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Shifting Endemicity of Schistosomiasis in Rural Yemen: Cross-Sectional Insights from Previously Hypoendemic Regions

Walid M. S. Al-Murisi[1] *, Yahia A. Raja'a[2] and Abdulsalam M. Al-Mekhlafi[1]

[1] **Department of Medical Parasitology, Faculty of Medicine and Health Sciences, Sana'a University, Sana'a, Yemen,**
[2] **Department of Community Medicine, Faculty of Medicine and Health Sciences, Sana'a University, Sana'a, Yemen.**

*Corresponding author: Email: wmurisi@yahoo.com

Abstract

Background: Schistosomiasis is a persistent health concern in Yemen, despite the continued mass drug administration campaigns using praziquantel. This survey investigated the epidemiology of schistosomiasis among schoolchildren in previously identified hypoendemic areas, more than ten years after the last national mapping in 2014 was conducted.

Methods: In June to August 2025, we conducted a cross-sectional survey of 348 children aged 5–15 years living in Jabal Ash Sharq, Hubaysh, and Amd districts. Simultaneously, the data on sociodemographic and behavioral characteristics were obtained through a standardized questionnaire. Urine filtration and the Kato-Katz technique were used to diagnose *Schistosoma haematobium* and *S. mansoni*, respectively. Statistical analyses, including binary logistic regression, were used to estimate the independent risk factors for schistosomiasis.

The combined prevalence of schistosomiasis was 19.3% (95% CI: 15, 23%), with S. haematobium (12 · 4 %) being more prevalent than *S. mansoni* (6.9%). All looked-at districts experienced a substantial increase in the infection rate compared to the 2014 baseline. The majority of infections were of light intensity; however, 16.3% and 20.8% of *S. haematobium* and *S. mansoni* cases were classified as moderate to heavy, respectively. Multivariable logistic regression analysis identified age $\geq$ 10 years (AOR = 2.3; CI: 1.17–4.55; P = 0.016) and higher frequency of contact with open water bodies (AOR = 2.2; 95% CI: 1.22–3.90; P = 0.009) as independent risk factors for schistosomiasis. Any clinical manifestation related to *S. haematobium* infection, including dysuria, gross hematuria, and dipstick hematuria with proteinuria, was significant.

Conclusion: Schistosomiasis has become meso-endemic in previously hypoendemic areas, with *S. haematobium* infection accounting for most cases among school children. A significant proportion of cases were mild, but a subset of moderate to heavy infections indicated ongoing transmission. This survey highlights the need to administer praziquantel twice a year to all school-aged children (SAC), along with other control measures, such as health education, improved sanitation, safe water supplies, and snail control.

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1. BACKGROUND

Schistosomiasis is a disease caused by parasitic flatworms belonging to the genus *Schistosoma* and is prevalent in tropical and subtropical countries [1]. *Schistosoma haematobium*, *S. mansoni*, and *S. japonicum* are the main species of schistosomes responsible for human schistosomiasis [2]. In 2023, the World Health Organization (WHO) reported that over 253 million people in 50 countries required preventive chemotherapy to mitigate the effects of schistosomiasis, the majority of whom were school-aged children (SAC) [3]. Several factors are involved in schistosome transmission, including poor sanitation, scarce potable water, agricultural activities, and contact with polluted water [4–6]. For decades, Yemen has been endemic for schistosomiasis, but the first official action was taken in 2010 when the Yemeni Ministry of Health established the National Schistosomiasis Control Program (NSCP) to eliminate schistosomiasis [7]. This project was supported by international partners, such as the WHO and the World Bank [7]. The approach taken by this program was to interrupt disease transmission and morbidity by implementing mass drug administration (MDA) of praziquantel (PZQ) to all community members in affected endemic districts [7]. Nevertheless, schistosomiasis remains endemic in several areas throughout Yemen. The national schistosomiasis survey in 2014 showed that approximately two-thirds of Yemeni districts were endemic to the infection, with most of them having a mild prevalence of less than 10% [8]. The latest estimates suggest that in 2023, approximately 3.7 million people will require preventive chemotherapy in Yemen, of whom over three million are SAC [9]. Although intestinal schistosomiasis due to *S. mansoni* was slightly more prevalent than urogenital schistosomiasis caused by *S. haematobium* in 2014, the latter is still found throughout many parts of the country [8]. Data from 2005 showed that the highest prevalence of *S. haematobium* infection among schoolchildren was in Khamir District, Amran Governorate, at up to 58.9% [10]. This decreased to 8.3% after multiple rounds of MDA in 2014 [11], but recent data from Kharif district within the same governorate have suggested a marked increase in prevalence to 34.8% by 2021, thus a transition from low to moderate endemicity [12]. A similar pattern was observed in Amd District, Hadhramaut Governorate, where the overall prevalence of schistosomiasis among schoolchildren in 2021 was 33.7%, including 31.6% for *S. haematobium* and 2.1% for *S. mansoni* [13]. Prolonged warfare and a weakened health system in Yemen may have disrupted critical public health measures, including neglected tropical disease (NTDs) programs. Interruptions in MDA and the lack of recent epidemiological data may be additional barriers to the control and elimination of the disease. Against this background, this study aimed to evaluate the current situation of schistosomiasis among schoolchildren in hypoendemic districts of Yemen. The purpose of this study was to estimate the prevalence and intensity of infection and identify associated risk factors. These results are crucial for guiding national control strategies.

2. MATERIALS AND METHODS

2.1. Study Design and Target Population

A cross-sectional, school-based survey was conducted among schoolchildren aged 5–15 years in three districts previously classified as hypoendemic for schistosomiasis.

2.2. Study Area

This study was conducted in three districts: Jabal Ash Sharq, Hubaysh, and Amd (Figure 1), which were assigned a hypoendemic status for schistosomiasis in 2014 [11]. The Jabal Ash Sharq District lies southeast of Sana'a in the Dhamar Governorate. The district covers approximately 366 km² and has over 100 thousand inhabitants. It is a rural district with scattered villages spread across valleys and mountain ridges. Agriculture is the main livelihood, primarily based on traditional farming methods, and is dependent on seasonal rainfall [14]. The Hubaysh District is situated in the central highlands of the Ibb Governorate. It is moderate in elevation, has good agriculture, a temperate climate, a geographical size of approximately 228 km², and a population of more than 152 thousand [14]. Finally, the district of Amd lies in the eastern part of Yemen in the Hadramout Governorate. It is a drier, semi-desert zone with intermittent water flow channels. It is large, with approximately 737 km², and less populated than the other two districts, with a population of over 31 thousand [14]. These sites were selected to provide a geographically and ecologically diverse cross-section of hypoendemic areas, where the prevalence of schistosomiasis was low-risk, and were ideal for estimating the status of schistosomiasis, given more than ten years of national schistosomiasis mapping.

2.3. Sampling Framework and Sample Size

The required sample size was determined using the EpiInfo program (https://www.cdc.gov/epiinfo/index.html), based on a schistosomiasis prevalence of 14.7% from a 2024 study conducted in rural communities [15]. The determination was made at a confidence interval of 95%, 5% precision, using a design effect of 1.5, and a 10% non-response rate. This resulted in a minimum sample size of 318 children. To improve the statistical power of this study, 348 schoolchildren were recruited. A multistage cluster sampling method was used to select participants. In 2014, three districts were randomly selected based on their endemicity classification. Two schools were randomly chosen from each district, yielding a total of six schools. Within each school, approximately 58 children were randomly selected based on enrollment size and gender balance as much as possible. When

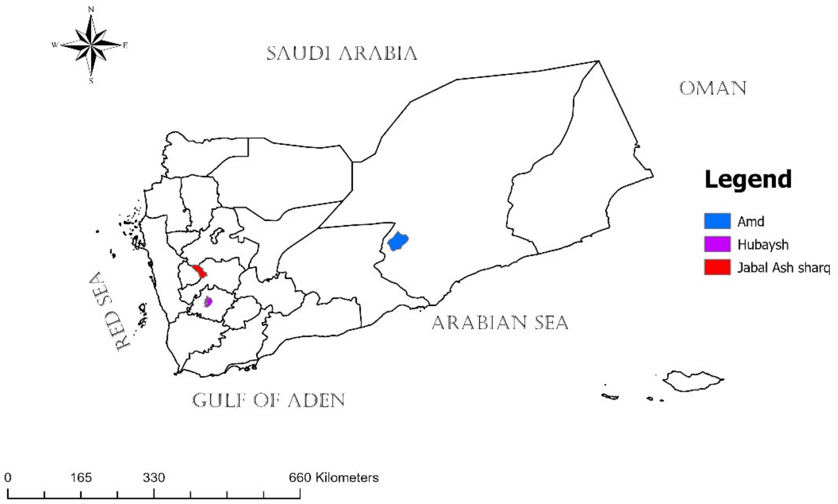

Figure 1. Map of Yemen showing the locations of surveyed districts

any selected child refused to participate, the next student listed on the school roll would take their place.

2.4. Questionnaire

A pre-tested, structured questionnaire was used to collect information on the participants' sociodemographic characteristics, water-contact exposure, sanitation and personal hygiene behaviors, previous schistosomiasis infection, history of schistosomiasis symptoms, and prior receipt of treatment with PZQ. Face-to-face interviews were conducted by trained data collectors, occasionally with a teacher assisting in facilitating understanding among younger students.

2.5. Parasitological Investigation

The study will be conducted from January to June 2025. Each participating child was asked to provide urine and stool samples between 10:00 a.m. and 2:00 p.m., which is the optimal time for detecting the parasite eggs. Following WHO guidelines [16]. The specimens were carefully labeled and processed. The urine samples were first examined macroscopically for gross hematuria and then tested for microhematuria and proteinuria using reagent strips (CYBOW^{TM} 10; DFI Co., Republic of Korea). The urine filtration method was used to detect and count *S. haematobium* eggs per 10 mL of urine (EP10mL) [17, 18]. According to the WHO, *S. haematobium* infection intensity was classified as light if the counted eggs were 1-50 EP10mL, and classified as heavy if the counted eggs were $\geq$ 50 EP10mL [16]. Fecal samples were examined using the Kato-Katz method to detect and count *S. mansoni* eggs on two slides per sample. The mean egg count was multiplied by 24 to obtain eggs per gram (EPG), and infection intensity was described as light ($<$100 EPG), moderate (100–399 EPG), and heavy ($\geq$400 EPG) [16, 19]. Quality control was maintained by randomly selecting 10% of the slides and re-reading them by a senior technician who was unaware of the diagnosis to confirm diagnostic accuracy [16].

2.6. Statistical Analysis

Statistical analyses were performed using the IBM SPSS Statistics Software (version 24). The findings are summarized using frequency tables and prevalence estimates (with 95% confidence interval, CI). The chi-square or Fisher's exact test was used to assess the association between independent variables and the prevalence of infection. The OR and 95% CI were determined. All variables included in the univariate analysis were entered into the multivariate logistic regression, and the findings were expressed as adjusted odds ratios (AOR) with 95% CI. Statistical significance was defined as a *P*-value below 0.05.

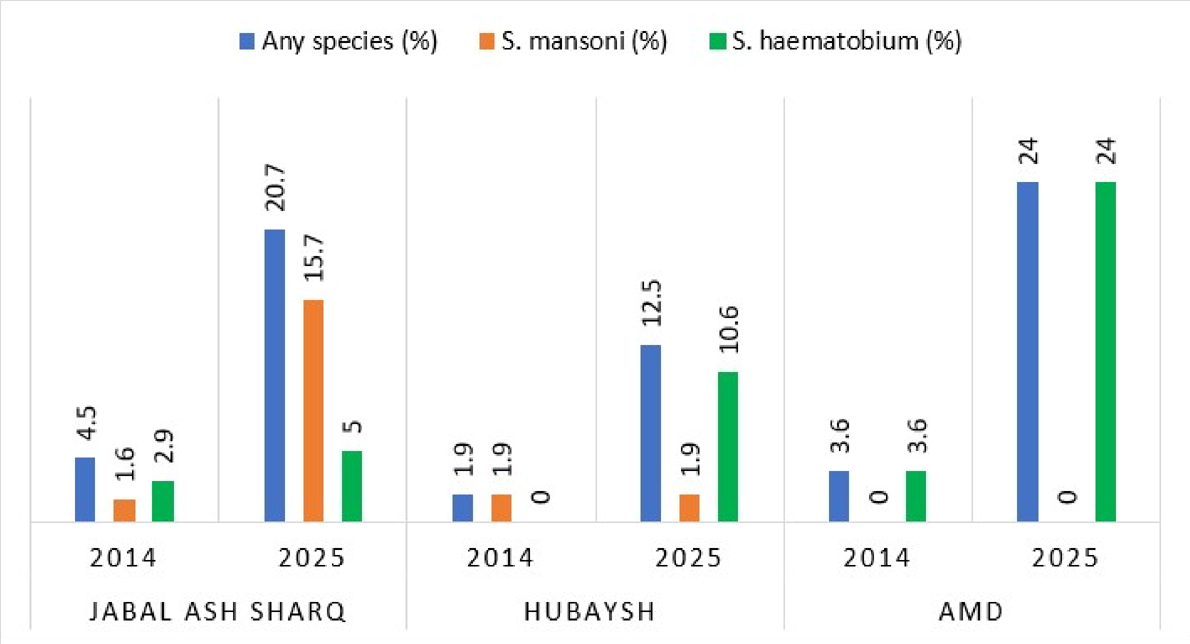

Figure 2. Schistosomiasis prevalence by district: 2025 study versus 2014 mapping.

2.7. Ethical Statement

This study was approved by the Ethics Committee of the Faculty of Medicine and Health Sciences, Sana'a University. Owing to the school-based nature of the study and the fact that it did not include any questions related to the child's family, written parental consent was not sought. However, verbal assent for participation was obtained from child participants once they had been informed in an age-sensitive manner about the purpose of the study. School principals provided their formal consent, with parents or guardians informed via school communication, retaining the right to decline participation. All information was treated with full respect for the privacy and dignity of the respondents. Children who tested positive for schistosomiasis were treated with praziquantel (PZQ) following informed consent from the parents and school authorities.

3. RESULTS

3.1. Characteristics of subjects

The participating schoolchildren in this study were 348, aged 5-15 years, with a mean age of 11 $\pm$ 2.4 years. Of these, 51.4% were female and 48.6% were male. Parents' educational status reveals that approximately two-thirds of the children's fathers (65.8%) were educated with at least a primary school certificate, compared to only 20.1% of mothers. Nearly half of the children's fathers were employed (48%), compared to only 4% of employed mothers. More than one-third of the children lived in overcrowded families with more than eight members (37.9%). The average household size was eight persons (Mean $\pm$ SD: 8.0 $\pm$ 2.4), and households with $\leq$ eight members accounted for 62.1%. Almost all (97.7%) children had a toilet in their homes, but 2.3% did not. Only 78.2% of the children stated that there are toilets in schools, and 21.8% do not have access to these facilities. Piped water was the major potential source of household water for 68.4% of the participants, and alternative sources were used by 31.6%. The home sanitation summary identified 63.8% of households as improved and the remaining (35.9%) as unimproved (Table 1).

3.2. Prevalence and distribution of schistosomiasis

The prevalence of schistosomiasis was 19.3% (67/348; 95% CI: 15–23%). Of these, 43 (12.4%) were infected with *S. haematobium*, and 24 (6.9%) were infected with *S. mansoni*. The prevalence of schistosomiasis by district is presented and compared with the national schistosomiasis map data from 2014 (Figure 2). The overall prevalence of schistosomiasis was higher in Jabal Ash Sharq (20.7% vs. 4.5%), Hubaysh (12.5% vs. 1.9%), and Amd districts (24% vs. 3.6%). *S. haematobium* was most common in the Amd and Hubaysh districts. In contrast, *S. mansoni* increased by more than fourfold in the Jabal Ash Sharq district, whereas *S. haematobium* nearly doubled in the same district.

These results revealed that all districts shifted to the mesoendemic risk level. Regarding infection intensity, 83.7% of *S. haematobium* and 79.2% of *S. mansoni* cases were classified as having light intensity. Only 16.3% of *S. haematobium* infections were classified as heavy, whereas 20.8% of *S. mansoni* infections were

Table 1. General characteristics of schoolchildren (N=348).

Characteristics	n (%)
Gender	
Male	169 (48.6)
Female	179 (51.4)
Age groups (years) Mean ± SD: 11 ± 2.4	
$<$ 10	111 (31.9)
$\geq$ 10 (11-15)	237 (68.1)
Fathers' education level	
Educated*	229 (65.8)
Non-educated	119 (34.2)
Mothers' education level#	
Educated*	70 (20.1)
Non-educated	277 (79.6)
Fathers' occupational status	
Employed	167 (48.0)
Unemployed	181 (52.0)
Mothers' occupational status	
Employed	14 (4.0)
Unemployed	334 (96.0)
Family size Mean ± SD: 8 ± 2.4	
$\leq$ 8 members	216 (62.1)
$>$ 8 members	132 (37.9)
Toilet in home	
Available	340 (97.7)
Not available	8 (2.3)
Toilet in school	
Available	272 (78.2)
Not available	76 (21.8)
Household water source	
Piped water	238 (68.4)
Other	110 (31.6)
Home sanitation[a]	
Improved	222 (63.8)
Unimproved	125 (35.9)

*At least a primary school education. #One case is missing. [a]Improved sanitation (flush/pour flush toilet to piped sewer system or pit latrine) and unimproved sanitation (no toilet or flush/pour flush toilet to open area).

Table 2. Schistosomiasis intensity among Yemeni schoolchildren in previously hypoendemic districts.

Infection intensity	Type of infection					
	S. mansoni			*S. haematobium*		
	n	(%)	Mean EPG (95% CI)	*n*	(%)	Mean EP10mL (95% CI)
Light	19	(79.2)	32.8 (24.0, 41.6)	36	(83.7)	15.9 (13.4, 18.4)
Moderate	5	(20.8)	178 (99.9, 255.3)	0	(0.0)	–
Heavy	0	(0.0)	–	7	(16.3)	139.6 (72.7, 206.5)
Overall	24	(6.9)	4.3 (1.9, 6.8)	43	(12.4)	4.5 (2.1, 6.8)

EPG: number of eggs per gram of feces. **EP10mL**: number of eggs per 10 mL of urine.

classified as moderate (Table 2).

3.3. Factors associated with schistosomiasis

Univariable analysis identified that children aged $\geq$ 10 years were associated with a higher risk of schistosomiasis (OR: 2.5, 95% CI: 1.28, 4.88; *P* = 0.006) than younger children. Regular contact with environmental open water sources (dams, streams, valleys, ponds, etc.) was a significant risk factor for schistosomiasis (OR = 2.5, 95% CI: 1.40–4.36; *P* = 0.001), with 25.8% of exposed children infected compared to 12.4% of the unexposed children. Additionally, children with a history of schistosomiasis had a statistically significant association with schistosomiasis (OR = 1.9, 95% CI: 1.12–3.34; *P* = 0.017). However, no significant association was found between schistosomiasis and sex, family size, parental illiteracy, employment status, history of praziquantel (PZQ) treatment, walking barefoot outdoors, lack of home or school latrines, and unimproved home sanitation. Multivariable logistic regression analysis identified age $\geq$ 10 years (AOR = 2.2; 95% CI = 1.10, 4.52; *P* = 0.026) and regular contact with open water sources (AOR = 2.6; 95% CI = 1.38, 4.75; P = 0.003) as independent risk factors for schistosomiasis (Table 3).

Table 4 shows the relationship between schistosomiasis and the frequency of exposure to open water bodies. Much greater odds of infection were found for children exposed daily to water than those who were not (OR 9.3, 95% CI 3.29–26.35, p $<$0.001). This was maintained for moderate exposure (2–3 times/week) (OR 2.6; 95% CI, 1.38–4.80; P = 0.003), while infrequent exposure ($<$1/week) was not significantly associated with increased odds. The results confirmed a positive dose-response relationship, which agrees with the fact that increased exposure to open water bodies is an important determinant of schistosomiasis.

3.4. Clinical manifestations of schistosomiasis

Univariable analysis identified a significant association between *S. haematobium* infection and dysuria (OR: 3.8, 95% CI: 1.96, 7.29; *P* $<$0.001), visible hematuria (OR: 2.9, 95% CI: 1.08, 7.95; *P* = 0.041), microhematuria (OR: 4.3, 95% CI: 2.04, 8.93; *P* $<$0.001) and proteinuria (OR: 4.0, 95% CI: 2.08, 7.74; *P* $<$0.001). Multivariable binary logistic regression analysis identified dysuria (AOR = 3.7; 95% CI: 1.84, 7.50; *P* $<$ 0.001), microhaematuria (AOR = 3.3; 95% CI: 1.47, 7.52; *P* = 0.004), and proteinuria (AOR = 3.3; 95% CI: 1.64, 6.82; *P* = 0.001) as significantly associated with *S. haematobium* infection (Table 5).

In contrast, diarrhea (*P* = 1.000), hematochezia (*P* = 1.000), and mucoid stool (*P* = 0.146) were not significantly associated with *S. mansoni* infection (Table 6).

4. DISCUSSION

This study aimed to determine the burden of schistosomiasis among schoolchildren in hypoendemic communities following over ten years of national schistosomiasis mapping. Despite the Yemeni NSCP's efforts, this study found that 19.3% of schoolchildren in hypoendemic districts were infected with at least one *Schistosoma* species, with a predominance of *S. haematobium* infection (12.4%) compared to 6.9% of *S. mansoni*. The results suggest that schistosomiasis endemicity in these districts has shifted to a meso-endemic level, as defined by the WHO guidelines (10–50%) [20]. This highlights the limitations of chemotherapy-based strategies in the absence of integrated control efforts [21]. The results of this survey are aligned with previous reports on schistosomiasis prevalence among SAC in Yemen, with rates of 31.8% [22], 27% [23], and 24.6% [24]. The prevalence of *S. haematobium* also aligns with earlier studies, showing 14.7% [15] and 18.1% [25] among SAC. Moreover, several regions in Yemen have reported high infection rates in children, including 34.8% [13] and 33.7% [12] of children infected. Conversely, lower prevalence rates

Table 3. Factors associated with schistosomiasis among schoolchildren in previously hypoendemic Yemeni districts

Variables	N	n (%)	OR (95%CI)	AOR (95%CI)	*P*-value
Gender					
Female	179	30 (16.8)	Reference		
Male	169	37 (21.9)	1.4 (0.82, 2.38)	1.3 (0.75, 2.40)	0.315
Age groups (years)					
< 10	111	12 (10.8)	Reference		
≥ 10	237	55 (23.2)	2.5 (1.28, 4.88)	2.2 (1.10, 4.52)	0.026
Fathers' education					
Educated	229	44 (19.2)	Reference		
Illiterate	119	23 (19.3)	1.0 (0.58, 1.77)	1.1 (0.52, 2.28)	0.834
Mothers' education*					
Educated	70	13 (18.6)	Reference		
uneducated	277	54 (19.5)	1.1 (0.54, 2.08)	0.7 (0.34, 1.63)	0.463
Fathers' occupational status					
Employed	167	31 (18.6)	Reference		
Unemployed	181	36 (19.9)	1.9 (0.64, 1.86)	1.0 (0.53, 2.05)	0.898
Mothers' occupational status					
Employed	14	3 (21.4)	Reference		
Unemployed	334	64 (19.2)	0.9 (0.24, 3.21)	1.2 (0.28, 4.82)	0.846
Family size					
≤ 8 members	216	37 (17.1)	Reference		
> 8 members	132	30 (22.7)	1.4 (0.83, 2.44)	1.6 (0.86, 2.84)	0.145
Regular contact with open water sources					
No	170	21 (12.4)	Reference		
Yes	178	46 (25.8)	2.5 (1.40, 4.36)	2.6 (1.38, 4.75)	0.003
Had schistosomiasis before					
No	235	37 (15.7)	Reference		
Yes	113	30 (26.5)	1.9 (1.12, 3.34)	1.9 (0.99, 3.57)	0.054
Prior anti-schistosome therapy					
Yes	159	27 (17.0)	Reference		
No	189	40 (21.2)	1.3 (0.76, 2.26)	0.8 (0.42, 1.54)	0.505
Wearing shoes when going outdoors					
Yes	291	57 (19.6)	Reference		
No	57	10 (17.5)	0.9 (0.42, 1.83)	0.7 (0.34, 1.64)	0.463
Toilet in the house					
Available	340	65 (19.1)	Reference		
Not available	8	2 (25.0)	1.4 (0.28, 7.15)	1.0 (0.17, 6.55)	0.960
Toilet in the school					
Available	272	55 (20.2)	Reference		
Not available	76	12 (15.8)	0.7 (0.37, 1.47)	0.6 (0.30, 1.33)	0.228
Household's water sources					
Piped	238	41 (17.2)	Reference		
Others#	110	26 (23.6)	1.5 (0.86, 2.59)	1.6 (0.88, 2.93)	0.127
Sanitation*					
Improved [a]	222	42 (18.9)	Reference		
Unimproved [b]	125	25 (20.0)	1.1 (0.62, 1.86)	1.2 (0.68, 2.28)	0.488

N, number of examined samples; **n**, number of positive samples; **OR**; Odds ratio; **CI**, confidence interval. **AOR**: adjusted odds ratio. *One case is missing. #Other sources of household water: streams, wells, dams, etc. [a] Improved sanitation (flush/pour flush toilet to piped sewer system or pit latrine). [b] Unimproved sanitation (no toilet or flush/pour flush toilet to open area).

Table 4. Association between frequency of exposure to water sources and schistosomiasis

Exposure frequency	N	n (%)	OR (95% CI)	P-value
Never	169	20 (11.8)	Reference	–
Daily	18	10 (55.6)	9.3 (3.29–26.35)	<0.001
2–3 times/week	117	30 (25.6)	2.6 (1.38–4.80)	0.003
Less than once/week	44	7 (15.9)	1.4 (0.55–3.58)	0.471

N; the number of examined samples, **n**; the number of positive samples, **OR**; Odds ratio, **CI**; confidence interval.

Table 5. Clinical manifestations of *S. haematobium* among schoolchildren in previously hypoendemic Yemeni districts

Indicator	N	n (%)	OR (95% CI)	AOR (95% CI)	*P*-value
Dysuria*					
No	259	21 (8.1)	Reference		
Yes	88	22 (25.0)	3.8 (1.96, 7.29)	3.7 (1.84, 7.50)	<0.001
Proteinuria					
Negative	251	19 (7.6)	Reference		
Positive	97	24 (24.7)	4 (2.08, 7.74)	3.3 (1.64, 6.82)	0.001
Microhematuria					
Negative	303	29 (9.6)	Reference		
Positive	45	14 (31.1)	4.3 (2.04, 8.93)	3.3 (1.47, 7.52)	0.004
Visible hematuria					
No	326	37 (11.3)	Reference		
Yes	22	6 (27.3)	2.9 (1.08, 7.95)	1.1 (0.34, 3.67)	0.860

*One case is missing. **N**; the number of examined samples, **n**; the number of positive samples, **OR**; Odds ratio, **CI**; confidence interval. **AOR**, adjusted odds ratio.

Table 6. Clinical manifestations of *S. mansoni* among schoolchildren in previously hypoendemic Yemeni districts

Indicator	N	n (%)	*P*-value
Diarrhoea			
No	302	21 (7.0)	
Yes	46	3 (6.5)	1.000
Hematochezia			
No	346	24 (6.9)	
Yes	2	0 (0.0)	1.000
Mucoid stool			
No	338	22 (6.5)	
Yes	10	2 (20.0)	0.146

N: number of examined samples; **n**: number of positive samples.

have been documented in some areas, such as 7.41% [26], 1.7% [27], and 3.3% [28]. The prevalence of S. mansoni in this study is similar to that in other studies in Yemen, which reported 6.5% [29] and 9.3% [22]. Higher rates have been observed in certain regions, including 33.9% [30], 20.8% [26], and 14.3% [31] in Canada and the United States. Conversely, some studies have reported much lower prevalence rates, such as 1.4% [30] and 1.1% [28]. These regional differences may be linked to ecological factors and behavioral changes, such as the presence of water bodies suitable for snail hosts or differences in water use and sanitation practices. Despite several rounds of MDA campaigns over several years, the findings indicate ongoing transmission [22, 24].

However, a comparison using the most recent national mapping data showed a substantial increase in infection prevalence across the surveyed districts. For example, the prevalence of schistosomiasis in Jabal Ash Sharq District increased significantly from 4.5% to 20.7%, with a tenfold increase in *S. mansoni* from 1.6% to 15.7%, while the prevalence of *S. haematobium* approximately doubled from 2.9% to 5.0%. Additionally, a sixfold increase in schistosomiasis prevalence in Hubaysh District from 1.9% to 12.5%, particularly *S. haematobium* infection, which has resurged from 0% to 10.6% without changes in *S. mansoni* infection. Similar changes were observed in the Amd district, where the prevalence of *S. haematobium* increased by more than sixfold, from 3.6% to 24.0%. However, this result is an indicator of the positive impact of MDA compared to a previous study conducted in 2021 in the same district (33.7%) [13]. The observed changes in patterns indicate changes in factors such as sociodemographic characteristics, water contact behavior, and the distribution of intermediate hosts. The high variation in *S. haematobium* prevalence calls for urgent and localized interventions.

In terms of infection intensity, 16.3% of *S. haematobium* infections and 20.8% of *S. mansoni* infections were classified as heavy and moderate, respectively, which is particularly associated with the severity of clinical symptoms and related complications [32, 33].

The risk factors identified in this study were consistent with previous studies, with age $\geq$10 years and contact with environmental water sources emerging as significant risk factors in the multivariate analysis, mirroring the findings from other Yemeni studies [12, 22, 30] and aligning with the findings of other studies conducted in different countries, including Sudan [34], Ghana [35], and other endemic African regions [36]. Despite a history of previous infection being significantly associated with infection in the univariable analysis, this association did not remain significant in the multivariable model, suggesting that its effect may be influenced or explained by other factors.

While preventive chemotherapy with reduced heavy infection burden has been successful [24], our and others' evidence from Yemen [12, 22, 29–31], shows that MDA alone is not enough to interrupt the transmission of schistosomiasis, as reinfection remains a continual challenge in endemic areas [37–39]. Political instability and the ongoing conflict in the country have contributed to the hindrance of the elimination of the disease. Historically, warfare has been linked to the aggravation of infectious disease mortality and morbidity. NTDs are directly impacted by wars in different areas [40, 41]. The findings observed in Yemeni governorates to date, Taiz [26, 31], Ibb [29], Amran [12], Sana'a [30], and Hadhramout [13], highlight the urgent need for integrated control measures. These should be based on an integrated approach of MDA with health education, WASH infrastructure, snail control, and community-targeted surveillance, as recommended by the WHO [16, 20]. While the present study deals with the burden of schistosomiasis in hypoendemic zones in Yemen, it has some limitations. The findings may not be universally generalizable to all hypoendemic districts within the country; hence, more research is required to provide definitive answers. In addition, it was a cross-sectional study and could not capture changes in infection patterns throughout the disease cycle. Furthermore, this study excluded preschool children and adults, indicating the need for community-based studies to provide a comprehensive evaluation of schistosomiasis status.

5. CONCLUSION

In the surveyed districts, schistosomiasis has shifted to a meso-endemic level, with *S. haematobium* being the predominant species affecting school children. These findings indicate that transmission is still ongoing and that control efforts must be modified accordingly. Twice-yearly PZQ treatment for all school-aged children, including those not attending school. Hematuria, microhematuria, and proteinuria were associated with *S. haematobium* infection and were helpful as markers for identifying cases in field studies. Older age and regular access to environmental water bodies were independent predictors of schistosomiasis. Together, these underline the need for a combined intervention that includes MDA, improved access to clean water, adequate sanitation, environmental management, and health education to successfully reduce levels of infection transmission and the frequency of reinfections.

AUTHORS' CONTRIBUTIONS

WMSA, YAR, and AMM conceptualized this study. WMSA was responsible for data curation and investigations. The methodology was developed by WMSA, YAR, and AMM. YAR was responsible for project administration, and WMSA prepared the original draft of the manuscript. YAR and AMM contributed to the review and editing of this manuscript.

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DATA AVAILABILITY

All data relevant to this study are presented in this manuscript. Additional datasets are available from the corresponding author upon reasonable requests.

DECLARATION OF COMPETING INTERESTS

The authors declare no competing interests.

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