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REVIEW

Gender-based differences in water, sanitation and hygiene-related diarrheal disease and helminthic infections: a systematic review and meta-analysis

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Background: Qualitative evidence suggests that inadequate water, sanitation and hygiene (WASH) may affect diarrheal and helminthic infection in women disproportionately. We systematically searched PubMed in June 2014 (updated 2016) and the WHO website, for relevant articles.

Methods: Articles dealing with the public health relevance of helminthic and diarrheal diseases, and highlighting the role of gender in WASH were included. Where possible, we carried out a meta-analysis.

Results: In studies of individuals 5 years or older, cholera showed lower prevalence in males (OR 0.56; 95% CI 0.34–0.94), while *Schistosoma mansoni* (1.38; 95% CI 1.14–1.67), *Schistosoma japonicum* (1.52; 95% CI 1.13–2.05), hookworm (1.43; 95% CI 1.07–1.89) and all forms of infectious diarrhea (1.21; 95% CI 1.06–1.38) showed a higher prevalence in males. When studies included all participants, *S. mansoni* and *S. japonicum* showed higher prevalence with males (OR 1.40; 95% CI 1.27–1.55 and 1.84; 95% CI 1.27–2.67, respectively). Prevalence of *Trichiuris* and hookworm infection showed effect modification with continent.

Conclusions: Evidence of gender differences in infection may reflect differences in gender norms, suggesting that policy changes at the regional level may help ameliorate gender related disparities in helminthic and diarrheal disease prevalence.

Keywords: Diarrhea, Gender, Helminths, Sanitation, Water

Introduction

Improper feces disposal can lead to consumption of food and water contaminated with enteric pathogens and helminth ova, thereby resulting in infection.[1] Skin contact with fecally contaminated soil and water can result in schistosomiasis and hookworm infection.[2] Preventing open defecation and ensuring hygienic management of drinking water and food can reduce the risk of infection from these infectious pathogens.[3]

Although impressive improvements in water and sanitation access occurred between 1990 and 2015, disparities in water and sanitation access exist. For example, globally, urban populations have higher access to improved drinking water sources than rural communities (96% of urban population vs 84% of rural population) and eight out of 10 people lacking access to improved sanitation facilities live in rural areas.[4,5]

Aside from rurality, gender is also a major source of inequality in safe water and sanitation access.[6] Women may not benefit from sanitation access as often as men, and thus may practice open defecation more often than men.[7,8] Globally, approximately 500 million women defecate in the open.[4,9]

Open defecation could increase the amount of time that women spend in environments that harbor parasites, thereby leading to increased risk of infections.[4,10] Women also perform gendered roles that entail fetching water for household needs and caring for young children. As water fetchers, they may spend more time in contact with surface waters that harbor water-based parasites like *Schistosoma mansoni*. As child caretakers, they regularly handle the feces of children who are likely to be infected with diarrheal pathogens.[11–13] Lack of access to safe water for handwashing[14,15] and sanitation facilities for disposal of child feces could increase their chances of direct exposure to parasitic organisms. Consequently, this could cause adverse effects on children's health due to typical female gendered roles. The ensuing gender disparity in health due to the lack of access to clean water and sanitation is a hidden public health issue. However, there is also the possibility of increased risk of exposures for males whose occupations (e.g., agriculture and fishing) may entail more contact with contaminated soil and water. Knowledge about gender-specific differences in water, sanitation and hygiene (WASH)-related diseases is lacking, although ending discrimination against females globally has been embedded in the Sustainable Development Goals, to ensure access to safe water and sanitation for all by 2030.[16]

Through our systematic review, we aim to answer the following questions: are females significantly more likely to experience diarrheal disease and helminth infection than males, and is this influenced by age?; and do the differences in diarrheal and helminth disease between males and females vary by geography or rural versus urban living conditions?

Quantitative information about current levels of WASH-related infections by gender will be important as a benchmark for future measurement of whether improvements in WASH in the Sustainable Development Goals era equally benefit males and females.

Methods

Search strategy and inclusion criteria

VS searched PubMed in June 2014 and an updated search was conducted in June 2016. No limit was set on the year of publication. Only peer-reviewed English articles were considered. The following keywords were used for the search: 'Gender' and ('diarrheal' or 'diarrhoeal'), 'religion' and 'access to clean water', ('water' or 'sanitation' or 'hygiene') and 'gender', 'access to clean water' and 'gender', 'helminth' and 'sanitation.' Based upon reviewers' comments and consensus among co-authors, our team decided to further update our systematic review in August 2016 by using additional search terms, 'cholera' and 'gender', and 'helminth' and 'water'. Apart from PubMed, relevant articles were also obtained from the website of WHO.[17] We decided to include religion as one of the key words, because some difference in prevalence in intestinal parasitic infections between males and females could be attributed to difference in religious practices.[18,19] The articles obtained through the above search criteria were reviewed by title and abstract by VS and a second coder independently (VS-JKS in 2014; VS-KRS and VS-CHD in June 2016; VS-CHD and VS-ICHF in August 2016). All of the articles considered to be relevant by both reviewers were included in the literature review. In case of any disagreement, ICHF made the final decision. All articles that focused on the public health relevance of diarrheal diseases and helminthic infections, role of gender or caretaker in access to clean water and sanitation, or discrepancies in rural and urban health were included in this study. No specific helminth or diarrheal disease-causing organisms were selected a priori in our searches. Articles that did not address the role of safe water, hygiene, and sanitation in health outcomes were excluded (Figure 1).

Data extraction

Data from 482 articles obtained up to June 2014 were extracted by two pairs of independent reviewers (KDP, KRS, JVH and MDP). We later updated our search to 2016, thereby obtaining an additional 40 articles, out of which three were chosen for meta-analysis. Data from these three additional articles were extracted by KRS and CHD. In addition, data was also extracted from 19 articles obtained from the additional keyword searches, which also contained relevant data. This was done by ICHF, CHD and VS. For each included article, we extracted relevant data such as the author, title, location of the study, study design, objective, explanatory and outcome variables, statistical analysis, number of males and females in the study and major findings of the study (Supplementary File 1: Table 1; Supplementary File 2). Only articles providing data necessary to calculate odds ratios (ORs) or provided OR estimates were included in our meta-analysis. A quality assessment was performed by BAS, LCS, KRS, CHD, ICHF and VS for each of the extracted articles by using a structured questionnaire adapted from the Effective Public Health Practice Quality Assessment Tool for Quantitative Studies (http://www.ephpp.ca/tools.html) and the Downs and Black Scale for Assessing the Quality and Risk of Bias in Randomized Controlled Trials.[20] The questionnaire assessed the quality of the study in each of the following categories that could potentially lead to bias within a study: reporting, selection bias, study design, blinding, confounders, exposure assessment, withdrawals and drop-outs and analysis. Each category was graded on a 'strong', 'moderate', and 'weak' scale. The global rating for each article was given based on the number of 'weak' ratings. Presence of one 'weak' rating earned a 'moderate' score for the article while the presence of two or more 'weak' ratings earned a 'weak' score for the article. Absence of any 'weak' rating earned a 'strong' score for the article. The scores were then assigned numerically on a 0, 1, 2 basis representing 'weak', 'moderate' and 'strong' respectively.

We used ORs as the effect measure for the meta-analysis. In articles where the OR was not provided directly, we calculated the OR using the data provided. Only unadjusted estimates of ORs were used to avoid the discrepancy in the degree of adjustment between studies. All the OR estimates used were obtained using females as the referent group. When ORs were provided using males as the referent group, we obtained the ORs for males by calculating the inverse of the ORs for females.

In most of the studies, standard errors were not provided for the OR estimates. Therefore, we estimated the standard errors of the natural logarithmic estimates of the ORs (LnOR) by obtaining the upper and lower 95% confidence limits of the

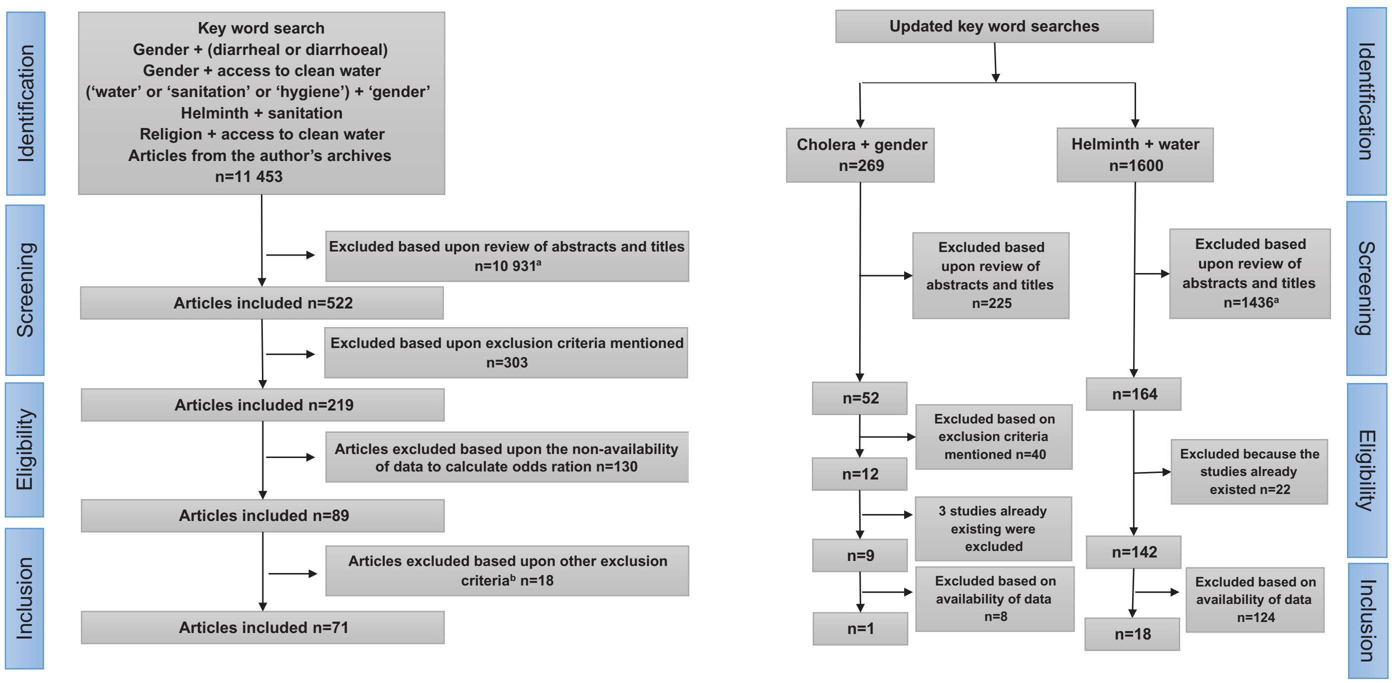

Figure 1. PRISMA flow chart of the screening and exclusion process of the literature. Chart shows number excluded at each level of the process. a Exclusion was done based on: studies, that were conducted exclusively in <5 year olds, topics that were mainly medically linked but not epidemiologically linked, articles that dealt with rare diseases such as borreliosis and Heterophyes, articles that dealt solely with ectopic manifestations of disease such as neural cysticercosis, articles that dealt with non-infectious causes of diarrhea such as ischemic colitis and pesticide contamination, articles that dealt with outbreaks in animal populations, prevalence of vectors, hepatitis C, studies that were conducted in the immunocompromised populations, efficacy of therapeutic techniques and vaccinations, molecular genetics, drug resistance and seasonal variations. b Other exclusion criteria include: studies that were conducted in urban jails, hospitals, health centers, focused on reinfection following chemotherapy, incidence studies, case reports, or studies that gave only adjusted estimates.

LnOR (LnUL and LnLL respectively) and then dividing the difference between LnOR and LnUL or LnLL by 1.96 (Supplementary File 1). After the standard error estimates were obtained, we conducted a meta-analysis using the statistical software R 3.2 (R Foundation for Statistical Computing, Vienna, Austria). We used exact counts and not percentage prevalence estimates for calculation of odds ratios because of the resulting inflation/deflation of standard error estimates.

Statistical analysis

Diarrheal and helminth parasites can have very different transmission ecologies, so articles included in the study were grouped according to genus taxonomy with the exception of studies that performed gender-based analysis for diarrheal symptoms of infectious etiology. A meta-analysis was conducted for each type of organism to generate pooled OR estimates for each pathogen by sex. Within each meta-analysis, separate analyses were conducted for individuals 5 years and older and also for all individuals in general. The R function 'metagen' was used with the inverse of the variance of each study as the study weight. Forest plots were created using the 'forest' function in R 3.2. An OR of <1 indicated that females had greater odds of harboring infection and an OR of >1 indicated males were more likely to harbor infection. To account for any unexplained variation between studies, we used the random effects model throughout our analysis.

Analysis of heterogeneity between studies was conducted using the Moran's I^2 test. We tested for publication bias by the Egger's test in SAS 9.4 (SAS Institute, Cary, NC, USA).

To account for the marked heterogeneity between studies, we conducted a meta-regression analysis with LnOR (natural log of odds ratio) as the primary outcome of interest, and age, location, quality rating, and rural/urban location of the study area as the explanatory variables. Meta-regression was conducted using PROC GLIMMIX in SAS 9.4 (Supplementary File 1).

Results

Out of 11 453 articles obtained through keyword searches, 522 were chosen to gather full-text based upon abstract and title review. Seventy-one articles were included in this systematic review and meta-analysis based upon our exclusion criteria (Figure 1).[13,19,21–89] In two articles, OR estimates were provided in two different locations each.[30,32] Hence a total of 73 estimates were used. All but one of the included studies were observational. The only experimental study was conducted to determine the effectiveness of schistosomiasis control interventions in Egypt.[26] When we included the new keywords in our search, we obtained a total of 1869 articles out of which 216 articles were chosen based upon abstract and title review. Among these, a total of 19 articles[90–108] provided relevant data and hence were included in the meta-analysis. In three articles, OR estimates were provided in two different locations each.[90,93,98] Hence a total of 22 estimates were used.

During the qualitative review process, we identified studies that described the differential trends between males and females in the prevalence of diarrheal disease-causing pathogens such as *Vibrio cholerae* and *Giardia* species, as well as helminthic pathogens such as *Ascaris, Trichiuris,* hookworm, *S. japonicum*, *S. mansoni* and bacterial diarrheal diseases such as typhoid. Supplementary File 1: Table 2 shows the total number of studies used in the meta-analysis for each pathogen. The Egger's test did not reveal any evidence of publication bias in our meta-analysis (Supplementary File 1: Figures 1 and 2, and Table 3). We also ensured that all the relevant characteristics that could lead to bias within studies were included in our quality assessment of articles.

When studies including participants of all ages were considered, *S. mansoni* and *S. japonicum* were the only pathogens associated with gender (OR 1.40, 1.27–1.55 and 1.84, 1.27–2.67 respectively) (Figure 4A left, 4B left). Restriction of analysis to individuals aged 5 years and above reduced heterogeneity in effect estimates across pooled studies. Among individuals aged 5 years and above, all forms of infectious diarrheal diseases (OR 1.21, 1.06–1.38) (Figure 2A right), hookworm (OR 1.43, 1.07–1.89) (Figure 3C right), *S. mansoni* (OR 1.38, 1.14–1.67) (Figure 4A middle) and *S. japonicum* (OR 1.52, 1.13–2.05) (Figure 4B right) showed a significantly higher prevalence in males compared to females. To account for the possible differences in age of peak prevalence with regard to *S. mansoni*, we further stratified the meta-analysis taking into consideration, individuals who were 15 years and older. We did not observe any significant findings within this group (OR 0.79, 0.41–1.53) (Figure 4A right).

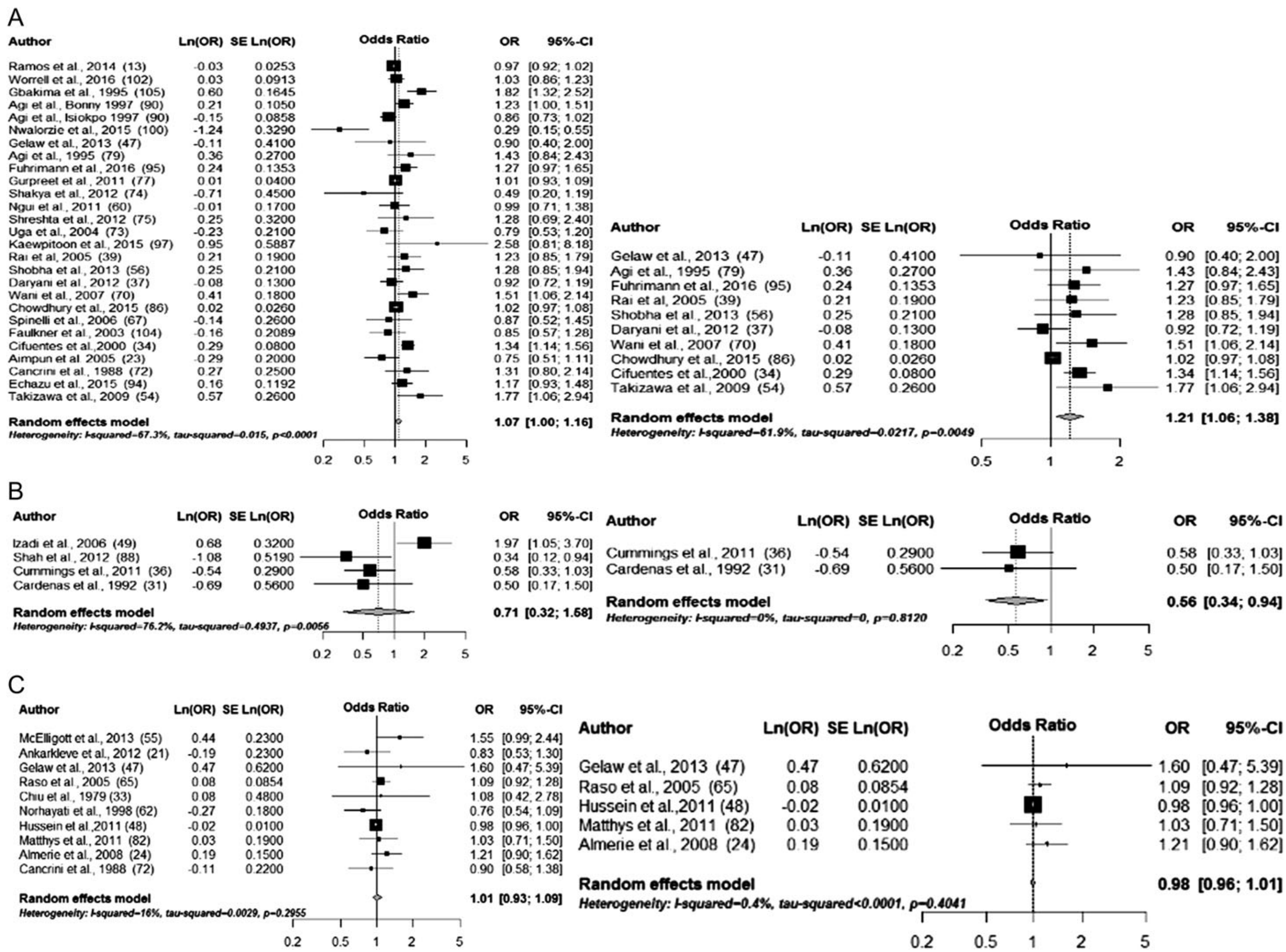

Figure 2. (A) Forest plots showing the OR and 95% CI of infection for all forms of infectious diarrhea: males versus females. The left plot indicates the OR for all ages, the right plot shows OR for ages 5 and above. Female gender was used as the reference group. (B) Forest plots showing the OR and 95% CI of infection for V. cholerae: males versus females. The left plot indicates the OR for all ages, the right plot shows OR for ages 5 and above. Female gender was used as the reference group. (C) Forest plots showing the OR and 95% CI of infection for Giardia: males versus females. The left plot indicates the OR for all ages, the right plot shows OR for ages 5 and above. Female gender was used as the reference group. The numbers in parantheses indicate the reference numbers.

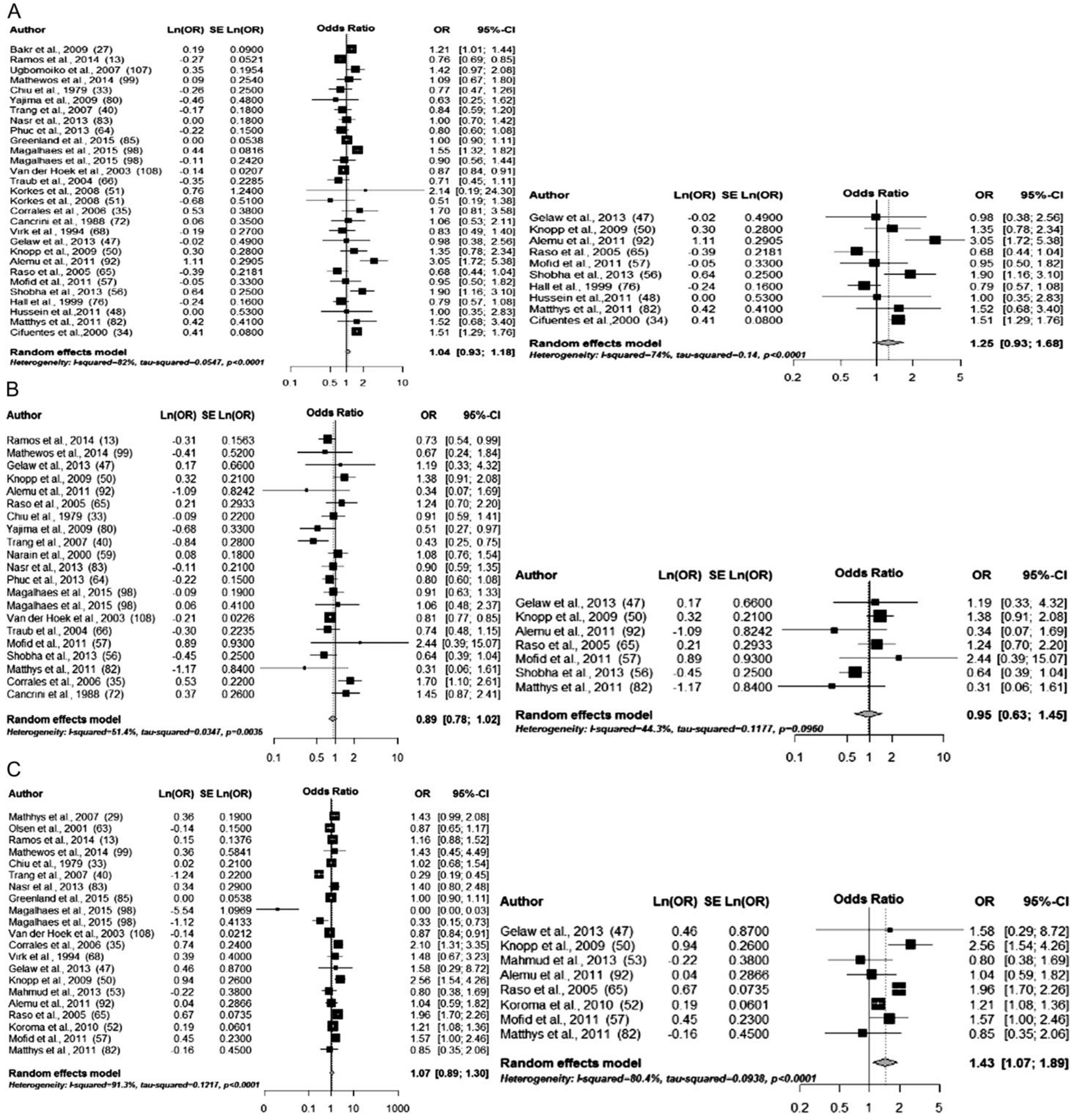

Figure 3. (A) Forest plots showing the OR and 95% CI of Ascaris infection in males versus females. The left plot indicates OR for all ages, and the right plot shows OR for ages 5 and above. Female gender was used as the reference group. (B) Forest plots showing the OR and 95% CI of Trichiuris infection in males versus females. The left plot indicates OR for all ages, and the right plot shows OR for ages 5 and above. Female gender was used as the reference group. (C) Forest plots showing the OR and 95% CI of hookworm infection in males versus females. The left plot indicates OR for all ages, and the right plot shows OR for ages 5 and above. Female gender was used as the reference group. The numbers in parentheses indicate the reference numbers.

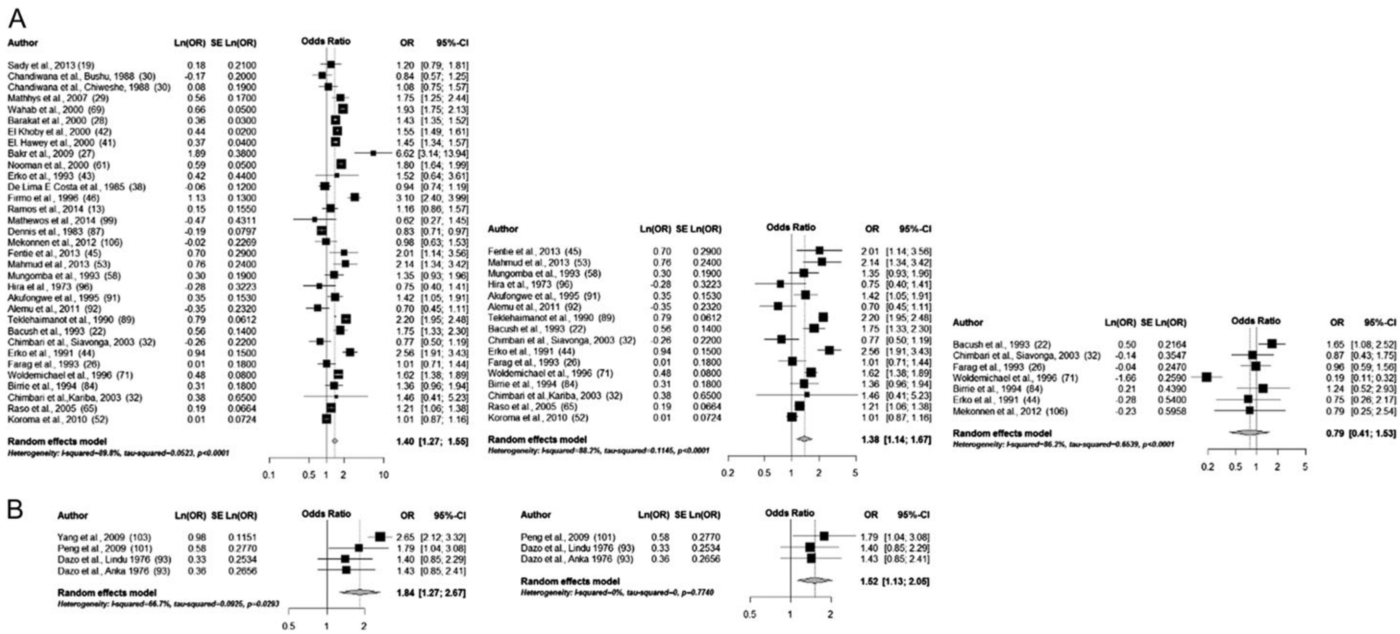

Figure 4. (A) Forest plots showing the OR and 95% CI of Schistosoma mansoni infection in males versus females. The left plot indicates OR for all ages, middle plot shows OR for ages 5 and above and the right plot shows OR for ages 15 and above. Female gender was used as the reference group. (B) Forest plots showing the OR and 95% CI of S. japonicum infection in males vs females. The left plot indicates OR for all ages and the right plot shows OR for ages 5 and above. Female gender was used as the reference group. The numbers in parentheses indicate reference numbers.

V. cholera exhibited higher prevalence in females compared to males in individuals 5 years and older (OR 0.56, 0.34–0.94) (Figure 2B right). Among the studies dealing with typhoid, two studies[25,78] did not report any significant difference in prevalence between males and females, while one study[81] reported a significantly lower odds of prevalence among males (OR 0.31, 0.30–0.32).

However, a significant amount of heterogeneity (I^2>75%) prevented us from obtaining a precise pooled estimate of association especially in cases of *V. cholerae* (all ages) (Figure 2B left), *Ascaris* (all ages, Asia and Africa) (Figure 3A left, Supplementary File 1: Figure 5), hookworm (all ages, 5 years and above and in Asia, Africa) (Figure 3C and Supplementary File 1: Figure 3), and *S. mansoni* (all ages, >5 years and >15 years) (Figure 4A). Hence, we conducted a meta-regression analysis.

In the meta-regression analysis (Supplementary File 1: Table 4), we found that age groups, rurality, continent of study, and quality rating of the paper were not significantly associated with the LnOR estimates. However, since geographic location is associated with the prevalence of pathogens,[6,109] a meta-analysis was conducted stratifying the studies that reported OR for prevalence of hookworm, all forms of infectious diarrhea, *Ascaris, Trichiuris* and *Giardia*, by location (Supplementary File 1: Figures 3–7 in the specified order). We did not conduct further meta-analysis with stratification by continent for *V. cholerae*, *S. japonicum* and *S. mansoni* because of paucity of data.

Of all the studies included in meta-analysis, about 40% (38/95) were conducted in Asia, 46% (44/95) in Africa, 11% (10/95) in South America, 1% (1/95) in Europe, and 2% (2/95) in North America (Supplementary File 1: Table 5). We stratified our meta-analysis by location of study for two continents, namely Asia and Africa. We did not sub-stratify our analysis further by age group because of paucity of data. Location did not have any significant effect on the OR estimates for all forms of infectious diarrhea and *Ascaris* (Supplementary File 1: Figure 4, 5). Odds ratio of prevalence for *Trichiuris* (Supplementary File 1: Figure 6) and hookworm (Supplementary File 1: Figure 3) showed significant effect modification with the location of study. *Trichiuris* showed significantly lower odds ratio for men when compared to women in Asia (OR 0.81, 0.72–0.90), while showing no significant relationship with gender in Africa (OR 0.96, 0.67–1.35). An inspection of the location of *Trichiuris* studies in Asia and Africa confirmed that sampling was conducted in countries having high, medium and low degree of *Trichuris* disease prevalence.[110] Hence observed differences by continent were unlikely to be confounded by prevalence. Hookworm showed significantly higher prevalence in males in Africa (OR 1.32, 1.04–1.67) while not showing any significance in Asia. This finding may be biased by the skewedness caused by an outlier when considering studies in Asia.[98] Nevertheless, after removing the outlier in Asia, our result did not show any difference.

Discussion

We systematically reviewed and quantified the difference in prevalence of infectious diarrheal diseases and helminthic infections between males and females. Familial and societal norms play an important role in determining the behaviors of males and females in any geographic location. For example, men in many countries are more likely to be employed in fishing and jobs away from home, while women are responsible for household chores such as washing dishes and caring for children and domestic animals. In practicing duties associated with these roles, women spend more time washing household items in surface waters harboring diarrheal pathogens or helminths.[109] They also experience more intimate contact with young children who are often infected with diarrheal disease-causing and helminthic pathogens. Additionally, due to gender disparities in women's ability to safely use sanitation facilities, women may spend more time in areas impacted by open defecation.[2,7] We hypothesized that gender-specific practices of women increases their exposure to environments harboring fecal pathogens, including orally transmitted diarrheal pathogens and helminthic ova and skin-transmitted helminth larvae. Despite socio-behavioral evidence suggesting that gender-based behaviors could create differences in exposure to infectious gastrointestinal pathogens between sexes, this issue has not been previously explored using quantitative methods.

Contrary to our hypothesis, our meta-analysis revealed that among individuals who were 5 years or older, there was a higher prevalence of hookworm, *S. mansoni*, *S. japonicum* and infectious diarrhea in males, while there was a higher prevalence of cholera in females. The increased prevalence of hookworm and *S. mansoni* and *S. japonicum* in males could be related to their common mode of transmission, i.e., through penetration of human skin by larvae living in contaminated soil and water. This could mean that males are at increased risk of exposure to outdoor contaminated surface waters and soil that harbors these larval forms. One plausible explanation would be that men spend more time fishing and farming in areas impacted by open defecation than women. In some areas, cultural and religious practices actually prohibit females from participating in activities such as swimming and fishing.[18,19] The increased prevalence of all forms of infectious diarrhea in males could be the result of difference in hand hygiene practices between males and females, as females are known to practice more hand hygiene measures than males.[111] The observation of gender differences in infection among older children and adults, but not among young children who have yet to assume gendered roles, supports the premise that infectious disease exposures are frequently modified by practices defined by gender norms. That being said, gendered roles can also start early in life, so the factors associated with differential prevalence among adults can also play a role in younger adults.[112,113]

There was also a significant differential effect of geographic location of study on estimates for *Trichiuris* and hookworm infection in males versus females. In the case of *Trichiuris*, females exhibited a significantly higher prevalence in Asia, while the effect of gender on its prevalence was insignificant in Africa. In the case of hookworm, higher prevalence was observed in males in Africa, while no gender-based differences were seen in Asia. While this finding may suggest the possibility of regional culture's effect on the discrepancy in prevalence of gastrointestinal pathogens between genders, several other factors could have played a role. For example, the higher prevalence of hookworm in Africa when compared to Asia,[110] might have increased the chances of detecting gender-based differences in prevalence in Africa, and not in Asia. There could be potential differences in prevalence of hand hygiene practices or occupational roles between males and females across the continents, resulting in differential effects across continents.[111] Other factors such as differences in biological susceptibility, knowledge, education, and attitude towards hygiene could also play a role.[114] A detailed study of these factors is beyond the scope of this paper. While there was no significant effect modification by continent in the case of Giardia, this could be due to a lack of sufficient number of studies. As Pullan et al.[110] have pointed out, the availability of point prevalence data across Asia and Africa is varied and hence in some countries, data might not be available at all. Taking this variation in data availability into consideration, we consider our study as a valuable pointer towards future research in this regard.

Strengths of the study

Similar research has been done with respiratory diseases such as tuberculosis.[115] However, our systematic review is the first to address the hypothesis of differential prevalence of infectious diarrheal diseases and helminthic infections between males and females. We decreased the possibility of publication bias by including articles that did not report any significant differences in the prevalence of helminthic or infectious diarrheal diseases. We ensured that we had a sufficient sample size of studies to conduct the meta-analysis.

Limitations of the study

First, many of our articles included study participants who were either in the adolescent or preadolescent age group at the time of the study, which may have caused some reporting bias. Age did appear to play a role in decreasing the precision of our estimates by introducing heterogeneity in the meta-analysis. This can be evidenced by the decrease in the I^2 statistic when age group was restricted to 5 and older for all the organisms studied. Second, exclusion of non-English articles might have resulted in information loss for our systematic review.[116] Third, females might have been underrepresented in some studies, which might have biased the results towards males or females.[65,70,71,73–75,117] For example, in two studies conducted in Nepal by Uga et al.,[73] and Shakya et al.,[74] the number of females that were included in the study was much lower than the number of males (239 males vs 157 females in the former and 97 males vs 68 females in the latter). In both cases it resulted in higher odds for females when compared to males. Fourth, we focused our research question on gender norms and associated differences in behavior between males and females, which may predispose a sex to an increased risk of infection. We acknowledge that biological differences between sexes might also contribute to the observed differences. We also acknowledge that sometimes in the literature, the word 'gender' is misused to refer to biological sex rather than personal or socially-defined identity. Fifth, we only searched one bibliographic database, PubMed. We might have omitted some relevant articles published in journals not indexed in PubMed. However, we did also search through WHO's website for related articles. Sixth, while we did address geographic variation, we did not have enough data to further explore gender-based differences between countries within a continent. Seventh, even though further age stratification for certain pathogens such as *Ascaris*, and *Trichiuris,* might have provided useful inferences, paucity of data did not allow us to do so. We did, however, provide further age stratification for *S. mansoni* (Figure 4A right). Eighth, although we report significantly higher odds of cholera in females than in males for individuals aged 5 and above, we recognize that only two studies were considered and hence recommend caution while interpreting this result. Lastly, the sole use of unadjusted estimates in this study is both a strength and a limitation. While it could have resulted in confounding bias, it also eliminated the problem of differential degrees of correction for confounding between studies. Given the heterogeneity across the studies, we decided to use unadjusted estimates for our meta-analysis.

Policy implications

The mechanism by which gender plays a role in disease burden involves an interaction of behavioral, epidemiological, and geographic factors. For example, women, when faced with scarcity of clean drinking water and sanitation facilities, are forced to use water from unsafe sources and to defecate in the open thereby leading to increased exposure to pathogens.[118] Men may be at higher risk of contracting certain pathogens such as *S. mansoni*, *S. japonicum* and hookworm due to occupational factors.

There could potentially be other independent psychological mechanisms and behavioral pathways that adversely affect health due to the lack of water and sanitation. Our study emphasizes the need for water and sanitation to be available to all in an affordable and safe manner, irrespective of age, location, or gender.[6]

Uncovering the pathways and mechanisms that play a role in gender-based public health disparities will help policy experts make decisions to ameliorate this differential disease burden. Our current study highlights: the importance of gender-based analysis of WASH-related health data, which will aid in revealing potential country-level patterns for focused policy action; the need for further clarity in behavioral-level differences between males and females, leading to differential gender-based burden of disease; the need to understand the behavioral, environmental and occupational determinants of differences in infection prevalence between genders, and identify effective gender-specific interventions that target the behaviors that lead to exposure,[119] and the need for context specific research, as identified by geographic variations in disease prevalence.[6]

As Taukobong and colleagues[120] have suggested, there is value to integrate interventions that promote gender equality and empower women and girls, with WASH interventions, so that we may simultaneously improve gender and WASH outcomes across different indicators. What we present here is only one of many problems in low income countries, specifically due to lack of water and sanitation. Further research can be done on other outcome measures, such as Years of Potential Life Lost and Disability Adjusted Life Years that can be influenced by gender.

In conclusion, despite some equivocal results with regard to diarrheal diseases and helminthic infections between males and females, some pathogens were shown to exhibit gender differences. Specifically, *S. mansoni*, *S. japonicum*, hookworm and all forms of infectious diarrheal pathogens were found to be more prevalent among men. *V. cholerae* was found to be more prevalent among women. Additionally, there was evidence for effect modification of the ORs due to geographic location for *Trichiuris* and hookworm. More research is needed to understand the precise causal pathways of the gender disparities in diarrheal and helminthic diseases that we have discovered here.

Supplementary data

Supplementary data are available at *Transactions of the Royal Society of Tropical Medicine and Hygiene* online.

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Authors' contributions: KDP, KRS, JVH, MDP, JKS, CHD, BAS, LCS contributed equally as co-second authors. VS and ICHF conceived the study; VS, KKB and ICHF designed the study protocol; VS, KDP, KRS, JVH, MDP, JKS, CHD, BAS, LCS and ICHF carried out the literature review; VS analyzed the data; VS, KKB and ICHF interpreted the data; VS drafted the manuscript; KRS, MDP, JKS, CHD, LCS, KKB, MG and ICHF critically revised the manuscript for intellectual content. All authors read and approved the final manuscript. VS and ICHF are guarantors of the paper.

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