scientific and Ethics Review Unit (SERU) of (KEMRI), Protocol Approval No. KEMRI/ SERU 3561. Before embarking on the field activities, the local community was briefed on the purpose of the project and the activities to be carried out. The risks and benefits of participating in the study were explained to the parents and children; participation was limited to stool sample collection, a non-invasive method with no real or perceived risks. Written informed consent was obtained from parents or guardians of the children recruited into the study. Study participants who were found positive for schistosomiasis or any other helminths were treated appropriately by a qualified clinician. All experimental animals were handled humanely and approval concerning the use of mice was obtained from the Animal Care and Use Committee of KEMRI.

3.10 Statistical Analyses

Data was analyzed using SPSS version 24.0. Descriptive statistics were used to summarize the quantitative data using percentages, bar graphs, and tables.

IV. FINDINGS & DISCUSSION

4.1 Findings

4.1.1 Presence of *B. pfeifferi* in Tharaka Nithi Rivers

Biomphalaria pfeifferi snails (vector for *S. mansoni*) were collected from Thanantu and Mukothima rivers but none of the snails were positive for *S. mansoni*. The findings on the number of snails collected and those that were found to be shedding non-human cercariae from the rivers are shown in Table 1. The percentages of non-human cercariae-positive snails from the first and second collections in Thanantu were 23.45% and 31.83% respectively and were not significantly different (z = -1.1172, p =0.2627). On the other hand, 18.42% and 20.34% positivity rates for non-human cercariae were observed from snails collected from Mukothima River during the first and second collections respectively, and were also not significantly different (z = -0.3044, p = 0.7641). Mean positivity rates between Thanatu and Mukothima rivers were also not significantly different from each other (Thanantu M = 27.64, SD = 5.9256; Muthokima M = 19.38, SD = 1.3576; t (2) = 1.9216, p = 0.1946).

Table 1

Number of Snails Collected and Positivity with Non-Human Cercariae

	Total snails screened	**Number positive with cercariae (non-human)**	**Percentage of the positivity**
Thanantu river			
1st collection 18/4/2019	145	34	23.45%
2nd collection 12/5/2019	44	14	31.83%
		Mean	**27.64%, 95% CI[19.4 , 35.9]**
Mukothima river			
1st collection 19/4/2019	114	21	18.42%
2nd collection 14/5/2019	59	12	20.34%
		Mean	**19.38%, 95% CI [17.5, 21.3]**

4.1.2 Compatibility of Collected *B. pfeifferi* Snails with *S. mansoni.*

The susceptibility of *B. pfeifferi* snails to *S. mansoni* was tested through infectivity studies. Snails from Mukothima River demonstrated a slightly higher susceptibility to *S. mansoni* compared to those snails collected from Thanantu River from F1 to F5 generations. However, the infection rate, defined as the proportion of snails producing cercariae, did not differ significantly from F1 to F5 generations in the snails collected from Thanantu River (Table 2). For snails collected from Mukothima River, infection in generation F1 was high but decreased in F2 but increased progressively thereafter. The mean *S. mansoni* infection prevalence in *B. pfeifferi* from F1 -F5 in Thanantu River was not significantly different from that in *B. pfeifferi* from Mukothima (Thanantu M = 49.8, SD = 6.02; Muthokima M = 57.4, SD = 12.54; t (5) = 1.2217, p = 0.2566) (Table 2).

Table 2

Susceptibility of *B. pfeifferi* Snails derived from Thanantu River and Mukothima River *S. mansoni*

No of snails exposed	Snail source	No of the snails survived to patency	No. positive snails	Infection prevalence (%)
20	Thanantu F1	17	9	53
20	Thanantu F2	15	6	40
20	Thanantu F3	18	9	50
20	Thanantu F4	12	6	50
20	Thanantu F5	18	10	56
			Mean	49.8%, 95% CI [44.5, 55.1]
20	Mukothima F1	16	11	69
20	Mukothima F2	16	7	43
20	Mukothima F3	15	8	53
20	Mukothima F4	14	7	50
20	Mukothima F5	14	10	72
			Mean	57.4%, 95% CI [46.4, 68.4]

4.1.3 Prevalence and intensity of *S. mansoni* Infections among School Children

Stool samples were collected from a total of 130 school children, 7 pupils from Mukothima primary school and 56 from Thanantu primary school with 79 of these being girls and 51 boys. The mean age of the children sampled was 11 (± 5 years) (range: 6 years to 16 years). The infection rate among pupils from Mukothima primary school was 14.9% (11 out of 74 pupils) while that among pupils from Thanantu was 16.1% (9 out of 56 pupils); the infection rates were not significantly different between the two sites ($z = -0.1888$, $p = 0.8493$). The overall mean infection rate was 15.5% (95% CI [15.35, 15.65]. Table 3 below shows the severity and prevalence of *S. mansoni* infection among the study participants based on the classification described by (Zeleke et al., 2021). Infections with heavy intensity occurred more frequently compared to either low or moderate infection intensities.

Table 3
Classification of Severity and Prevalence of *S. mansoni* Infections

Classification of *S. mansoni* counts in EPG)	Number (n) of samples with *S. mansoni*	Relative rate of positivity (%)
Light (1-99 EPG)	7	5.4
Moderate (100-399 EPG)	4	3.1
Heavy (>10 EPG)	9	6.9

4.1.4 Prevalence of other parasites compared to *S. mansoni*

Compared to the other infections detected among the pupils, the prevalence of *S. mansoni* was the highest, with a positivity rate of 15.5%. The other parasites detected were *Ascaris Lumbricoides* with a prevalence rate of 9.23%, *Entamoeba histolytica* (8.48%), *Hymenolepis nana* with a prevalence rate of 2.31% while 1.54% of pupils tested positive for *Trichuris trichiura* and *Giardia lamblia*. Nonetheless, most samples (61.54%) were negative for the parasites tested (Figure 2).

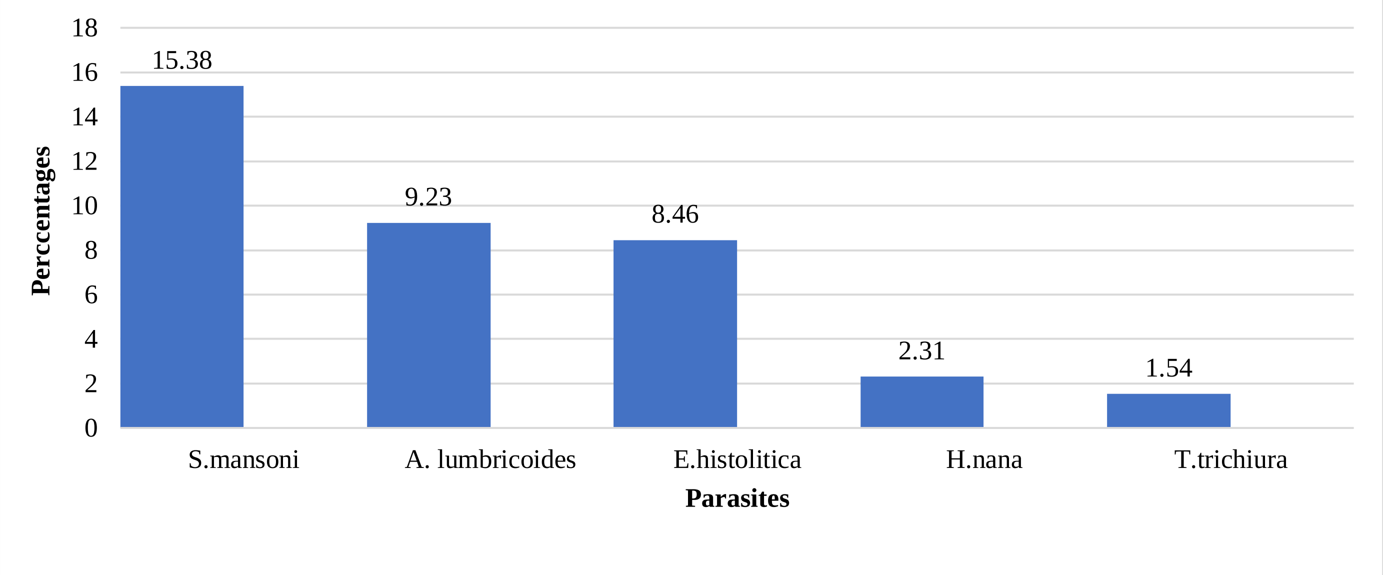


Figure 2
Prevalence of Soil-Transmitted Geo-Helminths and Intestinal Protozoans

4.2 Discussion

Healthcare systems in many developing countries are challenged by the lack of adequate funding and as a result, most disease prevention, diagnosis, and management efforts tend to focus on zones with clearly characterized disease transmission patterns. Healthcare systems in many developing countries are challenged by the lack of adequate funding and as a result, most disease prevention, diagnosis, and management efforts tend to focus on zones with clearly characterized disease transmission patterns. The current study sought to provide critical data on schistosomiasis in an area where such information is lacking or scarce to inform policies on the prevention, diagnosis, and management of the disease. Results suggest that schistosomiasis alongside other helminth infections is a concern in the study area. The presence of intestinal protozoa and helminth infections among primary school pupils may be attributed to favorable climatic conditions prevailing in the area and poor hygiene among the pupils (Thiam et al., 2022). Intestinal parasitic infections and helminths were found to be common among the pupils in the study area. Similar types of intestinal parasites, namely *Entamoeba histolytica* and *Giardia lamblia*, were previously identified in other studies done in Kenya (Kihara et al., 2011) identified these same parasites together with schistosomes in the Mwea irrigation scheme, Kirinyaga County which is adjacent to the current study area.

Transmission of intestinal parasitic and helminthic infections in the area most likely occurs during engagement in farming activities and the resultant human contact with soil potentially contaminated with the parasite's ova (fecal-oral route). Contamination of the water may be through open defecation by infected persons harboring the infective stage of the parasite (ova-cercariae). School children from the area work on farms after school hours and during the school holidays, resulting in frequent contact with the soil which, when combined with the possibility of poor hand-washing habits would result in helminth infections. Wild animals, which are also infected with *G. lamblia*, are an important source of contamination of water along streams (Mwandawiro et al., 2019).) The current study site is located downstream of the Nyambene Hills which is one of the water towers of Kenya that feeds the streams of Mukothima and Thanantu rivers. It is therefore possible that the wild animals contribute to the presence of *G. lamblia* infections among the study population in Tharaka Nithi County.

The overall infection rate for both helminths and protozoa in the current study was 38.46%. For the infectivity studies, F1 – F5 generation snails were used in this study to allow snails to adapt to a laboratory-rearing environment and thus determine infectivity without interference from environmental factors. The schistosome parasite and its intermediate host snails are for example very sensitive to water temperature. Increasing temperatures in freshwater bodies in sub-tropical and tropical areas may therefore alter the geographic distribution of schistosomiasis. Schistosome snail hosts exist in a complex environmental setting that can influence their capability to support transmission (Masaku et al., 2017).

The transmission potential of most neglected tropical diseases is partly dependent on abiotic factors that affect either free-living life stages and/or those that occur in poikilothermic organisms such as snails and mosquitoes (McCreesh et al., 2015). Using the agent-based model, it has been shown that *S. mansoni* infection risk may increase in Eastern Africa over the next few years due to the increase in temperature (El Naga et al., 2010).

Using the model, simulations indicated that snail populations can be established in areas where conditions become newly suitable for schistosome transmission. The movement of snails may be from interconnected water bodies during flooding or through short-distance transportation on objects like fishing nets (Mohammed et al., 2016). In cooler areas where snails are found but without current schistosome transmission occurring, transmission foci may quickly become established as temperatures become suitable. In addition to temperature, other climatic changes like drought, rainfall patterns, and flooding are expected to impact the prevalence of schistosomiasis in the future. Favorable environmental conditions have been shown to enhance embryonation of helminth eggs leading to higher infection rates (De Leo et al., 2020).

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

Although field-collected *B. pfeifferi* snails sampled from Mukothima and Thanantu rivers were not infected with *S. mansoni*, the snails were found to be compatible with the parasite when maintained and exposed in the laboratory. Some children from the study area, which is a rural, poor resource area with challenges in the availability of adequate sanitation, were also found to be infected with *S. mansoni* when their fecal samples were examined. It is therefore highly likely that schistosomes from fecal matter will encounter the compatible snails and result in the area being a schistosomiasis transmission focus. The predicted changes in temperatures favorable for increased schistosome transmission over eastern Africa are likely to worsen the situation.

5.2 Recommendations

The findings of this study underscore the need for putting in place sanitation and water hygiene measures both in schools and in the general community to help in the control of geo-helminths. There is also a need for periodic snails' surveillance of the two rivers under study as well as other neighboring water bodies to establish possible transmission sites. This will improve understanding of the transmission dynamics of the disease, which will guide the implementation of programs to control the possible spread in this newly emerging area of transmission. The area should also be considered for coverage during the national deworming program to control helminth infections.

Additional Information

Authors' Contributions

AM: Contributed to the development of the concept and formulation of the study design, acquisition of the data, analysis, and interpretation of the results, drafting of the manuscript, and dissemination of the study findings.

RM: Participated in the identification of the study subjects, data collection, development, and review of the manuscript.
JM: Provided technical assistance and participated in the identification of the study subjects and the acquisition of the data.
NK: Contributed to proposal development, laboratory analysis of samples, and manuscript development.
MM: Contributed to the data analysis, manuscript development, and review.
LK: Contributed to the development of the concept and supervised all the study activities, guided the planning and execution of the study activities and data interpretation, and reviewed the manuscript.

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Conflict Of Interest: The authors declare no conflict of interest.

Data Availability: All data sets analyzed in this study are available from the corresponding author on request.

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