Schistosoma mansoni and soil-transmitted helminths among schoolchildren in An-Nadirah District, Ibb Governorate, Yemen after a decade of preventive chemotherapy

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Abstract

The Ministry of Public Health in Yemen continues the implementation of school and community-based preventive chemotherapy with praziquantel and albendazole for the control and elimination of schistosomiasis and soil-transmitted helminths (STH). The latest remapping to update the distribution of schistosomiasis and STH was conducted seven years ago. This study aimed to estimate the prevalence, intensity and associated risk factors of Schistosoma mansoni and STH among schoolchildren in An-Nadirah District, Ibb Governorate, Yemen. A cross-sectional study was carried out among schoolchildren aged 6–15 years in four selected schools. Biological, demographic, socioeconomic and environmental data were collected using a pre-tested questionnaire. S. mansoni and STH eggs were detected and counted by the microscopic examination of Kato-Katz fecal smears. Out of 417 schoolchildren, 17.0% were infected with at least one intestinal helminth. Prevalence of S. mansoni and STH were 6.5% and 9.1%, respectively. The most prevalent parasite among STH was Ascaris lumbricoides (8.4%). Unemployed fathers (Adjusted Odds Ratio (AOR) = 3.2; 95% Confidence interval (CI): 1.23, 8.52; P = 0.018), eating exposed food (AOR: 2.9; 95%CI = 1.24, 6.89; P = 0.014), not washing hands before eating and after defecation (AOR: 4.8; 95%CI = 1.77, 12.81; P = 0.002), and schools located close to water stream (AOR: 22.1; 95%CI = 5.12, 95.46; P < 0.001) were independent risk factors of ascariasis. Swimming in ponds/stream (AOR: 3.9; 95%CI = 1.63, 9.55; P = 0.002), and schools close to the stream (AOR: 24.7; 95%CI = 3.05, 200.07; P = 0.003) were independent risk factors of intestinal schistosomiasis. The present study does not indicate a reduction in the prevalence of intestinal schistosomiasis in this rural area since the latest remapping conducted in 2014, although ascariasis was reduced by half. The prevalence of the two parasites was highly focal in areas close to the valley, suggesting a significant role of the stream in sustaining and accelerating the parasitic infection. Children practicing swimming and having poor hygienic practices were at high exposure to S. mansoni and A. lumbricoides, respectively.
Sanitation and Hygiene intervention, school–based health education, and snail control, in addition to mass drug administration, will help in the interruption of transmission of schistosomiasis and STH.

1. Introduction

*Schistosoma mansoni* and soil-transmitted helminths (STH) (*Ascaris lumbricoides*, *Trichuris trichiura*, and hookworms) are neglected tropical diseases (NTDs) causing morbidity and mortality worldwide. The 2015 global estimates showed that schistosomiasis, ascariasis, trichuriasis and hookworm infections affect 0.25 billion (95% uncertainty interval (95%UI): 0.21–0.32 billion), 0.76 billion (95%UI: 0.68–0.86 billion), 0.46 billion (95%UI: 0.43–0.50 billion) and 0.43 billion (0.40–0.47 billion), respectively [1]. These parasitic infections have adverse effect on the nutritional status, cognitive function, and physical and mental development of children [2–4].

*S. mansoni* and STH have a widespread prevalence in communities with poor sanitary condition, low-income, and overcrowded places [5]. Furthermore, unsafe drinking and irrigation water sources are risk factors for *S. mansoni* [6–9]. Preventive chemotherapy through mass drug administration (MDA) is the main intervention for the control and elimination of schistosomiasis and STH [10–13]. Ministry of Public Health, Yemen, has been implementing nationwide MDA, with praziquantel for schistosomiasis and albendazole for STH through school and community channels since 2010 [14]. The nationwide remapping survey, conducted in 2014, showed that overall prevalence of schistosomiasis and STH was reduced to 3.2% and 8.8%, respectively [15]. However, there is no updated picture about *S. mansoni* and STH in the last seven years. It is noteworthy that Yemen is suffering from ongoing war started in early 2015, which might affect the distribution of *S. mansoni* and STH. Besides, foci with high prevalence of *S. mansoni* and STH have been reported [16, 17]. The present study aimed to determine the prevalence of STH and *S. mansoni*, and identify their risk factors among schoolchildren in An-Nadirah District, an endemic area in Ibb Governorate, Yemen.

2. Materials and methods

2.1. Study area

An-Nadirah District is a mountainous area in Ibb Governorate, Yemen. It is located at an altitude of 2153 meters above sea level along Bana Valley, which combines a permanent stream flowing toward Abyan Governorate. Stream, underground wells and rains are the main water sources for domestic and irrigation purposes. The district is endemic for *S. mansoni* and STH and has been targeted by the preventive chemotherapy. Therefore, it was purposively selected as an example to assess the impact of the MDA campaigns on the prevalence of *S. mansoni* and STH.

2.2. Study design and population

A cross-sectional study was carried out among schoolchildren aged 6–15 years. The study targeted four primary schools with a total of 1429 students attending school during the scholarly year 2019.

2.3. Sample size and sampling strategy

The minimum sample size was calculated EpiInfo programme (https://www.cdc.gov/epiinfo/index.html) using the following parameters; 95% Confidence interval and precision of ± 5%.
The highest prevalence reported by the latest remapping, conducted in 2014, was 14% for *A. lumbricoides* [15], which was used for the sample size calculation. The sample size was inflated by the design effect of two and an expected non-response rate of 10% due to absenteeism or other reasons. The total sample size required was 408 schoolchildren, although 417 children were enrolled from four schools that were selected using cluster sampling approach. The students were first ranked according to their class levels (grade 1–9). A proportional sample was then selected from each class by systemic random sampling using school records as the sampling frame.

2.4. Questionnaire

A pre-tested questionnaire was used to collect information on the demographic, socio-economic background, hygienic practices and environment through face-to-face interview with schoolchildren. Information about personal hygiene, fingernails trimming and walking barefoot was collected by direct observation.

2.5. Parasitological examination

A single fecal specimen was obtained from each study participant and two Kato-Katz thick smears were prepared from each fecal sample in the field following a standard protocol [18]. The smears were examined microscopically for the presence of hookworm’s eggs in a half to one hour after the preparation. Then, Kato-Katz thick smears were transferred to the Department of Parasitology, Faculty of Medicine, Sana’a University, and examined for STH and *S. mansoni* eggs using light microscopy by two experienced laboratory technologists, independently. Smears with discrepancies in results between the two readers were re-examined by a third lab technician who was blinded to the first results. Following the WHO guidelines, the intensity of *S. mansoni* was classified into light (1–99 eggs/gram of stool (epg)), moderate (100–399 epg) and high (≥ 400 epg), while the intensity of *A. lumbricoides* was classified into light (1–4,999 epg), moderate (5,000–49,999 epg), and high (≥ 50,000 epg) [19]. The area was classified according to the prevalence of *S. mansoni* into high-risk (prevalence ≥ 50%), moderate-risk (prevalence = 10–50%), and low-risk (prevalence = 1–<10%), while the area was classified to high and low risk if the prevalence of STH was ≥50% and ≥20–<50%, respectively [20].

2.6. Data analysis

Data analysis was conducted by using the IBM SPSS Statistics version 24 (IBM Corp., Armonk, NY, USA). Data were presented in frequency tables. Prevalence was reported with its corresponding 95% confidence interval (CI). The association between independent and dependent variables was tested using Chi-square or Fisher’s exact tests when applicable with reporting odds ratio (OR) and its corresponding 95% CI. Multivariable analysis using binary logistic regression model was developed for all variables included in the univariable analysis and adjusted odds ratio (AOR) with its corresponding 95% CI were reported. P-value < 0.05 was considered significant.

2.7. Ethical clearance

This research protocol was approved by the Research and Ethics Committee (REC) of the Faculty of Medicine and Health Sciences, Sana’a University. Permission was obtained from each schoolmaster/schoolmistress after clarifying the importance of the study. Each child was voluntarily involved after explaining the nature of their participation in the study in a way that the child can understand and give his/her assent. Since the study protocol was conducted in
schools where children’s parents/guardians were not existing, no informed consent was obtained, although those parents/guardians were informed about the study and had the right to refuse the participation of their children. The lack of child’s caretaker consent was approved by the REC. Anonymity, dignity and privacy of each child and his/her family were protected.

3. Results

3.1. Characteristics of subjects

A total of 417 schoolchildren aged 6–15 years with a mean age of 11.2 years have participated in this study (54.4% were males and 45.6% were females). Overall, more than three-quarters (83.7%) of fathers were educated with at least a primary school certificate while about two-thirds of mothers were uneducated. A total of 157 (37.6%) and 131 (31.4%) children were living in houses without access to piped water and improved sanitation, respectively (Table 1).

Table 1. Characteristics of schoolchildren (n = 417).

| Characteristics                      | n   | (%) |
|--------------------------------------|-----|-----|
| Gender                               |     |     |
| Male                                 | 227 | 54.4|
| Female                               | 190 | 45.6|
| Age groups (years)                   |     |     |
| ≤ 10                                 | 157 | 37.6|
| > 10 (11–15)                         | 260 | 62.4|
| Fathers’ education level             |     |     |
| Educated                             | 349 | 83.7|
| Uneducated                           | 68  | 16.3|
| Mothers’ education level             |     |     |
| Educated                             | 143 | 34.3|
| Uneducated                           | 273 | 65.5|
| Fathers’ occupational status         |     |     |
| Employed                             | 213 | 51.1|
| Unemployed                           | 204 | 48.9|
| Family size                          |     |     |
| < 8 members                          | 216 | 51.8|
| ≥ 8 members                          | 201 | 48.2|
| Toilet in home                       |     |     |
| Available                            | 389 | 93.3|
| Not available                        | 28  | 6.7 |
| Toilet in school                     |     |     |
| Available                            | 355 | 85.1|
| Not available                        | 62  | 14.9|
| Source of household’s water          |     |     |
| Piped water                          | 260 | 62.4|
| Other                                | 157 | 37.6|
| Sanitation                           |     |     |
| Improved                             | 286 | 68.6|
| Unimproved                           | 131 | 31.4|

* 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).

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3.2. Prevalence and distribution of Intestinal helminths

The prevalence of intestinal helminths among schoolchildren was 17%. For soil-transmitted helminths, the prevalence of *Ascaris lumbricoides*, *Trichuris trichiura*, and hookworm was 8.4%, 0.7%, and 0.5%, respectively. The prevalence of *Schistosoma mansoni* was 6.5%. The majority of infections with *S. mansoni* or *A. lumbricoides* were light infections (Table 2). Children from schools close to stream had higher infection rate compared to other schools (Table 3).

3.3. Factors associated with *A. lumbricoides* infection

Univariable analysis identified a significant association between *A. lumbricoides* infection and uneducated father (OR = 3.0; 95%CI = 1.43, 6.45; P = 0.005), not washing hands before eating and after defecation (OR: 4.3; 95%CI = 2.04, 9.15; P <0.001), eating uncooked vegetables and fruits (OR: 2.9; 95%CI = 1.38, 6.01; P = 0.006), eating exposed food (OR: 4.6; 95%CI = 2.25, 9.41; P <0.001), and schools close to the stream (OR: 11.0; 95%CI = 3.31, 36.56; P <0.001). Multivariable analysis using binary logistic regression model identified unemployed father (AOR: 3.2; 95%CI = 1.23, 8.52; P = 0.018), not washing hands before eating and after defecation (AOR: 4.8; 95%CI = 1.77, 12.81; P = 0.002), eating exposed food (AOR: 2.9; 95%CI = 1.24, 6.89; P = 0.014), and schools close to the stream (AOR: 22.1; 95%CI = 5.12, 95.46; P <0.001) as independent risk factors of *A. lumbricoides* infection (Table 4).

Table 2. Prevalence of intestinal helminths among schoolchildren in An-Nadirah District, Ibb Governorate, Yemen (n = 417).

| Parasites | Positive | 95%CI |
|-----------|----------|-------|
| Intestinal helminths’ infection | 71(17.0) | (13.4, 20.6) |
| STH infection | 38(9.1) | (6.2, 11.8) |
| Type of infection | | |
| *A. lumbricoides* | 35(8.4) | (5.3, 10.7) |
| *T. trichiura* | 3(0.7) | (0.2, 2.0) |
| Hookworms | 2(0.5) | (0.0, 1.0) |
| *S. mansoni* | 27(6.5) | (3.6, 8.4) |
| *H. nana* | 20(4.8) | (3.0, 7.1) |
| *E. vermicularis* | 4(1) | (0.1, 2.0) |
| Fasciola spp. | 2(0.5) | (0.0, 2.0) |
| Mixed infection | | |
| *S. mansoni* & *A. lumbricoides* | 9(2.2) | (0.6, 3.4) |
| *S. mansoni* & *T. trichiura* | 2(0.5) | (0.0, 1.0) |
| Intensity of *S. mansoni* | | |
| Light | 21(5.0) | (11.4, 24.7) |
| Moderate | 6(1.5) | |
| Intensity of *A. lumbricoides*# | | |
| Light | 34(8.2) | (17.1, 32.9) |
| Moderate | 1(0.2) | |

*; eggs number in this study ranged from 24–96 eggs per gram of stool for light infection and 126–312 eggs per gram of stool for moderate infection

#; eggs number in this study ranged from 24–1272 eggs per gram of stool for light infection and only one case was moderate infection (37200 eggs per gram of stool).

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3.4. Risk factors associated with *S. mansoni* infection

Univariable analysis identified an association between *S. mansoni* infection and uneducated father (OR: 3.4; 95%CI = 1.47, 7.71; P = 0.006), swimming or having contact with stream water (OR: 3.5; 95%CI = 1.58, 7.69; P = 0.002), and schools close to the stream (OR: 26.3; 95%CI = 3.53, 195.49; P < 0.001). Multivariable analysis using binary logistic regression model identified swimming in ponds/stream (AOR: 3.9; 95%CI = 1.63, 9.55; P = 0.002), and schools close to the stream (AOR: 24.7; 95%CI = 3.05, 200.07; P = 0.003) as independent risk factors of *S. mansoni* infection (Table 5).

4. Discussion

The present study aimed to determine the prevalence of STH and *S. mansoni* in an endemic area after a decade of regular school-based and community-based preventive chemotherapy. The prevalence of STH was 9.1% with *A. lumbricoides* being the most common STH (8.1%). This finding indicates reduction in the prevalence of STH among schoolchildren in An-Nadirah District compared to a previous survey conducted in the same area (8.1% vs 14%) [14], classifying this district as a low risk area (Low risk: <20%) [20]. This, in turn, indicates that MDA has achieved success in the control of STH. The predominance of *A. lumbricoides* compared to other STH is consistent with previous studies conducted in Yemen [14, 15], Middle East and north Africa region [21].

*A. lumbricoides* infection was higher among children from schools that are close to the stream than children from other schools. Besides, multivariable analysis identified schools close to the stream as independent risk factor of ascariasis. The statistical analysis does not suggest household’s drinking water or contact with the stream as predictors of ascariasis in this area even after controlling the location using stratified analysis. Therefore, the clustering of *A. lumbricoides* infection in schools close to the stream could be explained by higher temperature in communities located in the valley that accelerates the development of helminth eggs and predicts the prevalence of ascariasis [22]. Besides, the stream water may increase the moisture of the soil in its banks, providing a suitable environment for sustenance and development of Ascaris eggs [23].

Not washing hands and eating exposed food variables were independent risk factors of ascariasis, which are in line with findings reported from different areas in Yemen [15, 24–26], and other countries such as Saudi Arabia [27], Ethiopia [28], China [29] and India [30]. These findings necessitate providing school-based health education and implementing the MDA with albendazole together. Schoolchildren whose fathers are unemployed had higher infection rate of ascariasis, which was in agreement with previous studies conducted in Yemen [16, 31], Ethiopia [32], Ghana [33] and Nigeria [34]. This finding may be attributed to those unemployed fathers who most often work in agricultural fields with a probability of accompanying their children during the work, a common practice in the rural areas of Yemen, and exposing them to contaminated soil.
Table 4. Factors associated with *A. lumbricoides* among schoolchildren in An-Nadirah District, Ibb Governorate, Yemen.

| Variables                          | N    | n(%)  | OR (95% CI) | AOR (95% CI) | P value |
|-----------------------------------|------|-------|-------------|--------------|---------|
| **Gender**                        |      |       |             |              |         |
| Male                              | 227  | 15(6.6)| Reference   |              |         |
| Female                            | 190  | 20(10.5)| 0.60(0.30, 1.21)| 0.90(0.39, 2.11) | 0.831   |
| **Age groups (years)**            |      |       |             |              |         |
| ≤10                               | 157  | 12(7.6)| Reference   |              |         |
| >10                               | 260  | 23(8.8)| 0.90(0.41, 1.76)| 1.30(0.49, 3.30) | 0.630   |
| **Father’s education**            |      |       |             |              |         |
| Educated                          | 349  | 23(6.6)| Reference   |              |         |
| Uneducated                        | 68   | 12(17.6)| 3.00(1.43, 6.45)| 1.30(0.44, 3.70) | 0.648   |
| **Mother’s education**            |      |       |             |              |         |
| Educated                          | 143  | 12(8.4)| Reference   |              |         |
| Uneducated                        | 273  | 23(8.4)| 1.00(0.48, 2.08)| 0.40(0.17, 1.17) | 0.102   |
| **Father’s occupation**           |      |       |             |              |         |
| Employed                          | 213  | 15(7.0)| Reference   |              |         |
| Unemployed                        | 204  | 20(9.8)| 1.40(0.71, 2.89)| 3.20(1.23, 8.52) | 0.018   |
| **Family size**                   |      |       |             |              |         |
| <8 members                        | 216  | 20(9.3)| Reference   |              |         |
| ≥8 members                        | 201  | 15(7.5)| 0.80(0.39, 1.59)| 0.70(0.30, 1.71) | 0.452   |
| **Household’s water**             |      |       |             |              |         |
| Piped water                       | 260  | 19(7.3)| Reference   |              |         |
| Other                             | 157  | 16(10.2)| 1.40(0.72, 2.89)| 0.60(0.27, 1.58) | 0.339   |
| **Sanitation**                    |      |       |             |              |         |
| Improved                          | 286  | 26(9.1)| Reference   |              |         |
| Unimproved                        | 131  | 9(6.9)| 0.70(0.34, 1.62)| 1.00(0.38, 2.54) | 0.965   |
| **Hand washing before eating and after defecation** | | | | | |
| Yes                               | 358  | 22(6.1)| Reference   |              |         |
| No                                | 59   | 13(22)| 4.30(2.04, 9.15)| 4.80(1.77, 12.81) | 0.002   |
| **Eating unwashed vegetables & fruits** | | | | | |
| No                                | 339  | 22(6.5)| Reference   |              |         |
| Yes                               | 78   | 13(16.7)| 2.90(1.38, 6.01)| 1.80(0.73, 4.55) | 0.196   |
| **Eating exposed food**           |      |       |             |              |         |
| No                                | 335  | 18(5.4)| Reference   |              |         |
| Yes                               | 82   | 17(20.7)| 4.60(2.25, 9.41)| 2.90(1.24, 6.89) | 0.014   |
| **Nails clipping**                |      |       |             |              |         |
| Yes                               | 328  | 23(7.0)| Reference   |              |         |
| No                                | 89   | 12(13.5)| 2.10(0.99, 4.34)| 1.00(0.38, 2.40) | 0.926   |
| **Shoes wearing**                 |      |       |             |              |         |
| Yes                               | 355  | 30(8.5)| Reference   |              |         |
| No                                | 62   | 5(8.1)| 1.00(0.35, 2.55)| 0.80(0.25, 2.62) | 0.715   |
| **Swimming in ponds/stream**      |      |       |             |              |         |
| No                                | 311  | 30(9.6)| Reference   |              |         |
| Yes                               | 106  | 5(4.7)| 0.50(0.18, 1.23)| 0.50(0.15, 1.48) | 0.196   |
| **Location of schools**           |      |       |             |              |         |
| Close (191–606 m)                 | 220  | 32(14.5)| Reference   |              |         |

(Continued)
### Table 4. (Continued)

| Variables          | N    | n(%) | OR(95%CI)      | AOR(95%CI)    | P value |
|--------------------|------|------|----------------|--------------|---------|
| Far (> 8 km)       | 197  | 3(1.5)| 11.0(3.31, 36.56) | 22.1(5.12, 95.46) | <0.001  |

N; the number of samples examined, n; the number of positive samples, OR; Odds ratio, AOR; adjusted OR, CI; confidence interval, other sources of drinking water; stream, wells, dams etc. *; 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), #; How far is the school from stream.

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### Table 5. Factors associated with S. mansoni among schoolchildren in An-Nadirah District, Ibb Governorate, Yemen.

| Variable          | N    | n(%) | OR(95%CI)      | AOR(95%CI)    | P value |
|-------------------|------|------|----------------|--------------|---------|
| Gender            |      |      |                |              |         |
| Male              | 227  | 11(4.8) | Reference      |              |         |
| Female            | 190  | 16(8.4) | 0.6(0.25, 1.22) | 1.1(0.38, 3.00) | 0.890   |
| Age groups (years)|      |      |                |              |         |
| ≤10               | 157  | 8(5.1) | Reference      |              |         |
| >10               | 260  | 19(7.3) | 0.7(0.29, 1.60) | 1.1(0.38, 3.00) | 0.897   |
| Father's education|      |      |                |              |         |
| Educated          | 349  | 17(4.9) | Reference      |              |         |
| Uneducated        | 68   | 10(14.7) | 3.4(1.47, 7.71) | 2.5(0.78, 8.05) | 0.125   |
| Mother's education|      |      |                |              |         |
| Educated          | 143  | 9(6.3) | Reference      |              |         |
| Uneducated        | 273  | 18(6.6) | 1.1(0.46, 2.40) | 0.5(0.18, 1.47) | 0.214   |
| Father's occupation|    |      |                |              |         |
| Employed          | 213  | 11(5.2) | Reference      |              |         |
| Unemployed        | 204  | 14(6.8) | 0.8(0.35, 1.77) | 0.8(0.29, 2.33) | 0.720   |
| Family size       |      |      |                |              |         |
| <8 members        | 216  | 16(7.4) | Reference      |              |         |
| ≥8 members        | 201  | 11(5.5) | 0.7(0.33, 1.59) | 0.8(0.31, 1.99) | 0.605   |
| Household's water |      |      |                |              |         |
| Piped water       | 260  | 14(5.4) | Reference      |              |         |
| Other             | 157  | 13(8.3) | 1.6(0.73, 3.45) | 1.5(0.60, 3.62) | 0.394   |
| Sanitation        |      |      |                |              |         |
| Improved          | 286  | 23(8.0) | Reference      |              |         |
| Unimproved        | 131  | 4(3.1)  | 0.4(0.12, 1.06) | 0.5(0.15, 1.63) | 0.246   |
| Swimming in ponds/stream | | | | | |
| No                | 311  | 13(4.2) | Reference      |              |         |
| Yes               | 106  | 14(13.2)| 3.5(1.58, 7.69) | 4.1(1.79, 10.28) | 0.001   |
| Location of schools# | | | | | |
| Close (191–606 m) | 220  | 26(11.8) | Reference      |              |         |
| Far (> 8 km)      | 197  | 1(0.5)  | 26.3(3.53, 195.49) | 22.6(2.80, 183.09) | 0.003   |

N; the number of samples examined, n; the number of positive samples, OR; Odds ratio, AOR; adjusted OR, CI; confidence interval, other sources of drinking water; stream, wells, dams etc. *; 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) #; How far is the school from stream.

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The prevalence of *S. mansoni* among schoolchildren in the present study was 6.5%, placing An-Nadirah District in the low-risk category [20]. However, the finding indicates no reduction in the prevalence of *S. mansoni* compared to the prevalence reported by latest remapping conducted in 2014 (5.4%) [15]. It is well known that treatment alone, the current strategy for prevention and control of schistosomiasis in Yemen, is not sufficient to achieve the interruption of the transmission and, therefore, environmental and educational interventions are recommended [20]. The unreduced prevalence *S. mansoni* in this community may be explained by environmental and human behavior–related factors such as the presence of a permanent water course in this district together with the water contact activities that favor the reinfection in spite of the regular preventive chemotherapy as observed elsewhere [35–37]. In this context, the study revealed that schoolchildren attending schools located close to the stream are at higher risk of *S. mansoni*, which was in agreement with previous studies conducted in Ethiopia [38], West Africa [39], and Sudan [40]. The permanent water stream, flowing in Bana Valley, might contribute to the high risk of infection by increasing presence and abundance of *Biomphalaria* snails shedding cercariae [41]. Therefore, reducing or eliminating intermediate snail hosts should be integrated as additional intervention for effective control strategy [42] beside preventing water contamination through improved sanitation [20, 43]. In addition, the focal nature of *S. mansoni* in this district suggests a reevaluation of subdistrict instead of district as the implementation unit for prevention and control of schistosomiasis. The focus on exposed communities at the district level will save resources particularly in Yemen, a country with limited resources and political instability.

Swimming was an independent factor associated with intestinal schistosomiasis among schoolchildren, which was consistent with previous studies conducted in Yemen [16, 24, 44] and other developing countries such as Egypt [45], Ethiopia [38, 46] and Sudan [40]. This finding could be attributed to the fact that swimming increases the duration of skin contact with water which causes skin penetration by *S. mansoni* cercariae. It is noteworthy that swimming is a recreation activity and WASH intervention may not have a significant impact on reducing swimming-related transmission. Thus, school-based health education should be a component of the control strategy of schistosomiasis [20, 47].

Besides abovementioned predictors that might contribute to unchanged prevalence of intestinal schistosomiasis, the impact of the ongoing war conflict on the regularity of the preventive chemotherapy should not be ignored. However, Ministry of Public Health and Population conducted several preventive chemotherapy campaigns following the start of the civil unrest in 2015 with support from the World Bank [48] and the World Health Organization as mentioned in a conversation with A.A.Q Thabit (July, 2022).

5. Conclusion

Although preventive chemotherapy as a single intervention has achieved success in reducing the prevalence of *A. lumbricoides* by half in An Nadirah District, Ibb Governorate, there has been no reduction in the prevalence of *S. mansoni* since the latest remapping survey conducted in 2014. However, the district is still classified in the low-risk category. The permanent water stream flowing in the district valley together with swimming behavior of schoolchildren seem to play significant roles in sustaining the transmission of *S. mansoni*. Poor hygienic practices contribute to the occurrence of *A. lumbricoides*. For eliminating the transmission, school-based health education, snail control, school- and community–based WASH programme and mass drug administration should be components in the control strategy of schistosomiasis and STH. The focal transmission suggests focusing the interventions on exposed communities instead of targeting the whole district.
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References
1. Kyu HH, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N, et al. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2018 Nov 10; 392(10159):1859–922.

2. Yap P, Utzinger J, Hattendorf J, Steinmann P. Influence of nutrition on infection and re-infection with soil-transmitted helminths: a systematic review. Parasites & vectors. 2014 Dec; 7(1):1–4. https://doi.org/10.1186/1756-3305-7-229 PMID: 24885622

3. Taylor-Robinson DC, Maayan N, Soares-Weiser K, Donegan S, Garner P. Deworming drugs for soil-transmitted intestinal worms in children: effects on nutritional indicators, haemoglobin, and school performance. Cochrane Database Syst Rev. 2015 Jul 23; 2015(7):CD000371. https://doi.org/10.1002/14651858.CD000371.pub6 Update in: Cochrane Database Syst Rev. 2019 Sep 11;9:CD000371. PMID: 26202783; PMCID: PMC4523932.

4. Pabalan N, Singian E, Tabangay L, Jarjanazi H, Boivin MJ, Ezeamama AE. Soil-transmitted helminth infection, loss of education and cognitive impairment in school-aged children: A systematic review and meta-analysis. PLoS neglected tropical diseases. 2018 Jan 12; 12(1):e0005523. https://doi.org/10.1371/journal.pntd.0005523 PMID: 29329288

5. Vos T, Barber RM, Bell B, Bertozzi-Villa A, Biryukov S, Bolliger I, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 2015 Aug 22; 386(9995):743–800. https://doi.org/10.1016/S0140-6736(15)60692-4 Epub 2015 Jun 7. PMID: 26069472; PMCID: PMC4561509.

6. World Health Organization. Fact sheet on Soil-transmitted helminths. [Internet]. Geneva. 2019 [cited 2019 Jul 26]. Available from: https://www.who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections

7. McCarty TR, Turkeltaub JA, Hotz PJ. Global progress towards eliminating gastrointestinal helminth infections. Curr Opin Gastroenterol. 2014 Jan; 30(1):18–24. https://doi.org/10.1097/MOG.0000000000000225 PMID: 24241244.

8. Steinmann P, Keiser J, Bos R, Tanner M, Utzinger J. Schistosomiasis and water resources development: systematic review, meta-analysis, and estimates of people at risk. The Lancet infectious diseases. 2006 Jul 1; 6(7):411–25. https://doi.org/10.1016/S1473-3099(06)70521-7 PMID: 16790382
9. World Health Organization. Accelerating work to overcome the global impact of neglected tropical diseases—A roadmap for implementation [Internet]. Geneva. 2012 [cited 2021 Sep 24]. Available from: https://www.who.int/publications/iitem/WHO-HTM-NTD-2012.1

10. Crompton DWT. Preventive chemotherapy in human helminthiasis: coordinated use of anthelmintic drugs in control interventions: a manual for health professionals and programme managers. Geneva, Switzerland: World Health Organization; 2006. p. 4–7.

11. World Health Organization. Helminth control in school-age children: a guide for managers of control programmes. [Internet]. 2011 [cited 2021 Sep 24]. Available from: https://www.cabdirect.org/cabdirect/abstract/20123121824

12. World Health Organization. Schistosomiasis and soil-transmitted helminthiases: numbers of people treated in 2017. Wkly Epidemiol Rec. 2017; 92(50):681–92.

13. Hotez PJ, Savioli L, Fenwick A. Neglected tropical diseases of the Middle East and North Africa: review of their prevalence, distribution, and opportunities for control. PLoS neglected tropical diseases. 2012 Feb 28; 6(2):e1475. https://doi.org/10.1371/journal.pntd.0001475 PMID: 22389729

14. Oshish A, AlKohlani A, Hamed A, Karmel N, AlSoofi A, Farouk H, et al. Towards nationwide control of schistosomiasis in Yemen: a pilot project to expand treatment to the whole community. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2011 Nov 1; 105(11):617–27. https://doi.org/10.1016/j.trstmh.2011.07.013 PMID: 21907376

15. Alia Johari MD. Mapping of Schistosomiasis and Soil—transmitted helminths in Yemen, and the push for elimination; [Internet]. Available from: https://www.givewell.org/files/DWDA2009/SCI/Mapping_of_Schistosomiasis_and_Soil-Transmitted_Helminths_in_Yemen_and_the_Push_for_Elimination.pdf

16. Sady H, Al-Mekhlafi HM, Mahdy MA, Lim YA, Mahmoud R, Surin J. Prevalence and associated factors of schistosomiasis among children in Yemen: implications for an effective control programme. PLoS neglected tropical diseases. 2013 Aug 22; 7(8):e2377. https://doi.org/10.1371/journal.pntd.0002377 PMID: 23991235

17. Al-Mekhlafi AM, Abdul-Ghani R, Al-Eyani SM, Saif-Ali R, Mahdy MA. School-based prevalence of intestinal parasitic infections and associated risk factors in rural communities of Sana’a, Yemen. Acta tropica. 2016 Nov 1; 163:135–41. https://doi.org/10.1016/j.actatropica.2016.08.009 PMID: 27515811

18. Katz N, Chaves A, Pellegrino J, et al. A simple device for quantitative stool thick-smear technique in Schistosomiasis mansoni. Rev Inst Med Trop Sao Paulo. 1972; 14(6):397–400. PMID: 4675644

19. Montresor A, Crompton DWT, Hall A, Bundy DA, Savioli L. Guidelines for the evaluation of soil-transmitted helminthiasis at community level: a guide for managers of control programmes. Geneva: World Health Organization; 1998.

20. WHO. Helminth control in school-age children: a guide for managers of control programmes. 2011: World Health Organization.

21. Rokni MB, Lotfy WM, Hotez PJ, de Silva NR. Soil-transmitted helminth (STH) infections in the MENA region. In: Neglected Tropical Diseases-Middle East and North Africa. Springer; 2014. p. 1–21.

22. Kim MK, Pyo KH, Hwang YS, Park KH, Hwang IG, Chai JY, et al. Effect of temperature on embryonation of Ascaris suum eggs in an environmental chamber. The Korean Journal of Parasitology. 2012 Sep; 50(3):239. https://doi.org/10.3347/kjp.2012.50.3.239 PMID: 22949753

23. Senecal J, Nordin A, Vinnerås B. Fate of Ascaris at various pH, temperature and moisture levels. Journal of Water and Health. 2020 Jun 1; 18(3):375–82. https://doi.org/10.2166/wh.2020.264 PMID: 32589622

24. Alwabr GM, Al-Moayed EE. Prevalence of intestinal parasitic infections among school children of Al-Mahweet Governorate, Yemen. European Journal of Biological Research. 2016 Mar 8; 6(2):64–73.

25. Asubaie AS, Azazy AA, Omer EQ, Al-Shibani LA, Al-Mekhlafi AQ, Al-Khawlanl FA. Pattern of parasitic infections as public health problem among school children: A comparative study between rural and urban areas. Journal of Taibah University Medical Sciences. 2016 Feb 1; 11(1):13–8.

26. Raja’a YA, Mubarak JS. Intestinal parasitosis and nutritional status in schoolchildren of Sahar district, Yemen. EMHJ-Eastern Mediterranean Health Journal, 12 (Supp. 2), S189–S194, 2006. PMID: 17361690

27. Al-Mohammed HI, Amin TT, Aboulmagd E, Hablus HR, Zaza BO. Prevalence of intestinal parasitic infections and its relationship with socio–demographics and hygienic habits among male primary schoolchildren in Al–Ahsa, Saudi Arabia. Asian Pacific Journal of Tropical Medicine. 2010 Nov 1; 3(11):906–12.

28. Hailu GG, Ayele ET. Assessment of the prevalence of intestinal parasitic infections and associated habit and culture-related risk factors among primary schoolchildren in Debre Berhan town, Northeast Ethiopia. BMC public health. 2021 Dec; 21(1):1–2.

29. Yang D, Yang Y, Wang Y, Yang Y, Dong S, Chen Y, et al. Prevalence and risk factors of Ascaris lumbricoidea, Trichuris trichiura and Cryptosporidium infections in elementary school children in Western
China: a school-based cross-sectional study. International journal of environmental research and public health. 2018 Sep; 15(9):1809. https://doi.org/10.3390/ijerph15091809 PMID: 30135364

30. Ranjan S, Passi SJ, Singh SN. Prevalence and risk factors associated with the presence of Soil-Transmitted Helminths in children studying in Municipal Corporation of Delhi Schools of Delhi, India. Journal of parasitic diseases. 2015 Sep; 39(3):377–84. https://doi.org/10.1007/s12639-013-0378-2 PMID: 26345038

31. Qasem EA, Edrees WH, Al-Shehari WA, Alshahethi MA. Frequency of intestinal parasitic infections among schoolchildren in Ibb city-Yemen. Universal Journal of Pharmaceutical Research. 2020; 5 (2):42–6.

32. Alamir M, Awoke W, Feleke A. Intestinal parasites infection and associated factors among school children in Dagi primary school, Amhara National Regional State, Ethiopia. Health. 2013 Sep 29; 2013.

33. Forson AO, Arthur I, Ayeh-Kumi PF. The role of family size, employment and education of parents in the prevalence of intestinal parasitic infections in school children in Accra. PloS one. 2018 Feb 7; 13(2): e0192303. https://doi.org/10.1371/journal.pone.0192303 PMID: 29415040

34. Gyang VP, Chuang TW, Liao CW, Lee YL, Akinwale OP, Orok A, et al. Intestinal parasitic infections: current status and associated risk factors among school aged children in an archetypal African urban slum in Nigeria. Journal of Microbiology, Immunology and Infection. 2019 Feb 1; 52(1):106–13.

35. Landoué A, Dembéle R, Goïta S, Kané M, Tuïmsma M, Sacko M, et al. Significantly reduced intensity of infection but persistent prevalence of schistosomiasis in a highly endemic region in Mali after repeated treatment. PLoS Negl Trop Dis, 2012 July 6(7): e1774. https://doi.org/10.1371/journal.pntd.0001774 PMID: 22860153

36. Koukounari A, Gabrielli AF, Touré S, Bosqui-Oliva E, Zhang Y, Sellin B, et al. Schistosoma haematobium infection and morbidity before and after large-scale administration of praziquantel in Burkina Faso. J Infect Dis. 2007; 196(5):659–69. https://doi.org/10.1086/520515 PMID: 17674306

37. Trieneke ns SCM, Faust CL, Besigye F, Lucy P, Edridah MT, Janet S, et al. Variation in water contact behaviour and risk of Schistosoma mansoni (re)infection among Ugandan school-aged children in an area with persistent high endemicity. Parasites Vectors. 15, 15 (2022). https://doi.org/10.1186/s13071-021-05121-6

38. Alebie G, Erko B, Aemero M, Petros B. Epidemiological study on Schistosoma mansoni infection in Sanja area, Amhara region, Ethiopia. Parasites & vectors. 2014 Dec; 7(1):1–0. https://doi.org/10.1186/1756-3305-7-15 PMID: 24406075

39. Dabo A, Diarra AZ, Machault V, Touré O, Niambiéle DS, Kanté A, et al. Urban schistosomiasis and associated determinant factors among school children in Bamako, Mali, West Africa. Infectious diseases of poverty. 2015 Dec; 4(1):1–3.

40. Ismail HA, Hong ST, Babiker AT, Hassan RM, Sulaiman MA, Jeong HG, et al. Prevalence, risk factors, and clinical manifestations of schistosomiasis among school children in the White Nile River basin, Sudan. Parasites & vectors. 2014 Dec; 7(1):1–1.

41. Opisa S, Odieri MR, Jura WGZO, Karanja DMS, Mwinzi PM. Malacological survey and geographical distribution of vector snails for schistosomiasis within informal settlements of Kisumu City, western Kenya. Parasit Vectors.2011; 4(1):226. https://doi.org/10.1186/1756-3305-4-226 PMID: 22152486

42. World Health Organization. Field use of molluscicides in schistosomiasis control programmes: an operational manual for programmemangers. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

43. Farrell SH, Coffeng LE, Truscott JE, Werkman M, Toor J, de Vlas SJ, et al. Investigating the effectiveness of current and modified World Health Organization guidelines for the control of soil-transmitted helminth infections. Clinical Infectious Diseases. 2018 Jun 1; 66(suppl._4):S253–9. https://doi.org/10.1093/cid/ciy002 PMID: 29860285

44. Al-Shamiri AH, Al-Taj MA, Ahmed AS. Prevalence and co-infections of schistosomiasis/hepatitis B and C viruses among school children in an endemic areas in Taiz, Yemen. Asian Pacific journal of tropical medicine. 2011 May 1; 4(5):404–8. https://doi.org/10.1016/S1995-7645(11)60113-2 PMID: 21771686

45. El Sharazy BM, Abou Rayia DM, Antonios SN, Eissa SH. Current status of Schistosoma mansoni infection and its snail host in three rural areas in Gharbia governorate, Egypt. Tanta Medical Journal. 2016 Oct 1; 44(4):141.

46. Alemayehu B, Tomasa Z, Wadillo F, Leja D, Liang S, Erko B. Epidemiology of intestinal helminthiasis among school children with emphasis on Schistosoma mansoni infection in Wolaita zone, Southern Ethiopia. BMC public health. 2017 Dec; 17(1):1–0.

47. World Health Organization. Health education in the control of schistosomiasis. World Health Organization. 1990. https://apps.who.int/iris/handle/10665/39567

48. The World Bank. Yemen Schistosomiasis Project: Implementation completion and results report. 2018. https://projects.worldbank.org/en/projects-operations/project-detail/P113102