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A cross-sectional study on schistosomiasis prevalence, intensity and risk factors in Kassala State, Sudan

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Despite decade-long global efforts, schistosomiasis remains a significant concern in Sudan. In 2017, a nationwide survey on schistosomiasis raised concerns about the existence of persistent "hot spot" areas that require more focused interventions and resources. The Sudanese Federal Ministry of Health (FMOH) and the Kassala State Ministry of Health have continued to implement school-based MDA. This study aimed to assess the prevalence and intensity of *Schistosoma mansoni* and *S. haematobium* infections and to identify associated demographic and environmental risk factors in high-endemic communities in Kassala State, Sudan. We conducted a community-based cross-sectional survey between 24th January and 13th February 2023 across 40 purposively selected villages in New Halfa and Nahr Atbara localities. Stool and urine samples were collected from 3,889 residents of all ages. *S. mansoni* infection was diagnosed via the Kato-Katz technique, and *S. haematobium* via urine centrifugation. Prevalence and infection intensity were modeled using a double hurdle model. Additional sociodemographic and behavioral data were collected through structured household interviews. The prevalence of *Schistosoma mansoni* in New Halfa and Nahr Atbara was 28.0% and 24.3%, respectively. In contrast, the prevalence of *Schistosoma haematobium* was relatively low, with a rate of 2.1% in New Halfa and no infections detected in Nahr Atbara. For *S. mansoni*, one village exhibited the highest prevalence of 68.2%. Out of 40 villages identified as potential hotspots, 25 had a prevalence exceeding 20%. In contrast, *S. haematobium* was found in only a few villages in New Halfa, with prevalence surpassing 10% in two of the 40 villages. The prevalence of infection among individuals aged 20 and older remained high in the identified villages. These findings suggest that the current mass drug administration (MDA)-only approach, which focuses primarily on school-aged children, is insufficient to prevent persistent reinfection at the local level. Therefore, updated guidelines tailored to the national context, expanded MDA with microplanning, awareness campaigns across all age groups, and improvements in water and sanitation are crucial components for effective schistosomiasis control. Moreover, the interruption of annual MDA programs due to civil conflict and reduced access to medication has exacerbated the situation, underscoring the urgent need for international attention and support.

Schistosomiasis is a parasitic infection caused by blood flukes of the genus *Schistosoma*[1]. A global estimate suggests that more than 200 million individuals require treatment for this condition[2]. The World Health Organization (WHO)'s road map for neglected tropical diseases (NTDs) for 2021–2030 established a target for the worldwide elimination of schistosomiasis by 2030. This plan calls for critical actions including defining a proper indicator for morbidity, MDA to all populations, securing access to medicine, deploying ecological approaches such as snail control, using mapping, and developing point-of-care diagnostics and new interventions. The road map

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also emphasizes the importance of intersectoral collaboration across sectors of water and sanitation, vector control, and animal and environmental health[2].

Schistosomiasis has long been present in Northeast Africa. Its longstanding presence in the region was first demonstrated in 1910, when eggs of *S. haematobium* were found in a mummy in Egypt[3]. In Sudan, extensive research into the ecology, disease modes, vectors, and treatment of schistosomiasis began in the 1920s, marked by large-scale surveys. The situation deteriorated during the Second World War as the disease worsened and resources to fight it dwindled. These efforts persisted into the mid-1950s and beyond, incorporating large-scale projects that combined research and intervention[4–7]. Nevertheless, controlling schistosomiasis has remained a challenge in Sudan for several decades. Over the past decade, the primary strategy for controlling schistosomiasis has been school-based MDA. However, the incidence of schistosomiasis has increased, as indicated by the annual statistical reports issued by the government[8]. For instance, the number of outpatient visits rose from 28,636 cases in 2016 to 44,819 cases in 2019, a significant increase even when considering factors such as heightened awareness, expanded access to healthcare, and improved government reporting systems[9]. Furthermore, despite the implementation of several interventions since the last national survey, only a few areas of the country have been examined in terms of local schistosomiasis prevalence and transmission patterns[10].

In 2017, a nationwide survey on schistosomiasis was conducted by the FMOH and the Korea International Cooperation Agency (KOICA), utilizing a school-based random sampling method. The findings indicated that the prevalence of *S. mansoni* and *S. haematobium* in Kassala State were 5.87% and 0.2%, respectively. Notably, there was a significant variation in prevalence among schools[11]. This survey provided crucial data for assessing the disease burden of schistosomiasis. Additionally, the survey raised concerns about the persistent “hot spot” areas that require more focused interventions and resources. To address this issue, the current study was designed to explore the prevalence of these suspected “hot spots” at the village level. Since the nationwide study in 2017, several studies[12–14] have been carried out in Kassala State, Sudan. However, these were either hospital-based studies targeting patients or systematic reviews. To date, there has been no large-scale community-based investigation, which represents not only a gap in the literature but also a critical lack of policy-relevant evidence needed to inform schistosomiasis control strategies.

Methods

Study setting

Kassala State is one of six states targeted by the schistosomiasis control project, funded by KOICA. The selection of these states was influenced by several factors: epidemiological characteristics, disease burden, area security, and input from government officials at the FMOH in Sudan. Kassala State exhibited the highest prevalence of *S. mansoni* in the previous survey[11]. The FMOH also recommended Kassala State as a key intervention area, emphasizing its strategic importance for cross-border disease control. Kassala State is home to 1.73 million people across 11 localities. As of 2018, the life expectancy in Kassala State was 67 years, slightly above the national average of 65 years. The GNI per capita (2011 PPP) stood at USD 3,219. The expected years of schooling in the state was 6.3 years, falling short of the national average of 7.74 years.

Kassala State is noteworthy for several reasons. First, it is one of two states in Sudan where the prevalence of *S. mansoni* is highest. Detecting *S. mansoni* is challenging because its most common symptoms, such as abdominal cramps and diarrhea, are not specific to this infection; severe symptoms like hematochezia and liver cirrhosis only appear in advanced stages. Second, the uneven distribution of schistosomiasis in Kassala State is significant. Among 11 localities, only New Halfa and Nahr Atbara are classified as high-endemic areas, which are targeted for MDA at the community level. These two localities feature irrigation systems established during British colonial rule, which serve as major sources of water for both human use and agriculture[6,15]. However, these irrigation systems also increase the risk of schistosomiasis by promoting more frequent water contact among residents compared to other areas[16]. Third, despite the longstanding donation of praziquantel and operational support from the global NTD community, the WHO’s goal of eliminating schistosomiasis has not been met in Sudan[2]. Investigating the underlying causes of the persistently high prevalence will inform the development of more effective strategies to eradicate schistosomiasis in the region. Lastly, the COVID-19 pandemic interrupted MDA in this area for at least two years, and the health system has collapsed due to the ongoing conflict in Sudan[17]. Although it is unlikely that schistosomiasis programs will resume under the current circumstances, an epidemiological analysis based on the latest data remains relevant and could guide future strategies should the situation improve.

Figure 1 presents a map and aerial photograph of Kassala State, Sudan. The left panel highlights Kassala State (yellow) within the national map of Sudan. The central panel shows administrative boundaries within Kassala, with the study area marked in orange. The right panel provides an aerial view of the Kassala area, where villages are typically situated within clusters of farmlands. Adjacent to the main river, green zones indicate areas of cultivated land supported by irrigation. We used MODIS daily reflectance data provided by NASA’s Land Processes Distributed Active Archive Center and generated the maps using QGIS (version 3.32.3: QGIS Project Steering Committee, Grüt, Gossau ZH, Switzerland).

Sampling

Initially, we planned to conduct a cluster randomized controlled trial (RCT) (ISRCTN75328855) at the village level; however, it was impossible to conduct an RCT due to the civil war in 2023. The sample size was estimated based on the RCT design. The study population includes individuals of all ages residing in Kassala State. To calculate the required sample size, we applied the formula proposed by Hayes and Bennett[18], which incorporates a correction for the design effect. Assuming a 6% population prevalence of schistosomiasis, a cluster size of 25 individuals, between-cluster variation (k) of 0.8, a precision level of 10%, a study power of 90%, and a 5% expected reduction in prevalence due to the intervention, we determined that a total sample of 4,000 individuals from 40

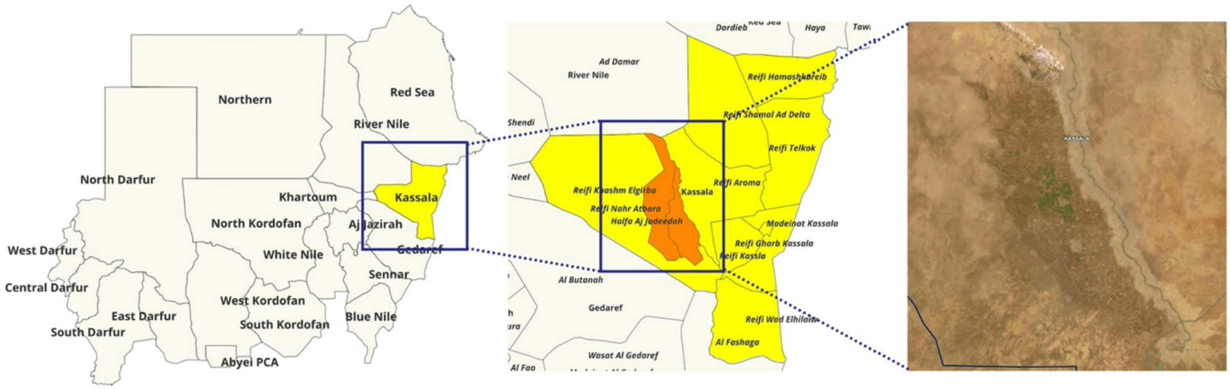

Fig. 1. Map and satellite image of Kassala State and the surveyed localities (Reifi Nahr Atbara and Halfa Aj Jadeedah), based on NASA ESDIS (accessed via EARTHDATA SEARCH: https://earthdata.nasa.gov/, May 2025. The maps were produced using QGIS (QGIS Project Steering Committee, Grüt (Gossau ZH), Switzerland) version 3.32.3).

communities would be adequate. This sample size is sufficient to detect the impact of the intervention on both prevalence and incidence. It also allows for an accurate estimation of schistosomiasis prevalence, particularly given that the prevalence is likely to be significantly higher than the assumed 6%. The target population of this study comprises individuals residing in high-risk areas for schistosomiasis in Kassala State, while the study population specifically includes those living in 40 villages suspected to have a high prevalence of the disease. The estimated population of Kassala State was 2.9 million in 2023[16,17]. In two localities, 40 villages were purposefully selected in consultation with federal and state government officials and the research team based on two criteria: an history of annual MDAs and estimated high prevalence rates despite annual interventions. In each village, two teams, each consisting of two interviewers, visited 25 households between 24th January and 13th February 2023. To avoid over-representation of certain parts of the village, the survey team, accompanied by a village leader or guide, circled the village in a pre-determined direction and visited houses using fixed interval for systematic sampling. In each household, the interviewees included two adults (one male and one female) and at least two children aged 5–15 years (one boy and one girl, when available). Before the interview, the teams explained the purpose of the study and obtained written informed consent from the heads of the households. They then proceeded with the interviews and specimen collection.

The research team initially developed the questionnaire in English, translated it into Arabic. It was subsequently back-translated into English by a different translator and compared with the original version to ensure consistency and accuracy (S1 Text, Questionnaire). The questionnaire was structured into two sections: one for household-related inquiries and another for individual-specific questions. The primary respondent answered both sections, whereas other household members only responded to the individual questions. The household section included questions regarding age, sex, occupation, education level, household possessions (such as radios, refrigerators, and bicycles), the primary source of drinking water, and ownership and usage of toilets. The individual section focused on basic knowledge about schistosomiasis, its symptoms, vectors, and treatment, as well as access to treatment, water contact behavior, and health facility use. The Arabic and English versions of the questionnaires are available in the appendix.

Data collection and diagnosis

Each interviewer entered responses using a tablet PC with a pre-defined questionnaire and distributed the collection bottles for urine and stool samples. All samples were transported to a laboratory temporarily established by the local government. Both stool and urine specimens were processed within 24 h by the two trained laboratory technicians. The technicians made two slides from one stool sample using the Kato-Katz technique[19] and processed urine samples using centrifugation. Once prepared, the samples were examined under a microscope, and the findings were recorded on the result forms. A state supervisor compiled all the notes and entered the data using a tablet PC (Samsung Galaxy T350NZAAXAR, Seoul, Korea; Huawei MediaPad T1 7.0, Shenzhen, China) and handheld GPS devices (eTrex, Garmin International, Olathe, KS, USA). We used a custom-developed software provided by a Sudanese company to enter data for our field study. At the data curation stage, the egg count was determined by multiplying the combined count from two slides for each specimen by 24, then dividing by 2. 10% of the samples were re-re-examined by federal-level and independent experts using diagnostic techniques—Kato-Katz for stool samples and urine centrifugation—to ensure the quality and reliability of the laboratory procedures[20].

Statistical analysis

A total of 25 households were surveyed per village, yielding approximately 100 individuals per site. In total, 40 villages were surveyed. Prevalence was calculated as the proportion of individuals who tested positive for *Schistosoma* infection among the total number sampled in each village. In addition to prevalence, the intensity of infection was also a crucial factor in understanding disease transmission. When modeling egg count data, applying a linear model can result in negative or non-integer predictions, which are inappropriate due to the nature of count data. The standard Poisson model, which assumes that the mean and variance are equal, is often inadequate for modeling egg count data because it fails to account for overdispersion. An alternative method to handle overdispersion is the negative binomial model. However, it might still fail to provide an adequate fit, particularly in cases with high zero counts and low disease prevalence.

Possible alternatives in this case include the zero-inflated model and the double hurdle model[21]. The double hurdle model separates the modeling process into two stages: the first hurdle models the infection status using a logit model, while the second hurdle employs either a zero-truncated model or a Poisson model, depending on the data characteristics. We employed a zero-truncated negative binomial model to address overdispersion in the count data among the infected. All statistical analyses were performed at a 95% confidence level. We used the Stata 17 statistical package, and all code is publicly available by request.

Primary outcome

The primary outcome was the village-level prevalence rate and intensity of schistosomiasis infection in high-endemic areas of Kassala State.

Ethics

The study received IRB approval from the National Research Ethics Review Committee in Sudan (approved on December 28, 2022: Number: 6-9-22). Prior to enrolling the study population, we obtained informed consent from each household. For individuals unable to provide informed consent due to age, verbal assent was obtained from the child, and written consent was obtained from their parents. Written informed consent was obtained from their legal guardians or parents. All methods were performed in accordance with relevant guidelines and regulations.

Results

Table 1 presents the basic socioeconomic characteristics of the households and respondents surveyed. A total of 3,889 individuals participated in the survey- 2,402 from the New Halfa and 1,587 from Nahr Atbara. Of these respondents, 45.6% were male and 54.4% were female, with a similar gender distribution in both locations. The overall average age of the respondents was 22.1 years. Specifically, the average age in New Halfa was 23.1 years, which is higher than in Nahr Atbara, where the average age was 20.7 years. For additional information about the region, including population size, latest year of MDA, and the number of primary health centers and health units, see Table S1.

The survey identified the occupation of the household head rather than the individual's occupation, with farmers constituting the majority at 52.2%, followed by commercial skilled workers. New Halfa had a higher proportion of farmer households, while Nahr Atbara had a greater proportion of fishermen. The average annual household income across the study was 255,150 Sudanese pounds (approximately USD 438 as of January 31, 2023). However, households in Nahr Atbara reported a higher average income of 389,994 Sudanese pounds (USD 670) compared to those in New Halfa. The ownership rates for radios, refrigerators, and bicycles among the households were 42.2%, 23.6%, and 14.3%, respectively. Health insurance coverage was reported by 63.1% of all households, with 99.5% of these being publicly insured. Health insurance coverage was also higher in Nahr Atbra (72.7%) than in New Halfa (56.8%).

Table 2 presents data on each household's access to water, sanitation, and excreta disposal. The questionnaire addresses household-specific issues regarding water and toilets, whereas questions about contact with water bodies are tailored to individuals. Among the total sample, 67.5% of households reported using packaged water, while 25.4% had piped water to the dwelling. In Nahr Atbara, 80.1% of households used packaged water, compared to only 59.2% in New Halfa. Meanwhile, approximately 34.8% of households in New Halfa reported having water piped into the dwelling.

In total, 70.7% of respondents reported having toilet facilities at home, with 72.7% in New Halfa and 67.7% in Nahr Atbara respectively. Regarding the type of toilet, pit latrine without slab was the most prevalent, accounting for 47.1%, followed by pit latrine with slab. Users of toilets that flushed into a septic tank or sewer pipe represented 8.3% and 3.4% of the total, respectively. Among the households without a toilet, about 20.1% used a neighbor's facility, 2.1% used a communal toilet, and the remaining 77.9% engaged in open defecation. Of those practicing open defecation, 51.1% did so within 10 feet of their dwelling, while 48.4% did so at a distance greater than 10 feet. Open defecation in water bodies was less frequent. Approximately 55.1% of respondents urinated within 10 feet of their dwelling, with the figures being 62.4% in New Halfa and 44.6% in Nahr Atbara.

When individuals were asked if they came into contact with water bodies, an average of 84.1% confirmed that they did, with a slightly higher rate reported in Nahr Atbara. The primary reasons for water contact were leisure and swimming, accounting for 40.2% and 17.2% respectively. Farming and wading into the water were the next most common reasons, at 11.6% and 11.2% respectively.

Table 3 shows the survey results concerning disease-related behaviors, awareness, praziquantel usage, health facility utilization, and perceptions of community health workers. The responses regarding awareness and treatment represent one family member, while data on health utilization encompass all participants, including children. Regarding awareness, an average of 85.2% of respondents were familiar with schistosomiasis, and 94% accurately identified its source. Additionally, 64.1% of respondents could correctly recognize at least one symptom of the disease, and 64.4% were aware of the vector involved. However, only one out of 849 respondents correctly identified praziquantel as the appropriate medication.

The proportion of individuals who reported taking schistosomiasis treatment within the past six months was 35.2% overall, with the rate being approximately 3.7% higher in Nahr Atbara. Among the 134 respondents who had received medication, 85.1% obtained it through a community campaign, while 7.5% acquired it from a local

	New Halfa (*N* = 2402)	Nahr Atbara (*N* = 1587)	Row total	*N*
Gender and age				
Male	1084 (45.1%)	736 (46.4%)	1820 (45.6%)	3989
Female	1318 (54.9%)	851 (53.6%)	2169 (54.4%)	
Mean age	23.1	20.7	22.1	
Age group = Under 18	1256 (52.3%)	836 (52.7%)	2092 (52.4%)	3989
18–29	365 (15.2%)	328 (20.7%)	693 (17.4%)	
30–39	337 (14%)	241 (15.2%)	578 (14.5%)	
40–49	223 (9.3%)	106 (6.7%)	329 (8.2%)	
50 or above	221 (9.2%)	76 (4.8%)	297 (7.4%)	
Household head's occupation				
Farmers	1328 (55.4%)	752 (47.4%)	2080 (52.2%)	3989
Fishermen	20 (0.8%)	52 (3.3%)	72 (1.8%)	
Governmental officials and teachers	32 (1.3%)	16 (1%)	48 (1.2%)	
Businessmen (small-scale)	32 (1.3%)	0 (0%)	32 (0.8%)	
Businessman (large-scale)	12 (0.5%)	0 (0%)	12 (0.3%)	
Unskilled/temporarily employed	28 (1.2%)	4 (0.3%)	32 (0.8%)	
Skilled/permanently employed	324 (13.5%)	404 (25.5%)	728 (18.3%)	
Other office workers	47 (2%)	12 (0.8%)	59 (1.5%)	
Others	576 (24%)	347 (21.9%)	923 (23.2%)	
Mean household head's income	166,059	389,994	255,150	
Income quartile				
Lowest	538 (22.4%)	492 (30.9%)	1030 (25.8%)	3989
Low-middle	668 (27.9%)	300 (18.9%)	968 (24.3%)	
Upper-middle	640 (26.7%)	463 (29.1%)	1103 (27.7%)	
Highest	552 (23.0%)	336 (21.1%)	888 (22.3%)	
Items at home				
Radio = No	1562 (65%)	744 (46.9%)	2306 (57.8%)	3989
Yes	840 (35%)	843 (53.1%)	1683 (42.2%)	
Refrigerator = No	1786 (74.4%)	1263 (79.6%)	3049 (76.4%)	3989
Yes	616 (25.6%)	324 (20.4%)	940 (23.6%)	
Bicycle = No	2026 (84.3%)	1391 (87.6%)	3417 (85.7%)	3989
Yes	376 (15.7%)	196 (12.4%)	572 (14.3%)	
Health insurance				
Health Insurance = No	1037 (43.2%)	433 (27.3%)	1470 (36.9%)	3989
Yes	1365 (56.8%)	1154 (72.7%)	2519 (63.1%)	
Type of health insurance = Public	1359 (99.6%)	1147 (99.4%)	2506 (99.5%)	2519
Private	6 (0.4%)	7 (0.6%)	13 (0.3%)	

Table 1. Basic characteristics.

pharmacy, and 3.7% received it at a health facility. The majority of respondents identified community health volunteers as the distributors of the medication, underscoring the significance of community campaigns as the primary source. Out of 840 respondents, each answering on behalf of their household, 87.4% experienced no difficulties in accessing praziquantel, whereas 12.6% faced challenges. Among those encountering difficulties, 62.6% attributed it to the unavailability of the drug in their town, and 27.1% cited its high cost.

Approximately 46.8% of respondents reported visiting a health facility in the past six months, with about 71.7% of those individuals visiting two or fewer times. Nearly 95.8% stated that the nearest health facility was within a 30-minute distance, and 56.5% were aware of their local health volunteer's identity.

Prevalence

Figure 2 illustrates the estimated prevalence for each locality and village. The prevalence of *S. mansoni* in New Halfa and Nahr Atbara was notably high at 28.0% and 24.3%, respectively. Conversely, the prevalence of *S. haematobium* was relatively low-2.1% in New Halfa and none in Nahr Atbara. Figure 2 (c) and (d) detail the prevalence for individual villages. For *S. mansoni*, one village reported a peak prevalence of 68.2%. Among the 40 villages identified as high-endemic, 25 recorded prevalence exceeding 20%. In contrast, as shown in Fig. 2 (d), *S. haematobium* was found in a few villages in New Halfa, with two out of the 40 villages showing prevalence above 10%. (Refer to Table S2, Table S3 and Table S4 by villages and by socio economic factors, and Fig. S1 for heatmaps of *S. mansoni* and *S. haematobium* infection.)

	New Halfa	Nahr Atbara	Row total	*N*
Water source = Piped into dwelling	209 (34.8%)	44 (11.1%)	253 (25.4%)	997
Piped into compound yard or plot	13 (2.2%)	1 (0.3%)	14 (1.4%)	
Piped to neighbor	11 (1.8%)	0 (0%)	11 (1.1%)	
Public tap/standpipe	4 (0.7%)	4 (1%)	8 (0.8%)	
Protected well	0 (0%)	6 (1.5%)	6 (0.6%)	
Unprotected well	1 (0.2%)	3 (0.8%)	4 (0.4%)	
Protected spring	0 (0%)	1 (0.3%)	1 (0.1%)	
Unprotected spring	1 (0.2%)	4 (1%)	5 (0.5%)	
Rainwater collection	2 (0.3%)	2 (0.5%)	4 (0.4%)	
Delivered water	1 (0.2%)	14 (3.5%)	15 (1.5%)	
Packaged water	355 (59.2%)	318 (80.1%)	673 (67.5%)	
Others	3 (0.5%)	0 (0%)	3 (0.3%)	
Toilet in home = no	166 (27.3%)	130 (32.3%)	296 (29.3%)	1010
Yes	441 (72.7%)	273 (67.7%)	714 (70.7%)	
Type of toilet in home = Flush to piped sewer system	13 (2.9%)	11 (4%)	24 (3.4%)	714
Flush to septic tank	51 (11.6%)	9 (3.3%)	60 (8.4%)	
Pit latrine with slab	174 (39.5%)	118 (43.2%)	292 (40.9%)	
Pit latrine without slab / Open pit	203 (46%)	133 (48.7%)	336 (47.1%)	
Twin pit with slab	0 (0%)	1 (0.4%)	1 (0.1%)	
Twin pit without slab	0 (0%)	1 (0.4%)	1 (0.1%)	
Place for defecation (no toilet at home) = Neighbor's toilet	27 (16.7%)	31 (24.4%)	58 (20.1%)	289
Communal toilet	2 (1.2%)	4 (3.1%)	6 (2.1%)	
Open defecation (including urination)	133 (82.1%)	92 (72.4%)	225 (77.9%)	
Place for open defecation = Near home	76 (57.1%)	39 (42.4%)	115 (51.1%)	225
10 feet or further from household	56 (42.1%)	53 (57.6%)	109 (48.4%)	
In a water body	1 (0.8%)	0 (0%)	1 (0.4%)	
Place for urination = Near my house compound (within 10 feet)	83 (62.4%)	41 (44.6%)	124 (55.1%)	225
10 feet or further from household	50 (37.6%)	51 (55.4%)	101 (44.9%)	
Do you come into contact with water bodies = No	432 (18%)	204 (12.9%)	636 (15.9%)	3989
Yes	1970 (82%)	1383 (87.1%)	3353 (84.1%)	
Reason for coming into contact with water = Fetching water	113 (5.7%)	41 (3%)	154 (4.6%)	3353
Doing laundry	26 (1.3%)	35 (2.5%)	61 (1.8%)	
Watering livestock	63 (3.2%)	12 (0.9%)	75 (2.2%)	
Fishery	63 (3.2%)	37 (2.7%)	100 (3%)	
Farming	260 (13.2%)	130 (9.4%)	390 (11.6%)	
Leisure	704 (35.7%)	645 (46.6%)	1349 (40.2%)	
Swimming	345 (17.5%)	231 (16.7%)	576 (17.2%)	
Car/motorcycle washing	82 (4.2%)	56 (4%)	138 (4.1%)	
Playing	95 (4.8%)	33 (2.4%)	128 (3.8%)	
Wading into the water	214 (10.9%)	163 (11.8%)	377 (11.2%)	

Table 2. Water and sanitation characteristics.

Figure 3 presents the prevalence by various socio-demographic characteristics. Among all respondents, no significant differences by gender in prevalence were observed. However, when examining prevalence by age group, some notable observations emerged. The prevalence in the under-18 age group was remarkably high, at 28.9%. In the age group of 20 and above, the prevalence remained 20%. This highlights the potential for significant prevalence in population groups beyond school-age children, particularly when exposure to infection is substantial and access to diagnosis and treatment is limited.

In the analysis of prevalence based on the occupation of each household head, families with office workers and small-scale business owners showed the highest prevalence, although the confidence intervals were wide. Households headed by farmers also showed a high prevalence, whereas those headed by fishermen had a relatively lower average prevalence. However, the confidence interval in this latter group was also broad.

In the few instances involving households of large-scale business owners, no infections were reported. Additionally, when analyzing household monthly income divided into quartiles, disparities between groups became apparent. The lower-middle income group exhibited the highest prevalence, in stark contrast to the highest-income group. Interestingly, the lowest income group, which one might assume to have poorer hygiene conditions, did not show the highest prevalence.

	New Halfa	Nahr Atbara	Row total	Total
Awareness				
Heard of schistosomiasis = No	99 (16.5%)	49 (12.3%)	148 (14.8%)	997
Yes	501 (83.5%)	348 (87.7%)	849 (85.2%)	
Correct answer for symptoms = No	172 (34.3%)	133 (38.2%)	305 (35.9%)	849
Yes	329 (65.7%)	215 (61.8%)	544 (64.1%)	
Aware of the source = No	31 (6.2%)	20 (5.7%)	51 (6%)	849
Yes	470 (93.8%)	328 (94.3%)	798 (94%)	
Aware of the vector = No	162 (32.3%)	140 (40.2%)	302 (35.6%)	849
Yes	339 (67.7%)	208 (59.8%)	547 (64.4%)	
Aware of the correct medication = No	500 (99.8%)	348 (100%)	848 (99.9%)	849
Yes	1 (0.2%)	0 (0%)	1 (0.1%)	
Treatment				
Taken praziquantel within 6 months = No	332 (66.3%)	218 (62.6%)	550 (64.8%)	849
Yes	169 (33.7%)	130 (37.4%)	299 (35.2%)	
Taken praziquantel within 1 year = No	332 (66.3%)	199 (57.2%)	531 (62.5%)	849
Yes	169 (33.7%)	149 (42.8%)	318 (37.5%)	
Where did you take it = community campaign	56 (80%)	58 (90.6%)	114 (85.1%)	134
Local pharmacy	7 (10%)	3 (4.7%)	10 (7.5%)	
Health facility	4 (5.7%)	1 (1.6%)	5 (3.7%)	
Others	3 (4.3%)	2 (3.1%)	5 (3.7%)	
Distributor = community health volunteers	50 (98%)	56 (98.2%)	106 (98.1%)	108
Other health professional	1 (2%)	1 (1.8%)	2 (1.9%)	
Finding praziquantel difficult to obtain = No	441 (88%)	301 (86.5%)	742 (87.4%)	849
Yes	60 (12%)	47 (13.5%)	107 (12.6%)	
Main reason why the interviewee finds praziquantel difficult to obtain = Because praziquantel is not available in my town	32 (53.3%)	35 (74.5%)	67 (62.6%)	107
Too expensive	17 (28.3%)	12 (25.5%)	29 (27.1%)	
Others	11 (18.3%)	0 (0%)	11 (10.3%)	
Health care utilization				
Visited health facilities in the last 6 months = No	1463 (60.9%)	660 (41.6%)	2123 (53.2%)	3989
Yes	939 (39.1%)	927 (58.4%)	1866 (46.8%)	
How many times = 1	329 (35%)	340 (36.7%)	669 (35.9%)	1866
2 times	482 (51.3%)	186 (20.1%)	668 (35.8%)	
3 times	121 (12.9%)	393 (42.4%)	514 (27.5%)	
4 or more times	7 (0.7%)	8 (0.8%)	15 (0.8%)	
Time to the nearest health facility = < 30 min	2244 (93.4%)	1578 (99.4%)	3822 (95.8%)	3989
30 min to < 1 h	155 (6.5%)	3 (0.2%)	158 (4%)	
1 h to < 2 h	1 (0%)	3 (0.2%)	4 (0.1%)	
≥ 2 h	2 (0.1%)	3 (0.2%)	5 (0.1%)	
Aware of community health workers = No	1244 (51.8%)	492 (31%)	1736 (43.5%)	3989
Yes	1158 (48.2%)	1095 (69%)	2253 (56.5%)	

Table 3. Awareness, treatment, and healthcare utilization.

Infection and its associated factors

Among the total 2,941 individuals analyzed, 779 (26.5%) tested positive for *S. mansoni*, exhibiting a mean egg count of 116.71 eggs per gram (EPG) (Fig. 4). The highest count recorded was 1,776 eggs. As shown in Fig. 4, the distribution of egg counts among positive cases was right-skewed. For *S. haematobium*, a total of 2,870 individuals were analyzed, of which only 33, or 1.2%, tested positive. Of those who tested positive, egg counts ranged from 2 to 190, with an average of 18.6.

Table 4 presents the results of the double hurdle model used to examine the factors associated with *S. mansoni* infection status and infection intensity. The first hurdle applied a logit model, while the second hurdle used a zero-truncated negative binomial model. In the case of *S. haematobium*, we only report the results of the logit model, which is the first hurdle. The reason is that there were only 1.2% of positive cases, and there was an overfitting problem when applying the zero-truncated negative binomial model.

First, socio-economic conditions were associated with the likelihood of infection. Compared with individuals under 18 years of age, the likelihood of infection was significantly lower among adults. Specifically, the adjusted odds of infection were reduced for those aged 18–29 years (aOR = 0.70, $p < 0.01$), 30–39 years (aOR = 0.64, $p < 0.01$), and 40–49 years (aOR = 0.68, $p < 0.05$). However, this trend was not observed among individuals aged

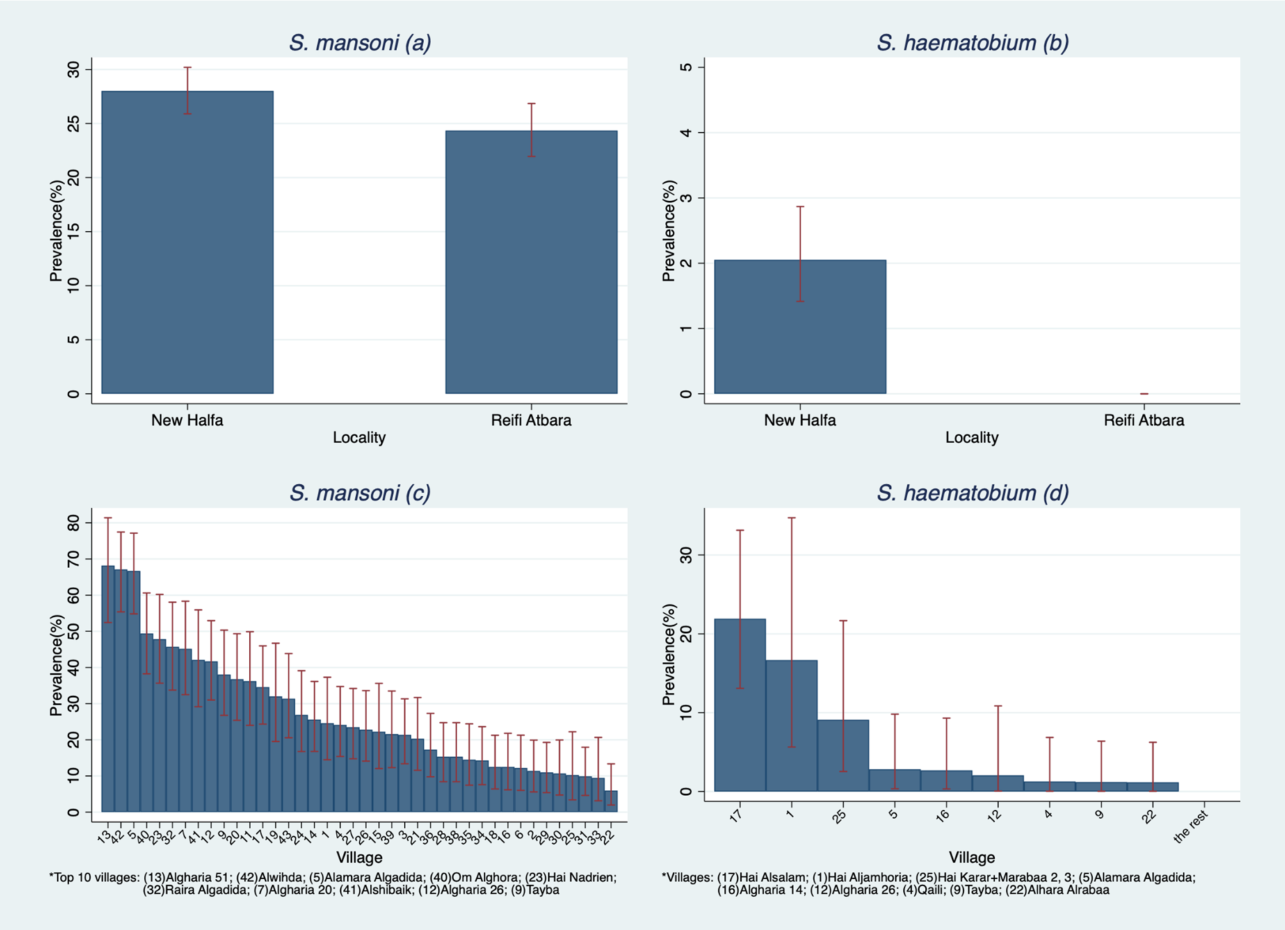

Fig. 2. The prevalence of schistosomiasis in each locality and village. (Note: The numbers on the horizontal lines in the figures below represent village numbers. The red bars indicate the 95% confidence interval.)

50 years and older. Furthermore, when analyzing the second hurdle, which related to the intensity of infection, no significant age-related differences were observed.

Gender differences in the likelihood of *S. mansoni* infection were not observed. However, females showed marginally lower infection intensity (IRR = 0.84, $p < 0.1$). However, disparities in infection status were evident based on the occupation of the household head. Compared to farmers, households headed by unskilled laborers (IRR = 0.52, $p < 0.05$), skilled laborers (IRR = 0.57, $p < 0.01$), and fishermen (IRR = 0.50, $p < 0.01$) had significantly lower *S. mansoni* infection intensity. In contrast, household members from families headed by businessmen (aOR = 2.17, $p < 0.01$) and other office workers (aOR = 2.65, $p < 0.05$) had significantly higher likelihood of infection compared with those from farmer-headed households, though not higher intensity. There were no significant differences in infection probability or intensity related to income or assets. Similarly, no variations in infection status or intensity were associated with owning a toilet in the household.

One of the strongest predictors of *S. mansoni* infection was regular water contact. Individuals with regular water contact had a strongly higher likelihood of infection (aOR = 1.87, $p < 0.01$) and significantly greater intensity (IRR = 1.79, $p < 0.01$). Regarding water source, rainwater collection was associated with marginally higher likelihood of infection compared to having piped water into the dwelling (aOR = 11.11, $p < 0.1$) and significantly greater intensity (IRR = 1.72, $p < 0.01$). On the other hand, protected wells were linked to significantly lower infection intensity (IRR = 0.44, $p < 0.01$), and using packaged water was marginally associated with lower intensity (IRR = 0.81, $p < 0.1$). Protected springs were associated with marginally higher intensity (IRR = 1.44, $p < 0.1$).

Regarding the association between *S. mansoni* infection status and healthcare facility utilization, individuals residing within a 30-minute distance from healthcare facilities were less likely be infected (aOR = 0.57, $p < 0.05$), though no significant association was observed with infection intensity. Having visited a health facility in the past six months was marginally associated with lower infection likelihood (aOR = 0.81, $p < 0.1$), but not with intensity.

The last column of Table 4 presents the analysis results on *S. haematobium* infection and its associated factors. For *S. haematobium* infection, no significant differences by age or gender were observed. However, individuals from households headed by unskilled laborers had a significantly higher probability of infection (aOR = 7.09, $p < 0.05$). Likewise, households owning bicycles (aOR = 3.57, $p < 0.05$) were significantly more likely to be

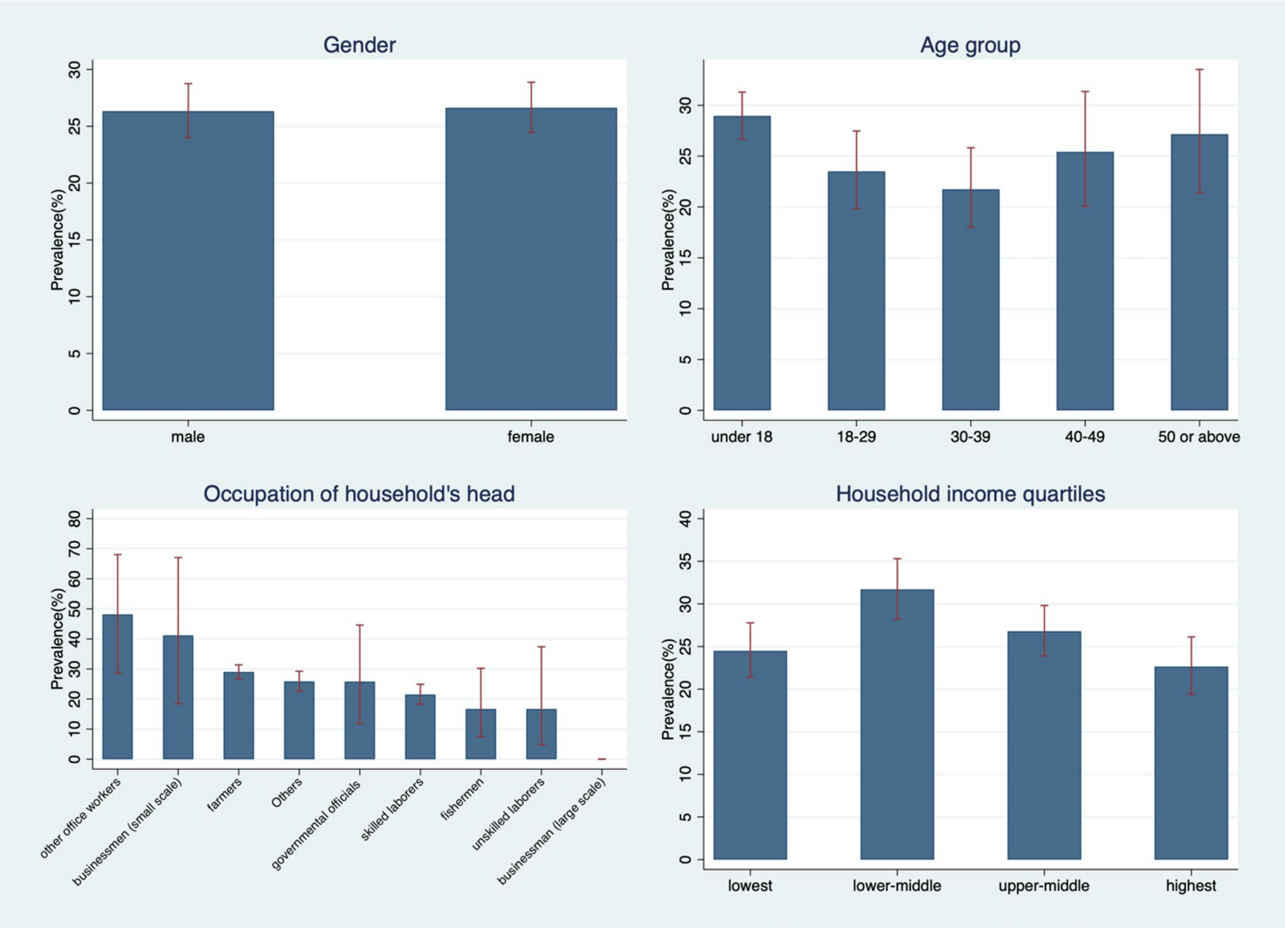

Fig. 3. The prevalence of *S. mansoni* according to socio-demographic factors (Note: The red bars indicate the 95% confidence intervals.)

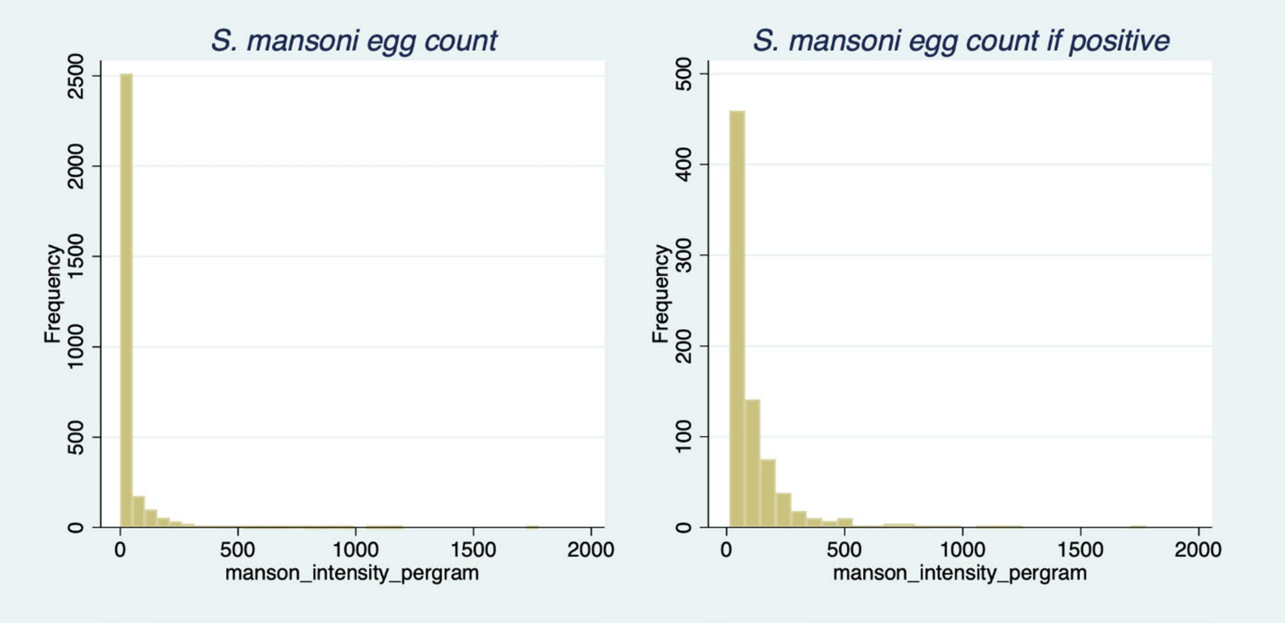

Fig. 4. The distribution of egg count: *S. mansoni*.

	(1)		(2)		(3)	
	S. mansoni				*S. haematobium*	
	First: logit		Second: ZTNB		First: logit	
Variables	aOR	Rob. S.E.	IRR	Rob S.E.	aOR	Rob. S.E.
Age group (ref. age group < 18)						
18–29	0.70***	(0.09)	0.92	(0.11)	0.28*	(0.19)
30–39	0.64***	(0.10)	1.08	(0.14)	1.63	(0.90)
40–49	0.68**	(0.13)	0.94	(0.15)	0.57	(0.56)
50 or above	0.73	(0.15)	1.02	(0.20)	-	-
Female (ref. male)	1.06	(0.10)	0.84*	(0.08)	1.26	(0.51)
Household head's occupation (ref. farmers)						
Fishermen	0.53	(0.21)	0.50***	(0.13)	2.69	(3.0)
Governmental officials	0.96	(0.50)	1.70	(0.78)	-	-
Businessmen	2.17***	(0.64)	0.80	(0.28)	-	-
Unskilled laborers	0.52	(0.31)	0.52**	(0.16)	7.09**	(6.96)
Skilled laborers	0.84	(0.12)	0.57***	(0.09)	0.83	(0.46)
Other office workers	2.65**	(1.16)	0.76	(0.22)	3.58	(2.81)
Others	0.89	(0.12)	0.88	(0.120)	0.72	(0.50)
Toilet at home (ref. no toilet at home)	0.93	(0.12)	0.92	(0.12)	1.14	(0.50)
Items						
Radio	0.78*	(0.11)	1.04	(0.15)	1.09	(0.59)
Refrigerator	1.05	(0.17)	0.95	(0.11)	1.56	(0.64)
Motorcycle	0.92	(0.15)	0.80	(0.11)	0.71	(0.43)
TV	0.85	(0.13)	0.88	(0.12)	0.39*	(0.22)
Bicycle	1.25	(0.22)	1.20	(0.19)	3.57**	(2.22)
Car	1.00	(0.16)	1.00	(0.20)	0.36*	(0.21)
Regular water contact	1.87***	(0.26)	1.80***	(0.20)	0.47	(0.28)
Water source						
Piped into dwelling	0.90	(0.19)	0.86	(0.15)	0.35	(0.40)
Piped into compound yard	2.53	(2.04)	1.450	(0.77)	4.25	(6.42)
Piped to neighbor	2.06	(1.60)	0.60	(0.20)	–	–
Protected spring			1.44*	(0.31)	–	–
Protected well	1.38	(1.73)	0.440***	(0.09)	–	–
Rainwater collection	11.11*	(14.27)	1.72***	(0.28)	48.18***	(49.05)
Delivered water	2.72*	(1.49)	0.89	(0.35)	–	–
Packaged water	1.22	(0.18)	0.81*	(0.10)	1.07	(0.74)
Others	6.58	(8.15)	1.28	(0.36)	–	–
Visited a health facility in the last 6 months	0.81*	(0.09)	0.96	(0.10)	0.97	(0.41)
Health facility within 30 min	0.57**	(0.13)	0.98	(0.14)	1.10	(1.14)
Health insurance status	1.04	(0.14)	1.08	(0.14)	5.66**	(4.32)
Constant	0.54**	(0.15)	95.02***	(17.79)	0.01***	(0.01)
N	2,920		779		2,578	

Table 4. Factors associated with schistosomiasis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, and aOR refers to adjusted odds ratio, Rob. S.E. refers to robust standard error. IRR refers to the incidence rate ratio. We report robust standard errors at the household level to account for potential heteroskedasticity.

infected. Interestingly, water contact was not significantly associated with *S. haematobium* infection. However, use of rainwater as the primary source was strongly associated with higher infection probability (aOR = 48.18, $p < 0.01$) Although there were notable variations in infection intensity among different groups, the small sample size in the model ($N = 33$) makes it difficult to draw meaningful conclusions from these differences.

Table 5 presents the associations between *S. mansoni* infection status, praziquantel consumption, and awareness of schistosomiasis. The analysis was limited to primary household respondents ($N = 556$) who provided information on praziquantel use in the past six months and their awareness of schistosomiasis, rather than including the entire sample. Therefore, Table 5 results separately from Table 4, although the same model was used in Table 4.

The participants who reported taking praziquantel within past six months exhibited a slightly lower probability of infection than those who did not take the medication. However, this difference was not statistically significant (aOR = 0.91, $p = 0.66$). Additionally, no statistically significant differences were found when investigating the

Variables	(1) First: logit[a] aOR	Rob S.E.	(2) Second: ZTNB[a] IRR	Rob S.E.
Took praziquantel within 6 months	0.91	(0.20)	1.16	(0.24)
Awareness, correct for				
Infection source	1.75	(0.78)	0.53*	(0.17)
Vector	0.63	(0.20)	0.93	(0.25)
Symptoms	0.95	(0.28)	0.62	(0.17)
Medication			3.21***	(1.38)
Constant	0.31	(0.38)	166.85***	(89.94)
N	637		173	

Table 5. Additional factors associated with *S. mansoni* infection. [a]All models were adjusted for age, gender, items, water source, water contact, risk behaviors, and healthcare utilization. The models included only main respondents. ***$p<0.01$, **$p<0.05$, *$p<0.1$.

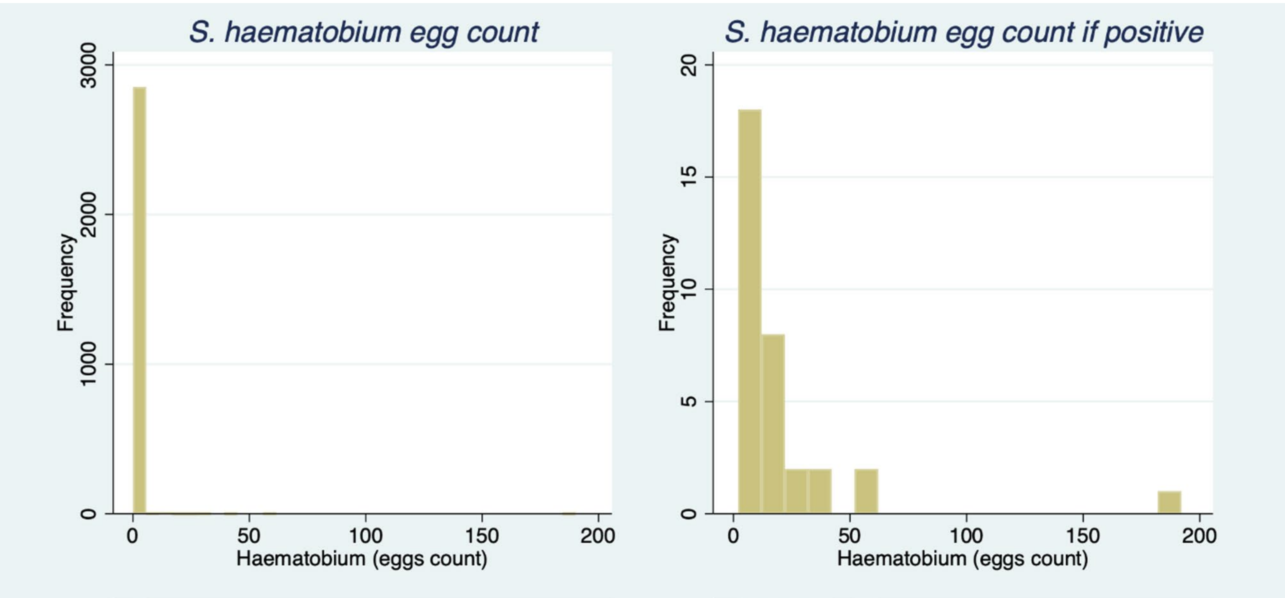

Fig. 5. The distribution of egg count: *S. haematobium*.

impact of accurate knowledge about the disease's source, vector, symptoms, and preferred treatment on the probability of infection. Nevertheless, individuals who accurately identified at least one symptom demonstrated significantly lower infection intensity than those who did not. Conversely, the group that correctly identified the medication showed higher infection intensity. This finding, however, may not be meaningful due to the very small number of individuals ($N=1$) who provided correct answers about the medication.

Figure 5 illustrates the *S. haematobium* egg count. The left graph includes zero observations, whereas the right graph displays only the distribution of positive cases. Out of the total 2,870 samples, a vast majority, 98.85%, tested negative. The mean prevalence was 2.16%, with the maximum egg count observed being 190.

Discussion

This community-based cross-sectional study revealed a high prevalence of *S. mansoni* infection in Kassala State, Sudan, with 25 out of 40 surveyed villages exceeding the 20% prevalence threshold, and some reaching as high as 68%. Although school-aged children exhibited the highest infection rates, adults aged 20 and above also showed notable prevalence, indicating sustained community-wide transmission. Water contact behavior, occupation, and poor access to safe water sources were strongly associated with infection status and intensity. These findings highlight persistent transmission foci despite annual MDA efforts and underscore the need for updated intervention strategies that address both child and adult populations.

The study is significant for several reasons. First, our findings revealed that a substantial proportion of villages still face high *S. mansoni* prevalence. This situation is concerning and calls for targeted and sustained interventions, particularly considering the morbidity and healthcare costs associated with prolonged *S. mansoni* infections. Several factors may contribute to this scenario. For example, MDA might have been conducted annually, but was of poor quality. Even if the quality of MDA was high, the rate of reinfection might have also been high. The COVID-19 pandemic could have disrupted MDA schedules and increased children's exposure to water due to school closures, leading to a surge in cases. Lastly, it is possible that adults were not included in the annual MDA, which could mean they play a significant role in the cycle of reinfection, particularly as most heads of households are farmers. Verifying these hypotheses would require historical data, which are challenging to obtain due to the lack of comparable data. It is unfortunate that the FMOH-KOICA project aimed to interrupt the infection cycle through integrated interventions, but it appears this goal was not met due to the civil conflict.

Second, the findings support precision mapping of the entire population[22]. A recent school-based survey in Kassala State revealed that the weighted population prevalence of *S. mansoni* was approximately 4.54%, with an estimated 81,300 individuals infected[11]. The survey indicated a high prevalence in some local schools, but showed very low prevalence in other parts of the country. Consequently, average estimates are unlikely to fully capture the extent of the problem. School-based surveys at the district level provide a broader perspective, which is particularly valuable in national surveys conducted in resource-limited settings. However, if prevalence varies significantly between subdistricts, as indicated by previous studies, more targeted surveys are necessary. Such focused efforts are crucial for designing effective intervention strategies for specific areas.

Third, the findings raise concerns about the quality and effectiveness of MDA. Various factors undermine MDA quality in the region, including insufficient funding, inadequate staffing, lack of microplanning, and insufficient post-MDA evaluation. Given the constrained budgets and limited personnel, there is an evident need for increased resources for both staffing and funding. From the perspective of the federal government, managing multiple NTDs across the country cannot depend solely on the government officials. Consequently, the role of community health volunteers becomes essential[23]. In the Kassala State, numerous volunteers have been trained through various specialized programs. They act as vital links between community needs and government interventions. According to this baseline survey, a significant number of village residents were aware of their community health volunteers, indicating that these volunteers are well-integrated and poised to play a crucial role in addressing diverse healthcare issues within their communities. However, improving the quality of MDA requires ongoing education for community health volunteers and systematic post-MDA monitoring using scientific methods[24]. Additionally, effectively covering MDA in densely populated areas poses a substantial challenge compared to the smaller, regionally confined villages, necessitating considerable resources[25].

There are a few limitations to this study. Firstly, as a cross-sectional survey, it lacks the capacity to establish a causal relationship between the causes and mechanisms contributing to the high prevalence in the State. It cannot demonstrate causality regarding multiple behaviors or interventions within the infection cycle. The project was initially designed as a cluster randomized controlled trial aimed at determining the differences between the integrated intervention and the traditional MDA-only group, assessing the cost-effectiveness of the integrated intervention, and planning for its scalability. However, the achievement of these objectives was hindered by COVID-19 lockdowns, delays in procuring supplies, and civil conflict. Once conditions improve, these studies and other initiatives are expected to resume to enhance the health of the population. Another limitation of this study is the reliance on microscopy-based diagnostics. While these are standard methods in field epidemiology, their sensitivity declines notably in low-intensity infections and post-treatment settings. If such underestimation is accounted for, the actual prevalence in these communities is likely to be substantially higher than reported—suggesting that the situation is even more alarming than our findings indicate.

In the effort to combat schistosomiasis, the role of primary care cannot be underestimated[26], especially as we progress toward the elimination phase. In the baseline survey, a weak association was found between healthcare visits and *schistosomiasis* infection. These findings suggest that primary care may not be playing a pivotal role in the diagnosis and treatment of schistosomiasis in the region. Primary care facilities ought to have the capacity to provide medication to residents who missed MDA due to personal circumstance. To facilitate this, policy adjustments might be necessary to ensure that medication remains in high-prevalence areas and to establish a regular medication supply system through government channels.

To effectively control schistosomiasis, it is crucial to understand the social determinants that influence the spread of the disease. While there is extensive research on the medical and health aspects of schistosomiasis, studies focusing on its social causes are less developed. Various social and political factors, such as population movements across states, civil conflicts[27], internal displacement[27], and climate change[27,28] also influence the spread of the disease. This macro perspective is essential as it informs long-term, macro-level strategies. The outbreak of a civil war can lead to the collapse of the health system and the suspension of many ongoing programs. However, even in such challenging conditions, local partners can remain influential. These strategies depend on a thorough understanding of both local and social factors, underscoring the need for continued, in-depth research into the social determinants of disease.

Conclusions

These findings suggest that the current MDA, which focuses primarily on school-aged children, is inadequate for preventing persistent reinfection at the local level. Therefore, updated guidelines tailored to the national context, an expansion of MDA or awareness campaigns across all age groups, and enhancements in water and sanitation are crucial for effective microplanning.

In addition to the importance of uninterrupted MDA implementation, it is equally critical to ensure rigorous monitoring to assess the quality and effectiveness of MDA delivery. Identifying areas with the highest transmission intensity is also vital. In such high-transmission settings, context-specific strategies—such as increasing the frequency of MDA compared to other regions—should be developed and implemented.

Moreover, high-risk groups vulnerable to reinfection (e.g., farmers and their children) should be closely tracked, and targeted MDA and intensified health education campaigns should be directed toward them.

Separately from the MDA campaign, it is also crucial to ensure that routine diagnostic services for schistosomiasis and access to praziquantel are consistently available at health centers and posts.

Lastly, the interruption of annual MDA programs due to civil conflict and reduced access to medication has exacerbated the situation, underscoring the urgent need for international attention and support.

The generalizability of this study is limited, as it was not designed to evaluate the impact of an intervention or to assess causal effects. The main objective was to assess the prevalence and intensity of schistosomiasis in high-endemic areas of Kassala State at the time of the survey. Nonetheless, we believe the findings reliably reflect the prevalence and intensity of schistosomiasis in high-endemic communities within Kassala State.

Data availability

Data are available upon request from Seungman Cha (jesusdongja@gmail.com).

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Author contributions

Conceptualization: Cha S, Ismail HAHA. Data curation: Kim SJ, Jung S, Cha S Formal analysis: Kim SJ Funding acquisition: Cha S Investigation: Ismail HAHA, Jung S, Mohammedahmed HIH, Lee KH Methodology: Kim SJ, Cha S, Jung S, Lee KH Project administration: Ismail HAHA, Jung S, Mohammedahmed HIH, Lee KH Resources: Cha S Software: Kim SJ Supervision: Cha S, Lee KH, Jung S Validation: Ismail HAHA, Jung S, Mohammedahmed HIH, Lee KH Visualization: Kim SJ Writing – Kim SJ Writing – review & editing: Ismail HAHA, Jung S, Mohammedahmed HIH, Lee KH.

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Declarations

Competing interests

The authors declare no competing interests.

Ethical approval and consent to participate

The study received IRB approval from the National Research Ethics Review Committee, Sudan (approved on December 28, 2022: Number: 6-9-22). Prior to enrolling the study population, we obtained informed consent from each household. In cases where an individual was unable to provide informed consent due to age under five, written informed consent was obtained from their legal guardians or parents.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-24231-0.

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