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Contextualizing *Schistosoma haematobium* transmission in Ghana: assessment of diagnostic techniques and individual and community water-related risk factors

Alexandra V. Kulinkina^{a,*}, Karen C. Kosinski^b, Michael N. Adjei^c, Dickson Osabutey^d, Bernard O. Gyamfi^e, Nana-Kwadwo Biritwum^f, Kwabena M. Bosompem^{c,d}, and Elena N. Naumova^{a,g}

^aTufts University School of Engineering, Medford, MA, USA

^bTufts University School of Arts and Sciences, Medford, MA, USA

^cCommunity Directed Development Foundation, University of Ghana, Accra, Ghana

^dNoguchi Memorial Institute for Medical Research, Accra, Ghana

^eUniversity College of Agriculture and Environmental Studies, Bunso, Ghana

^fGhana Health Service, Accra, Ghana

^gTufts University Friedman School of Nutrition Science and Policy, Boston, MA, USA

Abstract

Objectives: The study assessed associations between *Schistosoma haematobium* infection (presence of parasite eggs in urine or hematuria) and self-reported metrics (macrohematuria, fetching surface water, or swimming) to evaluate their performance as proxies of infection in presence of regular preventive chemotherapy. It also examined community water characteristics (safe water access, surface water access, and groundwater quality) to provide context for schistosomiasis transmission in different types of communities and propose interventions.

Methods: Logistic regression was used to assess the associations between the various measured and self-reported metrics in a sample of 897 primary school children in 30 rural Ghanaian communities. Logistic regression was also used to assess associations between community water characteristics, self-reported water-related behaviors and *S. haematobium* infection. Communities were subsequently categorized as candidates for three types of interventions: additional safe water sources, water treatment, and education about water-related disease risk, depending on their water profile.

Results: Microhematuria presence measured with a reagent strip was a good proxy of eggs in urine at individual (Kendall's $\tau_b = 0.88$, $p < 0.001$) and at school-aggregated (Spearman's $r_s = 0.96$, $p < 0.001$) levels. Self-reported macrohematuria and swimming were significantly associated

*Correspondence to Alexandra V. Kulinkina, alexandra.kulinkina@tufts.edu; akulinkina@gmail.com.

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($p < 0.05$) with egg presence, but self-reported fetching was not. Of the community water characteristics, greater surface water access and presence of groundwater quality problems were significantly associated with increased likelihood of fetching, swimming, and *S. haematobium* infection. Access to improved water did not exhibit an association with any of these outcomes.

Conclusions: The study illustrates that in presence of regular school-based treatment with praziquantel, microhematuria assessed via reagent strips remains an adequate proxy for *S. haematobium* infection in primary schoolchildren. Community water profiles, in combination with self-reported water-related behaviors, can help elucidate reasons for some endemic communities continuing to experience ongoing transmission and tailor interventions to these local contexts to achieve sustainable control.

Graphical abstract

Keywords

schistosomiasis; self-reported risk factors; swimming; fetching water; improved water access; surface water access; water quality; interventions

1. Introduction

Schistosomiasis infections cause a significant health burden in low-income countries, especially among school-aged children. Being a disease of poverty, 97% of all infections and 85% of the global population at risk are concentrated in Africa (Steinmann et al., 2006). Ghana is endemic, with an estimated country-wide prevalence of 23.3% (Lai et al., 2015), and focal prevalence levels $>50\%$ (Steinmann et al., 2006; Utzinger et al., 2009). *Schistosoma haematobium* is the most commonly occurring schistosome species in Ghana (Lai et al., 2015) and is the subject of this study. *S. haematobium* infections often present with symptoms of hematuria as parasite eggs are excreted through the bladder, and is associated with increased risk of HIV (Brodish and Singh, 2016; Kjetland et al., 2014; Ndeffo Mbah et al., 2013; Secor, 2012) and bladder cancer later in life if the infection remains untreated (Gryseels et al., 2006; Palumbo, 2007).

Part of the *S. haematobium* life cycle takes place in freshwater bodies that are contaminated with human waste and that harbor *Bulinus* snails which serve as an intermediate host. Snails are infected by miracidia that are released from parasite eggs excreted in urine of infected individuals. Human infections occur when cercariae released by the snails penetrate intact skin during water-related activities (Gryseels et al., 2006). Infections most commonly occur in populations that rely on lakes, rivers, and streams for domestic, recreational, and occupational water-based activities such as laundry, bathing, swimming, fishing, washing cars, etc. (Colley et al., 2014).

The infection is treatable by the drug praziquantel, and periodic school-based deworming is the predominant control strategy in Ghana and in other African countries (Doenhoff et al., 2008). However, reinfection is common in resource-poor areas with insufficient access to improved water, sanitation, and hygiene (WASH) infrastructure and extensive reliance on surface water for daily needs. Therefore, WASH improvements have gained prominence as a complementary strategy to preventive chemotherapy (Campbell et al., 2014; Colley et al., 2014; Secor, 2014; Pullan et al., 2014), supported by the recent meta-analysis, which found safe water supplies and adequate sanitation facilities to be significantly associated with lower schistosomiasis risk (Grimes et al., 2014). If designed and implemented appropriately, WASH improvements can interrupt schistosomiasis transmission. Importantly though, schistosomiasis transmission is entrenched in complex socio-ecological systems of cultural and environmental factors (Grimes et al., 2015) that influence water use patterns and transmission profiles. These community-specific factors and their bearing on the effectiveness and sustainability of WASH interventions in schistosomiasis control are still relatively poorly understood.

To target endemic communities with interventions, reliable information about the geographic and demographic distribution of schistosomiasis cases is required. Due to the limitations of disease surveillance and reporting systems in low-income countries (Liang et al., 2014; Wrable et al., 2019), field-based prevalence surveys remain a necessary component of schistosomiasis monitoring and control. Field-based diagnostic methods such as parasite egg counts, hematuria detection via a reagent strip, and blood in urine symptom questionnaires continue to be used despite their high cost and low sensitivity in lightly infected populations that participate in regular deworming (Doenhoff et al., 2004; Knopp et al., 2013; Kosinski et al., 2011). It is necessary to continue to develop and refine reliable and cost-effective surveillance strategies to inform decisions as to where, when, and among which demographic groups to deploy preventive chemotherapy and other interventions (Knopp et al., 2013; Kosinski et al., 2016a; WHO, 2012).

We conducted a *S. haematobium* prevalence survey in 30 rural communities in the Eastern region of Ghana with multiple diagnostic and screening methods (presence of parasite eggs in urine; microhematuria; self-reported macrohematuria, swimming, and fetching water from local surface water bodies). The first objective was to assess the associations among various measured and self-reported prevalence metrics in the presence of routine school-based deworming with praziquantel. The second objective was to assess the associations between community water characteristics (safe water access, surface water access, and groundwater quality), self-reported water-related behaviors, and *S. haematobium* infection and to propose

potential interventions that account for these community-specific social and environmental factors.

2. Methods

2.1 Study design and recruitment

The study was conducted in 30 rural communities (population range 800 to 5,000) from 10 administrative districts of the Eastern region, Ghana (Figure 1). The region was selected due to the existing knowledge of endemic communities with extensive reliance on surface water from prior studies (Kosinski et al., 2012, 2016a, b; Kulinkina et al., 2016, 2017a). The 30 communities for this study were randomly selected from 74 communities for which water characteristics were available (Kulinkina et al., 2017a).

In advance of the study, letters of approval were obtained from national and regional offices of Ghana Education Service (GES) and Ghana Health Service (GHS). District-level GES and GHS offices were also notified. Subsequently, letters describing the study activities were delivered to members of the traditional leadership and the head teacher of the largest primary school in each community. Upon receiving the letters in June 2015, the community leaders and school teachers were encouraged to inform parents that their children may be asked to participate in the upcoming study using their regular means of communication (e.g. town meetings, announcements, parent-teacher meetings, etc.). Parents were asked to contact the school and/or members of the study team if they had questions or wished to exclude their children from the study activities.

It is important to note that most of the study communities had more than one primary school, of which the largest school was selected. The validated assumption that underlies this sampling method is that where a child lives and attends school are not spatially dependent, suggesting that schistosomiasis prevalence measured in one school is representative of community-level prevalence (Kulinkina, 2017).

On days of data collection (November 2 – 15, 2015), the head teacher or acting head teacher of each participating school provided written consent for the study on behalf of the parents. Verbal assent was sought from the children following a detailed explanation of the study, making it clear that participation was voluntary and anonymous, and that children could opt out at any time. The opt-out approach has been previously approved as an ethical and practical way of informing participants in similar low-risk studies (Kosinski et al., 2011). A total of 30 children (15 boys and 15 girls) were randomly selected from grades 3 and 4 attendance registers in each school. Study activities included answering three yes/no questions and providing a urine sample for analysis. This study was approved by the Institutional Review Board (IRB) at Tufts University in Boston, United States of America (protocol #11688) and the Noguchi Memorial Institute for Medical Research in Accra, Ghana (protocol #1133).

2.2 Primary data collection

Children who assented to study participation were given a paper survey (different colors for boys and girls) and a urine sample container, labeled with matching, unique IDs. The survey

questions were written in English and translated verbally one by one into Twi by a native speaker. Study participants were asked to circle “yes” or “no” in response to the following three questions: (1) Do you fetch water to bring home from a river, stream or pond near your town? (2) Do you swim in a river, stream or pond near your town? and (3) Have you seen blood in your urine in the past two weeks? A simple illustration accompanied each question to aid in the understanding and ordering of the questions. No identifying information was collected about the participants.

Upon completion of the written survey, participants received entertaining demonstrations on how to collect the terminal drops of urine, which are more likely to contain blood, into the collection cup. Subsequently, they were asked to go to their regular place of urination and bring back at least 10 mL of urine for testing. All urine samples were tested on-site for hematuria via a semi-quantitative reagent strip test and subsequently categorized as a binary variable, with any blood presence coded as a positive reading (Kosinski et al., 2011). Urine samples were also tested for *S. haematobium* eggs off-site using filtration methods of 10 mL of the urine sample (Kosinski et al., 2012) and subsequently categorized as a binary variable with 1 egg/10 mL of urine coded as “presence”. All samples were collected between the hours of 10:00 and 14:00 and analyzed within 8 hours of collection. Treatment with praziquantel by weight in a private location was offered to any child experiencing hematuria by a local GHS nurse or community health worker accompanying the study team. All study activities occurred in public spaces (except for treatment to keep infection status confidential) and under observation of the study lead and the school teachers. Safeguarding practices were in place to ensure that children were treated with respect and protected from abuse or any negative consequences of participating in the study.

2.3 Secondary data sources

To achieve the study objectives, primary data described in Section 2.2 were combined with secondary data from two additional sources. These included information about the timing and coverage of praziquantel distribution, which affected prevalence measures, and about the distribution of available water sources (infectious and non-infectious) that influenced community transmission profiles.

2.3.1 School-based praziquantel distribution—School-based deworming records were obtained from GHS. Approximately one year prior to the study (December/January 2014), preventive chemotherapy with praziquantel, albendazole, and mebendazole was conducted by GHS and GES in the Eastern region. Six of the study districts participated, including 21 of the 30 schools (Table 1), with average treatment coverage of 80%, ranging from 14% to 100%. Another round of praziquantel treatment occurred immediately after the study in December/January 2015, which included all of the study schools, with similar average treatment coverage (83%), ranging from 44% to 100% (unpublished GHS data, 2015).

2.3.2 Community water sources—Prior studies showed that most of the study communities relied on a combination of water sources, including deep groundwater (boreholes or piped water systems), shallow groundwater (hand-dug wells), surface water,

and privately collected rainwater (Kulinkina et al., 2017a). The use of schistosome-free groundwater sources was mediated by groundwater quality, specifically elevated iron concentration and excess salinity (Kulinkina et al., 2017b). Groundwater sources with these primarily aesthetic problems caused them to be abandoned or underutilized in preference of abundant surface water. As such, elevated groundwater iron concentration was also identified as a significant risk factor for *S. haematobium* infection in a spatial modeling study (Kulinkina et al., 2018). Community water profiles were obtained from prior studies with the intention of examining why some of the communities continue to have *S. haematobium* prevalence >40% despite regular praziquantel distribution.

The available variables included access to an improved water source (IWS) within 300 meters, access to a surface water source (SWS) within 300 meters, and presence of a groundwater quality (GWQ) problem. Improved water sources are incapable of transmitting schistosomiasis and include communal standpipes on piped water systems, drilled boreholes, and protected hand-dug wells, in accordance with the WHO and UNICEF's Joint Monitoring Programme definition (UN, 2003). Surface water sources often can sustain transmission and include access points (or specific places that were in use by the local population) on rivers, streams, lakes, or ponds. As mentioned above, two GWQ problems known to positively influence surface water use in the study area included elevated iron concentration and excess salinity (Kulinkina et al., 2017b).

2.4 Data analysis

The first study objective was to assess the agreement between *S. haematobium* egg presence and four other metrics: hematuria presence and self-reported hematuria, swimming, and fetching. This objective was achieved using a nonparametric Kendall τ_b test (Kendall, 1938; PennState, 2018) on the full sample (N=897) and stratified by community (n=30). Correlation analysis was followed by mixed effects logistic regression models to determine which metrics were significant predictors of egg presence, after accounting for the clustering of observations by community. The models were conducted for boys and girls separately and for all children combined to assess the potential effect of gender. *S. haematobium* infection rates were also compared between schools that participated in the deworming exercise and those that did not, using the nonparametric Mann-Whitney U test on aggregated school-level prevalence and univariate logistic regression on individual-level binary data. All data analysis was conducted in R software (version 3.4.3).

The second study objective was to assess the associations between community water characteristics, self-reported water-related behaviors, and *S. haematobium* infection. To achieve this objective, data about improved water access, surface water access, and groundwater quality problems were used to examine communities in terms of their transmission profile and to develop suites of recommended interventions to specifically target each type of profile.

Prevalence.—Communities with >10% prevalence of eggs in urine were categorized as moderate-prevalence communities, and those with ≤10% prevalence were classified as low-prevalence communities.

Self-reported water-related behaviors.—Self-reported fetching and swimming were summarized at the community level and categorized to represent high, medium, and low transmission risk if ≥75%, 50-74%, and <50% of the school children reported performing the water-related behavior, respectively.

Community water characteristics.—Three community water characteristics were also categorized to represent low, moderate, or high schistosomiasis transmission risk. IWS access was categorized as high (risk score = 1) if ≥75% of the residents had access to a functional IWS within 300 m, moderate (risk score = 2) if 50-74% had access, and low (risk score = 3) if <50% had access. SWS access was categorized as high (risk score = 3) if ≥75% of the residents had access to a SWS within 300 m, moderate (risk score = 2) if 50-75% had access, and low (risk score = 1) if <50% had access. Severity of GWQ problems was considered high (risk score = 3) if the community had elevated groundwater iron concentration, which negatively affects taste and suitability of the water for washing and cooking, moderate (risk score = 2) if excess salinity was present, and low (risk score = 1) if the community had no GWQ problems (Kulinkina et al., 2017b). Community-level risk scores were explored as categorical predictors of egg presence and self-reported water-related behaviors at the individual level in logistic regression models, with risk score of 1 serving as the reference category.

3. Results

3.1 *Schistosoma haematobium* prevalence

A total of 900 children (15 boys and 15 girls from 30 primary schools) were enrolled into the study. Only two children were excluded from the study by their teachers during enrollment for religious reasons or physical disability that made the child unable to participate. Of the 900 children who enrolled, 897 completed the study by returning a complete written survey and a urine sample. Of the 897 children who provided complete data, 128 (14%) had ≥1 *S. haematobium* egg per 10 mL of urine. Prevalence of eggs in urine varied among schools from 0% to 45% (Table 1, Figure 1). Individual infection intensities ranged from 1 to 2,800 eggs/10 mL (mean = 103; median = 21); 5% of the children (41/897) had heavy infections (> 50 eggs/10 mL). A total of 137 children (15%) had measured hematuria; school-level prevalence ranged between 0% and 45%. The overall prevalence of self-reported hematuria, swimming, and fetching of surface water were 26%, 65%, and 76%, respectively, and varied among schools (Table 1).

There was no difference between the mean egg prevalence in schools that participated in school-based praziquantel distribution one year prior to the study and those that did not participate. Average prevalence of eggs in urine at the school level was 13.5% (SD = 12.9%) in the 21 schools that participated in praziquantel distribution, as compared to 15.9% (SD = 13.4%) in the 9 schools that did not participate ($p>0.05$). Similarly, no association was observed in a univariate logistic regression model conducted at the individual level with binary presence of eggs as the outcome variable and belonging to a school that did or did not receive praziquantel as the predictor variable ($p>0.05$).

3.2 Associations among prevalence metrics

School-wide prevalence values (%) of eggs in urine and microhematuria were compared using a Spearman's rank correlation test. Correlation values were 0.96 ($p < 0.001$) overall, 0.96 ($p < 0.001$) for boys, and 0.90 ($p < 0.001$) for girls. Scatter plots (Figure S1, Supporting Information) showed that the values were tightly clustered around the line of equality, meaning that at an aggregated level, prevalence of microhematuria as measured using the reagent strip is a good proxy for prevalence of eggs in urine measured using filtration. The self-reported metrics performed poorly, with low correlation coefficients (not all statistically significant) and significant deviations from the line of equality (Figure S1, Supporting Information).

The Kendall τ_b coefficient between binary egg presence and microhematuria status for individual children was also relatively high 0.88 ($p < 0.001$). Weaker associations were observed between egg presence and self-reported hematuria ($\tau_b = 0.25$; $p < 0.001$) and self-reported swimming ($\tau_b = 0.12$, $p < 0.001$), while self-reported fetching did not exhibit any association with egg presence ($\tau_b = 0.05$, $p > 0.05$) (Table S1, Supporting Information). Associations between microhematuria presence and the self-reported metrics were essentially identical to those with egg presence. Furthermore, self-reported hematuria was mildly correlated with self-reported swimming ($\tau_b = 0.12$, $p < 0.001$) and self-reported swimming with self-reported fetching ($\tau_b = 0.17$, $p < 0.001$).

Kendall τ_b coefficients were also computed for each school. Correlations between egg and hematuria presence were high in all schools (0.64 – 1.00, $p < 0.001$). Correlations between egg presence and self-reported hematuria were only moderately high (0.39 – 0.52, $p < 0.05$) in four schools. Correlations between egg presence and self-reported swimming were in some cases positive (0.48; $p < 0.05$ in Moseaso) and in some cases negative (–0.47; $p < 0.05$ in Boma). Correlations between egg presence and self-reported fetching varied in direction, were primarily low in magnitude, and not statistically significant (Table S1, Supporting Information).

A series of mixed effects logistic regression models were conducted to predict the presence of eggs in urine, with a base model including only a random effect for community ID, and each subsequent model containing combinations of other binary predictor variables (Table 2). The base model explained 13% of the variability in the data overall, with a slightly higher R^2 value for boys (0.22) than for girls (0.14). Hematuria status, as tested by the reagent strip (model 1), was a better predictor than the three self-reported metrics (model 2) with much higher R^2 values (0.78 vs. 0.19). Children with hematuria were 2.35 (CI_{95%}: 2.27, 2.42) times as likely to have *S. haematobium* eggs in their urine as those who did not, with a slightly higher OR for boys (2.46; CI_{95%}: 2.36, 2.57) than for girls (2.18; CI_{95%}: 2.09, 2.28). The addition of self-reported metrics (model 3) did not improve model performance. When only self-reported predictors were used (model 2), self-reported hematuria was a significant predictor for boys (OR=1.16; CI_{95%}: 1.08, 1.24) and for girls (1.21; CI_{95%}: 1.13, 1.29), self-reported swimming only for boys (OR=1.09; CI_{95%}: 1.02, 1.18), and self-reported fetching was not significant for either.

3.3 Community water characteristics

Examination of community water profiles showed that 24 of 30 (80%) communities had relatively good access to improved water (>50% of the population living within 300 meters of a functional IWS). Six communities, however, did not score well in IWS access (Table S2, Supporting Information). Five of these six communities struggled with borehole functionality. For example, in Krodua and Breman, there were no functional IWS at the time of the study. These communities relied exclusively on water obtained from the Ayensu River (Figure 1); hence 87–93% of the surveyed children in these towns reported fetching river water and *S. haematobium* prevalence was 10% and 17%, respectively. Similarly, in Awaham and Bomso, as well as Oda-Nkwanta, >60% of the boreholes were not functioning at the time of the study. In Awaham and Bomso, approximately 80% of the children reported fetching water from local streams, resulting in *S. haematobium* prevalence of 20%. In Oda-Nkwanta, where surface water is less abundant, only 23% reported fetching and prevalence was much lower at 3% (Table S2, Supporting Information).

Even in communities with very high improved water access like Mepom, that has a piped water system giving 99% of the population access to a communal standpipe within 300 m, there were 7 surface water access points and 87% of the children reported fetching water from these locations due to groundwater salinity. Similar salinity problems were present in 8 other study communities. High groundwater iron concentrations have also been shown to propagate surface water use. For example, Bansa also has high improved water access, with 97% of the population living within 300 m of a borehole. However, very high iron concentrations (up to 2.5 mg/L as compared to the WHO standard of 0.3 mg/L) result in 100% of the children fetching surface water for domestic use and 37% *S. haematobium* prevalence (Table S2, Supporting Information).

Lastly, there were several communities where recreational water use was very common, regardless of the other dimensions we measured. Examples of rivers from four communities in which >65% of the children reported swimming are depicted in Figure 2. *S. haematobium* prevalence in these communities ranged between 17% and 45%.

3.4 Associations with community water profiles

A summary heat map of the information presented in Table S2 in Supporting Information revealed that in general, moderate prevalence communities tended to have lower IWS access, higher SWS access, and higher prevalence of GWQ problems (risk scores of 2 or 3), as compared to low prevalence communities (Figure 3). Consequently, higher rates of swimming and fetching surface water (>50%) were also observed in moderate prevalence communities.

Logistic regression revealed that IWS score was not a significant predictor of self-reported fetching or swimming (Table 3). On the other hand, SWS and GWQ scores of 2 (but not 3) were associated with a higher likelihood of fetching and swimming. School children living in communities with 50–74% of the population having access to a SWS within 300 m were 2.54 times (CI_{95%}: 1.66, 3.89) and 1.54 times (CI_{95%}: 1.11, 2.15) as likely to self-report fetching surface water and swimming, respectively, as those living in communities with less

than 50% of the population having SWS access within 300 m (reference category). School children living in communities with saline groundwater were 2.41 times (CI_{95%}: 1.59, 3.65) and 1.47 times (CI_{95%}: 1.04, 2.08) as likely to self-report fetching surface water and swimming, respectively, as compared to those living in communities with no GWQ problems (reference category).

Similarly, IWS score was not, but SWS and GWQ scores were associated with presence of *S. haematobium* eggs in urine. Children who lived in communities with 75% or more of the population having SWS access within 300 m were 1.81 times (CI_{95%}: 1.08, 3.03) as likely to have eggs in urine as those in the reference category. Furthermore, children living in communities with excess groundwater salinity were 1.94 times (CI_{95%}: 1.20, 3.13) and those living in communities with elevated iron concentration were 1.72 times (CI_{95%}: 1.07, 2.76) as likely to have eggs in urine as those in the reference category.

3.5 Recommended interventions

Based on the water profile characteristics, we proposed potential interventions for each community. The interventions included provision of additional improved water sources in communities with low IWS access, education on water-related disease risk posed by extensive reliance on untreated surface water in communities with high SWS access, and provision of water treatment in communities with GWQ problems. According to these criteria, 14 communities required additional IWS, 12 required health education, and 19 required water treatment (Figure 3).

Some communities required a combination of interventions to adequately address risk factors for ongoing schistosomiasis transmission; thus, each of the 30 study communities was further assigned to one of eight groups of recommended interventions (Figure 4). The most common group (high IWS access, low SWS access, and GWQ problems) included six communities, and was most suited for water treatment interventions. The second two equally common groups included five communities each, where additional IWS provision with water treatment, or water treatment with education were needed. A total of three communities qualified for all three interventions, and four communities did not fit the criteria for any of the proposed interventions. Two of these four communities (Adarkwa and Ayeh Kokoso) had *S. haematobium* prevalence of 10% despite having an unfavorable community water profile for sustaining transmission: high IWS access, low SWS access, and no GWQ problems. Further investigation into these communities is necessary to determine appropriate alternative interventions.

4. Discussion

The study illustrates that despite regular, recent treatment with praziquantel, the reagent strip test for microhematuria correlates well with egg presence at the individual and school levels and remains a reasonable inexpensive proxy of *S. haematobium* infection in endemic areas. Furthermore, self-reported measures of macrohematuria and swimming were significant predictors of infection at the individual level, similar to the findings of a prior study (Kosinski et al., 2016a); however, their predictive power was low, so they should be interpreted with caution and locally validated before use in other settings. The low

correlation of *S. haematobium* egg presence with self-reported hematuria was potentially caused by the predominance of light infections, which young children were less likely to notice as bloody urine. The low correlation with swimming may have been attributed to children being less likely to report this controversial behavior despite the anonymous nature of the survey questions, because it is banned in many of the study communities by traditional leaders.

Counter to the findings of a recent study in Ethiopia, which showed that fetching surface water for school use was associated with higher *S. mansoni* infection intensity (Grimes et al., 2016), our study did not detect an association between fetching surface water for domestic use and *S. haematobium* infection. Although the two studies are not directly comparable to each other in their methodology and the schistosome species under study, the lack of association between fetching and infection status was surprising. We hypothesize it may have been caused by most of the children (76%) reporting this behavior, causing a lack of variability in the dataset.

Most of the infections in the study were light infections, with only 5% of the children experiencing heavy infections (>50 eggs/10 mL of urine). This number is still too high, as compared to the goal of 1% or lower according to the global morbidity control strategy (Lo et al., 2016). Nearly 25% of the heavy infections were observed in a single community (Mankrong) that had not been included in the school-based treatment schedule in 2014. However, approximately half of the heavily infected children came from communities that did experience treatment. This suggests that treatment coverage may be insufficient; the doses may be too low to fully clear the infections; there is inadequate follow-up of children who are absent during treatment; parents of children with infections may be opting out of treatment; or more frequent treatment than once per year may be necessary.

Overall, one third of the study communities (10 of 30) had relatively high prevalence levels of *S. haematobium* infections (20–45%) one year after treatment. It should be noted that despite good correlation with each other, the sensitivity of both egg counts and reagent strips is likely poor in a lightly infected population and actual prevalence values are expected to be substantially higher than those observed in the study (Kosinski et al., 2011). Although self-reported data were of limited utility in predicting individual infection status based on the results of a single urine sample, they are useful in describing community-level risk profiles. High reinfection rates are very likely in these communities due to widespread fetching of surface water (70–100%) and swimming (40–87%); however, reinfection rates were not specifically measured in this study. Analysis of community water profiles suggests that reliance on surface water manifests from a variety of factors, including abundance of rivers and streams, insufficient IWS access, borehole functionality issues, and GWQ problems.

Counter to the findings of a meta-analysis by Grimes et al. (2014), our study showed that availability of safe water supplies was not associated with a reduced risk of *S. haematobium* infection. Unsatisfactory quality of these water sources for domestic purposes, coupled with an abundance of surface water, both significant risk factors of *S. haematobium* infection in the regression model, likely negate the benefits of safe water supplies in the study area. Communities like Mepom and Bansa described in the results section serve as examples of

this dynamic. Over fifty years ago, Farooq (1966) studied the effect of water supplies on both *S. mansoni* and *S. haematobium* and illustrated the complexity of water use behavior and simultaneous use of several different water sources. Our study illustrates that this complexity still exists today in rural Ghanaian communities.

From the water profiles, eight potential combinations of interventions emerged. It should be noted that these interventions focus on only one component of transmission: improving the community water profile to discourage surface water use. Increasing utilization of safe water sources and reducing reliance on surface water can be achieved in several ways: fixing the existing broken boreholes or drilling more boreholes in locations with good groundwater quality; treating groundwater from existing boreholes to remove excess iron and salinity; treating surface water using the conventional water treatment processes to make it safe for drinking and other household uses, as well as safe from schistosomes (Braun et al., 2018); and health education about the risks and benefits of using various water sources.

The proposed water treatment intervention refers to groundwater treatment; the study did not assess suitability of surface water treatment as an intervention due to the focus on groundwater. However, this is a viable option in communities located on large rivers, especially those with known groundwater quality challenges. Although targeted health education was specified only for communities with abundant surface water sources to discourage their use, it is likely that it would benefit all communities as some surface water is available throughout. Furthermore, exploring additional components of the transmission profile described below to identify alternative interventions is required.

In terms of evaluating all possible means of reducing or eliminating schistosomiasis risk, the study has several limitations that can become subjects of future studies. First, the proposed interventions focus on limiting human surface water contact as a means of disease prevention, while it is also known that sanitation improvements to reduce contamination of water bodies with human waste, as well as snail control methods to reduce the intermediate host population can also interrupt transmission (Secor, 2014).

Second, the proposed interventions primarily concern reducing reliance on surface water for domestic use, but recreational water contact also occurs in many of the study communities. The recommended interventions are unlikely to affect transmission risk in communities with a well-established swimming culture. Construction of a swimming pool has been successfully used in Adasawase, a rural Eastern region community in our study area (Kosinski et al., 2011; Kosinski et al., 2012). This intervention may provide a preferred recreational alternative for similar communities with a single small swimming hole, but not likely for those with large flowing rivers with multiple fetching and swimming locations like those shown in Figure 3. Furthermore, occupational activities such as fishing, rice farming, and alluvial gold mining are prevalent in some of the study communities and may necessitate the use of boots and gloves to prevent exposure.

Third, the focus of the proposed interventions on providing safe water alternatives for domestic use is likely more nuanced than what is presented in the study. For example, some communities may be using surface water primarily for laundry or for bathing, in which case

installation of washing stations or bathing/showering facilities (Grimes et al., 2015) along with hand-dug wells may be a lower cost alternative to drilling boreholes in locations with suitable depth to groundwater and adequate shallow groundwater quality. Lastly, seasonality of water use patterns is important to consider when implementing many of these interventions to ensure year-round reduction in exposure and long-term sustainability of the associated infrastructure.

5. Conclusions

The study illustrates that despite regular school-based treatment with praziquantel, some endemic communities continue to experience ongoing schistosomiasis transmission. Control efforts require new inexpensive diagnostic and disease surveillance tools to obtain reliable information about geographic and demographic distribution of infections and to monitor effectiveness of interventions. Meanwhile, hybrid approaches comprised of questionnaires and screening show promise in gaining insight into local drivers of transmission. The study showed that when considering water infrastructure improvements as a means of reducing reliance on surface water and thereby reducing schistosomiasis risk, availability of surface water sources and water quality in improved water sources according to the local perceptions are more important than access to safe water. It is now widely accepted that improved WASH is a necessary complement to preventive chemotherapy to achieve sustainable control and move towards elimination of schistosomiasis in sub-Saharan Africa. However, further studies are needed to comprehensively evaluate WASH intervention alternatives and their fit for specific types of communities and transmission profiles to ensure successful implementation and lasting impact.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights:

- Despite regular school-based praziquantel treatment, prevalence >40% persists.
- Positive reagent strip test for hematuria remains a good proxy of infection status.
- Self-reported hematuria, swimming, and fetching are poor proxies of infection status.
- Abundant surface water and poor groundwater quality are risk factors for infection.
- Community water profiles offer important context for tailoring WASH interventions.

Figure 1.

Map of the study area and spatial distribution of *S. haematobium* egg prevalence (%) in 30 schools across 10 districts. Figure was created from the following data sources: Major rivers and town locations were obtained from CERGIS, Accra, Ghana; hillshade relief surface was created from elevation data obtained from ASTER Global Digital Elevation Model (v2); prevalence data were collected by A. Kulinkina.

Figure 2.
Examples of rivers with the corresponding % of children who self-report swimming: (A) Mankrong – 66%; (B) Awaham – 79%; (C) Banso – 73%; (D) Nyanoa – 87%.

Figure 3.
Heat map of community water characteristics and proposed potential interventions.

N	IWS access	SWS access	GWQ problem	characteristic summary	recommended intervention
6	↑↑↑↑	↓	●	↑↑↑ high	provision of IWS
5	↑↑↑↑	↑↑↑↑	●	↑↑↑ moderate/high	health education
5	↑↑	↓	●	↑↑ low/moderate	provision of GW treatment
4	↑↑↑↑	↓	○	↓ low	
3	↑↑	↓	○	○ absent	
3	↑↑	↑↑↑↑	○	● present	
3	↑↑	↑↑↑↑	●		
1	↑↑↑↑	↑↑↑↑	○		

Figure 4.
Potential interventions developed from community water characteristics.

Table 1:

Summary of *S. haematobium* prevalence (eggs and blood in urine) and self-reported metrics (hematuria, swimming, and fetching of surface water) among school children in 30 communities in the Eastern region, Ghana (November 2015).

Community	Population #	Sample size Total [M F]	Eggs in urine N % [range]	Hematuria N %	SR hematuria N %	SR swim N %	SR fetch N %
Mankrong	1,166	29 [14 15]	13 45 [6-449]	12 41	11 38	19 66	21 72
Asamama *	2,888	30 [15 15]	13 43 [2-176]	13 43	19 63	26 87	26 87
Akim-Kokoben *	1,773	30 [15 15]	11 37 [1-400]	12 40	15 50	20 67	21 70
Banso *	2,587	30 [15 15]	11 37 [2-52]	10 33	8 27	22 73	30 100
Kuano	1,732	30 [15 15]	9 30 [1-547]	10 33	5 17	12 40	28 93
Okorase *	3,415	29 [15 14]	6 21 [17-1464]	6 21	4 14	23 79	27 93
Awaham *	1,949	30 [15 15]	6 20 [8-2800]	8 27	13 43	25 83	25 83
Bomso *	1,817	30 [15 15]	6 20 [2-267]	6 20	10 33	22 73	24 80
Dome	810	30 [15 15]	6 20 [10-803]	8 27	7 23	21 70	24 80
Kyekyewere	995	30 [15 15]	6 20 [7-385]	4 13	10 33	26 87	25 83
Nyanoa *	1,978	30 [15 15]	5 17 [7-222]	6 20	5 17	26 87	28 93
Breman *	1,633	30 [15 15]	5 17 [2-169]	4 13	10 33	26 87	26 87
Kwasi Nyarko *	1,519	29 [15 14]	4 14 [1-26]	4 14	6 21	17 59	26 90
Topremang *	5,004	30 [15 15]	4 13 [3-17]	4 13	11 37	20 67	20 67
Krodua *	1,952	30 [15 15]	3 10 [14-51]	4 13	10 33	25 83	28 93
Adarkwa	1,181	30 [15 15]	3 10 [2-12]	4 13	7 23	14 47	12 40
Ayeh Kokoso	884	30 [15 15]	3 10 [18-42]	3 10	4 13	20 67	26 87
Bomaa *	1,127	30 [15 15]	3 10 [2-379]	5 17	10 33	20 67	21 70
Abakoase *	2,829	30 [15 15]	2 7 [10-50]	4 13	5 17	21 70	20 67
Abenaso *	1,803	30 [15 15]	2 7 [13-36]	2 7	5 17	27 90	27 90
Moseaso *	3,176	30 [15 15]	2 7 [1-2]	1 3	4 13	7 23	22 73
Otchereso	5,196	30 [15 15]	2 7 [20-107]	3 10	4 13	15 50	25 83
Mepom *	5,132	30 [15 15]	1 3 [162]	3 10	8 27	15 50	26 87
Oda-Nkwanta	4,366	30 [15 15]	1 3 [90]	3 10	9 30	13 43	7 23
Topaase *	1,868	30 [15 15]	1 3 [1]	3 10	5 17	16 53	10 33
Adubiase	2,632	30 [15 15]	0 0 [--]	0 0	5 17	19 63	19 63
Asikasu *	3,436	30 [15 15]	0 0 [--]	0 0	5 17	12 40	24 80
Dwenase *	2,205	30 [15 15]	0 0 [--]	0 0	12 40	22 73	27 90
Ekoso *	4,533	30 [15 15]	0 0 [--]	0 0	5 17	15 50	13 43
Tweapease *	3,333	30 [15 15]	0 0 [--]	1 3	7 23	15 50	27 90
All	2,500	897 [449 448]	128 14 [1-2800]	137 15	239 26	581 65	685 76

* Communities/schools that participated in deworming conducted 11 months prior to the study by GES/GHS. Treatment coverage ranged between 14% in Ekoso to 100% in Dwenase, Topremang, and Bomso as reported by GHS.

[#]Estimated 2015 population is presented that was projected from the 2000 Census data using the 2.1% annual population growth.

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Table 2.

Results of three mixed effects logistic regression models predicting the likelihood of having *S. haematobium* eggs in urine as a function of measured and three self-reported metrics (shown in first column) for three populations (shown in top row).

	All	Boys	Girls
Model 1	[R ² = 0.78]	[R ² = 0.81]	[R ² = 0.75]
Measured hematuria (reagent strip)	2.35 (2.27, 2.42) ***	2.46 (2.36, 2.57) ***	2.18 (2.09, 2.28) ***
Model 2	[R ² = 0.19]	[R ² = 0.24]	[R ² = 0.17]
Self-reported hematuria	1.19 (1.13, 1.25) ***	1.16 (1.08, 1.24) ***	1.21 (1.13, 1.29) ***
Self-reported swimming	1.05 (1.01, 1.11) *	1.09 (1.02, 1.18) *	1.01 (0.96, 1.07)
Self-reported fetching	1.00 (0.95, 1.05)	0.98 (0.91, 1.06)	1.04 (0.97, 1.12)
Model 3	[R ² = 0.78]	[R ² = 0.81]	[R ² = 0.75]
Measured hematuria (reagent strip)	2.33 (2.26, 2.40) ***	2.45 (2.35, 2.56) ***	2.16 (2.06, 2.26) ***
Self-reported hematuria	1.02 (1.00, 1.05)	1.00 (0.97, 1.04)	1.04 (1.00, 1.08) *
Self-reported swimming	1.01 (0.98, 1.03)	1.02 (0.98, 1.06)	0.99 (0.96, 1.02)
Self-reported fetching	1.00 (0.97, 1.02)	0.98 (0.95, 1.02)	1.02 (0.99, 1.06)

*
p < 0.05;

**
p < 0.01;

p < 0.001

Table 3.

Results of univariate logistic regression models predicting three outcomes (shown in top row) with the three community water characteristic scores (shown in first column).

	SR fetching	SR swimming	Eggs in urine
IWS score (ref = 1)	[R ² = 0.01]	[R ² = 0.01]	[R ² = 0.01]
Score 2	1.23 (0.84, 1.78)	1.19 (0.86, 1.65)	1.22 (0.79, 1.87)
Score 3	0.97 (0.65, 1.45)	1.42 (0.98, 2.06)	0.91 (0.55, 1.52)
SWS score (ref = 1)	[R ² = 0.03]	[R ² = 0.01]	[R ² = 0.01]
Score 2	2.54 (1.66, 3.89) ***	1.54 (1.11, 2.15) *	1.30 (0.84, 2.01)
Score 3	0.80 (0.52, 1.24)	0.98 (0.65, 1.48)	1.81 (1.08, 3.03) *
GWQ score (ref = 1)	[R ² = 0.02]	[R ² = 0.01]	[R ² = 0.01]
Score 2	2.41 (1.59, 3.65) ***	1.47 (1.04, 2.08) *	1.94 (1.20, 3.13) **
Score 3	1.22 (0.86, 1.74)	1.08 (0.78, 1.49)	1.72 (1.07, 2.76) *

*
p < 0.05;

**
p < 0.01;

p < 0.001