Prevalence and associated factors of microbial water quality from drinking water in Ethiopia: A Systematic Review and Meta-Analysis study

Asmamaw Deguale Worku[1, 2*], Bezatu Mengistie Alemu[1], sisay Abebe debela[1], and Abreham Mota[2]

[1]Department of Water and Health, Ethiopian Institute of Water Resources, Addis Ababa University, Addis Ababa, Ethiopia, [2] Department of Public Health Emergency Management, Addis Ababa Health Bureau, Addis Ababa, Ethiopia.

* Corresponding author

Email: asmamaw.deguale@aau.edu.et (ADW)

Abstract

Introduction: Drinking water contamination is a worldwide problem and causes a major public health threat, with most water contamination prevalent in developing countries, including Ethiopia. There is no pooled overall prevalence of fecal coliform contamination and its contributing factors in drinking water in Ethiopia.

Method: The review was conducted under the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and registered in PROSPERO CRD42024537804. The following databases were used: PubMed/MEDLINE, Worldwide Science, Google Scholar, and Science Direct. Two independent reviewers identified studies, extracted data, and assessed the risk of bias, and methodological quality. Statistical techniques like Higgins I2 were used to investigate heterogeneity among the included studies. A funnel plot was developed to evaluate reporting bias, and Begg's and Egger's tests were used to check funnel plot symmetries.

Result: The overall pooled prevalence of fecal coliform contamination of drinking water in study area was 55% (95% CI: 34, 77). Factors such as improved water sources, humans sharing their house with animals, water shortage experience, and educational status were significantly associated with fecal coliform contamination. All factors had high heterogeneity, and we used a random effect model to estimate the pooled odd ratio.

Conclusion: The pooled prevalence of fecal coliform contamination of drinking water was considerably high. Consumption of drinking water from improved water

sources, shortages of water, shared houses with animals, and educational statuses were significantly associated with fecal coliform contamination of drinking water in the country. All concerned body ought to provide due attention.

Keywords: prevalence, microbial water quality, fecal coliforms, associated factors, drinking water, systematic review and meta-analysis, Ethiopia

1. Introduction

Pollution of drinking water poses a serious risk to human health and is a global issue. Many microorganisms can spread through drinking water that has been contaminated at the source, along the distribution chain, and at the end consumer (1, 2). Water covers around 70% of the earth's crust, but most of the bodies of water are non-consumable, with the drinkable type constituting only 2.5–3% of the land's water (3, 4). Drinking water availability is not only essential for well-being but also for acceptable development, food security, and the improvement of living conditions. Safe and clean drinking water were recognized as fundamental human rights by the UN General Assembly (5-8). Access to safe and affordable drinking water is basic human rights to enjoy and harmonize their life (9, 10).

Worldwide, 1.8 billion people use feces-contaminated drinking water, of which 1.1 billion drink water that has at least "moderate" risk (>10 E. coli or thermo-tolerant coliform per 100 ml) (11). Pollution is most prevalent in South-East Asia (35%) and Africa (53%), with drinking water being more contaminated in rural (41%) than urban (12%) regions (12). In poor and middle-income nations, fecal coliform bacteria pollution of drinking water in rural communities poses a serious threat to public health (13). Numerous studies also revealed that fecal coliforms contaminate drinking water. For example, in Nepal, 81% of drinking water was contaminated at household storage containers and 68% at the point of collection (14), 94% of drinking water in Myanmar was contaminated with thermo tolerant (fecal) coliforms *(*15*)*, 78.42% of drinking water sources in Pakistan were contaminated with *fecal coliforms bacteria* (16, 17), and another study conducted in Pakistan also found that 80% of drinking water sources were contaminated with sewage (fecal) matter (18).

According to Ethiopian Standard Agency rules and WHO 2017 guidelines about drinking water and water quality, coliform bacteria cannot be found in 100-ml water samples (19-21). Waterborne and water-related illnesses affect among 60% to 80% of Ethiopia's populations (11). Fecal coliforms, also known as thermo-tolerant coliforms (TTC), are frequently employed as markers of recent fecal contamination, which is dangerous for human health. *Escherichia coli*, *Klebsiella*, *Enterobacter*, and *Citrobacter* are examples of thermo-tolerant coliform bacteria that can produce, recognize, and evaluate possible health concerns (22, 23). However, for the purposes of this investigation, we employed fecal coliforms or thermo-tolerant coliforms instead of each individual species (24).

Fecal pollution of drinking water is still a major public health concern in Ethiopia, despite numerous encouraging initiatives and attempts in recent years to give the country's citizens a safe water supply (2, 25). Fecal pollution of drinking water was attributed by latrine availability, family size, economic level, experience with water shortages, and educational attainment (26-28). In Ethiopia, the prevalence of fecal coliforms and the factors that are linked to them in drinking water varies depending on the region, in urban and rural. The exact pooled total prevalence of fecal coliforms (also known as thermo tolerant coliforms) and the factors that contribute to it are unknown in Ethiopia. Furthermore, little is known about the current total pooled prevalence of fecal coliforms in drinking water. Thus, the goal of this systematic review and meta-analysis study is to compile the prevalence and contributing factors of fecal coliform contamination in drinking water from Ethiopian studies that are currently available.

2. Method

The review was conducted per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and has been registered in PROSPERO under registration number CRD42024537804 (29, 30)**.**

2.1. Search strategy

The studies were identified from peer-reviewed articles, grey literature, and submissions from experts. To identify peer-reviewed literature, the topic “microbial water quality” was combined with terms to restrict the search for drinking water and measure the prevalence and associated factors of microbial water quality. We further restricted the search in Ethiopia. The following databases were used: PubMed/MEDLINE, Worldwide Science.org, Google Scholar, and Science Direct.

Search terms

To increase the probability of all-inclusiveness of the findings, search terms were developed and combined using Boolean operators as follows:

The search terms used were “prevalence," “associated factors," “microbial water quality," “bacterial water quality," and “drinking water in Ethiopia. Prevalence and associated factors of microbial water quality or associated factors of bacterial water quality from drinking water in Ethiopia. We would undertake advanced searching by combining the search terms using Boolean operators.

Search detail

((("epidemiology"[MeSH Subheading] OR "epidemiology"[All Fields] OR "prevalence"[All Fields] OR "prevalence"[MeSH Terms] OR "prevalance"[All Fields] OR "prevalences"[All Fields] OR "prevalence s"[All Fields] OR "prevalent"[All Fields] OR "prevalently"[All Fields] OR "prevalents"[All Fields]) AND ("associate"[All Fields] OR "associated"[All Fields] OR "associates"[All Fields] OR "associating"[All Fields] OR "association"[MeSH Terms] OR "association"[All Fields] OR "associations"[All Fields]) AND ("factor"[All Fields] OR "factor s"[All Fields] OR "factors"[All Fields]) AND ("microbial"[All Fields] OR "microbially"[All Fields] OR "microbials"[All Fields]) AND ("water quality"[MeSH Terms] OR ("water"[All Fields] AND "quality"[All Fields]) OR "water quality"[All Fields])) OR (("associate"[All Fields] OR "associated"[All Fields] OR "associates"[All Fields] OR "associating"[All Fields] OR "association"[MeSH Terms] OR "association"[All Fields] OR "associations"[All Fields]) AND ("factor"[All Fields] OR "factor s"[All Fields] OR "factors"[All Fields]) AND ("bacterial"[All Fields] OR "bacterially"[All Fields] OR "bacterials"[All Fields]) AND ("water quality"[MeSH Terms] OR ("water"[All Fields] AND "quality"[All Fields]) OR "water quality"[All Fields]) AND ("drinking water"[MeSH Terms] OR ("drinking"[All Fields] AND "water"[All Fields]) OR "drinking water"[All Fields]) AND ("Ethiopia"[MeSH Terms] OR "Ethiopia"[All Fields] OR "Ethiopia s"[All Fields]))).

All searches were restricted to the year "between" 2000/1/1:2024/3/11 [pdat] and only English language; however, each online database varies in terms of the earliest articles available online.

Grey literature search terms were modified in the databases where required. Basic terms were used for the grey literature. Bibliographies of included studies and relevant reviews were searched. Based on the resources available, the titles and abstracts from selected journals were reviewed. These papers were selected based on the number of eligible articles identified in each paper in prior searches.

.

2.4. Eligibility criteria for study selection

Studies that meet the following inclusion criteria were included in the systematic review and meta-analysis study.

- Water samples that were taken from the sources, reservoir, or point of use (tape or container) that was used for drinking purposes.
- The article contained extractable data on fecal coliform bacteria or thermo-tolerant coliform bacteria.
- The article was published in the years between 2000 and 2024.

- Only observational study designs such as cross-sectional, case-control, or cohort studies were included.

We excluded the microbial water quality study that was not done in the English language and out of Ethiopia. We included all studies conducted at all drinking water sources, either protected or unprotected wells, springs, taps, and any water sources that are used for drinking purposes. Furthermore, we included articles on fecal coliform studies only, instead of articles on each specific species of fecal coliform.

2.5. Study selection

The approach differs for peer-reviewed and grey literature. Bibliographic software (Endnote) was used to identify and remove duplicate articles. In addition, the manual removal of duplicate articles was also done. Study selection was conducted in two stages: screening of titles and abstracts, followed by screening of full texts, as well as applying inclusion and exclusion criteria. Peer-reviewed articles selected to be included in the study were put on an easy spreadsheet for easy manipulation.

Grey literature was screened by one reviewer. Search terms used in each database were recorded, and the number of studies returned was recognized together with the number selected based on the title and/or abstract. Selected studies were included in the spreadsheet with the peer-reviewed literature, with an additional column to indicate their source.

2.6. Data extraction and collection

A data extraction table was developed in Excel to facilitate the extraction process. Descriptive data from eligible studies (author, year of publication, sources, etc.) was extracted, and we also extracted additional study characteristics thought to influence microbial water quality. Then characteristics of the study were extracted, such as country, region, setting (community or facility-based), study design, sample size, and the number of samples that tested positive. We classified studies based on study design, as this is thought to affect the extent to which they are affected by bias. Our classification includes cross-sectional, case-control, and cohort studies. Additional data were extracted specific to the quality parameters that the study examined (prevalence and associated factors of fecal coliform contamination in drinking water. Data extraction table for the characteristics of the studies included in the systemic review (Table 1).

Once the data extraction was completed, 10% of the included studies were randomly selected to assess the correctness of the data extracted (31). The results from all reviewers were compared to determine the variability in data extraction, and any disagreements were resolved by the third reviewer.

2.7. **Assessment of study quality**

The studies included were determined in terms of quality based on the criteria listed in the GBI quality parameters (32, 33). A quality rating was based on the quality of the paper in terms of methodology, outcome, reliability of measurement, and appropriateness of statistical analysis, resulting in a point score of more than or equal to 5. The final quality score was set for each study design through the discussion of the reviewers. The study was not excluded based on a low-quality score, but we were exploring the influence of study quality on findings from the review by putting them in two separate ways.

2.8. Analysis

Data were extracted in Microsoft Excel format, followed by analysis using STATA Version 17 statistical software (34). The prevalence of fecal coliform contamination of drinking water was determined for individual studies, and then the prevalence ratio (PR) was calculated considering a 95% confidence interval (CI). Since there was no heterogeneity, the analysis was performed using the fixed effect model (inverse variance) (35). Moreover, associated factors for fecal coliform contamination of drinking water were assessed, and the overall effect was determined in the form of an odds ratio.

2.9. Regarding the missing data

The initial and/or corresponding authors were contacted by phone, email, or other method to request any missed data and/or further information if any were not included in the included research.

2.10. Heterogeneity

We used simple approaches to explore variations among all studies in alignment with our research objectives. Heterogeneity was evaluated statistically by the P-value of Cochrane Q-test statistics and the inverse variance index (I^2). P-values less than 0.05 were statistically significant heterogeneity, whereas I^2 values were classified as follows: low heterogeneity (0–25%), moderate heterogeneity (25–50%), and high heterogeneity (> 50%) (36, 37). We anticipated diverse results among the studies and endeavored to understand the potential reasons for any specific outcomes. Forest plots were done to produce the pooled estimates of the prevalence of fecal coliform contamination of drinking water. The pooled prevalence of fecal coliforms was homogeneous, and a fixed effect model was used to estimate. We used a random effect model (DerSimonian and Laird's) for associated factors of fecal coliform contamination of drinking water because the pooled effect of associated factors had high heterogeneity.

2.11. Publication bias

Studies with negative findings and, depending on the journal, interest could be published less frequently, thereby creating a publication bias. The extent of publication bias was measured using a funnel plot and Egger's test for small study effects (38). We also used Begg's test to quantify publication bias. There was no publication bias or small study effect in the funnel plot of this study.

2.12. Plans for updating the review

If necessary, revised or expanded versions of this systematic review and meta-analysis will be made available.

3. Results

3.1. Search results

First, 220 articles were retrieved from different databases and gray literature reporting the prevalence and/or associated factors of microbial water quality in drinking water. Of these articles, 49 were excluded due to duplication. From the remaining 171 articles, 103 were excluded after a review of their titles and abstracts, which were useless to this review. Then, 40 articles were excluded depending on full-text criteria. Consequently, 28 full-text articles were accessed and evaluated for eligibility based on the pre-set criteria, which led to the further exclusion of 15 articles. Finally, 13 publications were gathered for this systematic review and meta-analysis. Eleven of the thirteen included studies in this systematic review and meta-analysis were published, while two were not. The review was conducted in according with the PRISMA guidelines and flow diagram (39, 40) (figure 1).

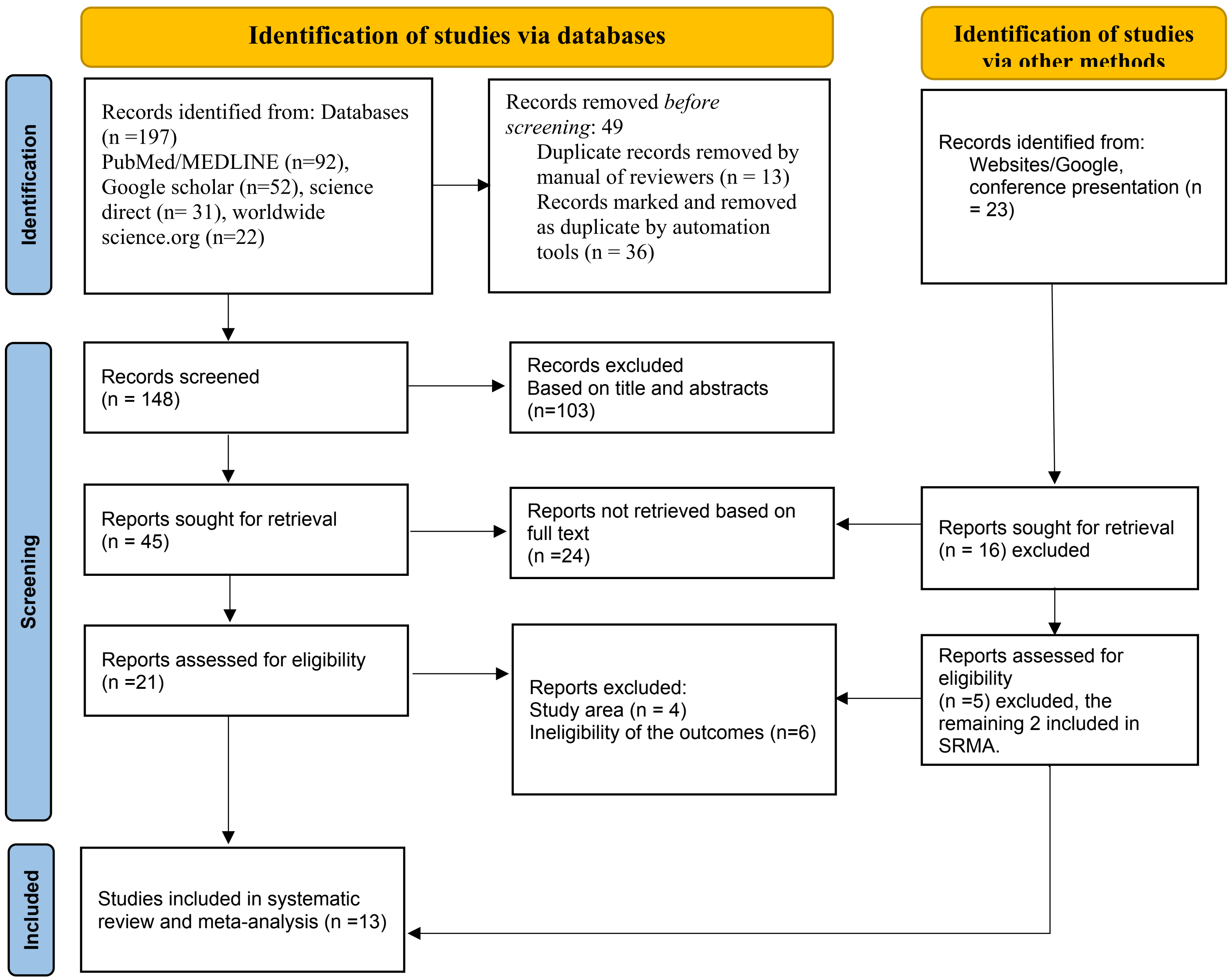

Figure1: Study selection procedure of flow diagram

3.2. Study characteristics

This systematic review and meta-analysis includes 13 eligible studies with 4530 water samples that were tested for the prevalence of microbial water quality in drinking water. The studies included both published and unpublished articles that were conducted in the years 2000–2024. The entire selection of studies was a cross-sectional study design. Regarding sample size, the sample size of the studies ranged from 93 to 736. The lowest prevalence (26.1%) of fecal coliform-contaminated drinking water was reported in a study conducted in Bahirdar City Administration, Amhara Region (41) , and 29% in Eastern Tigrai (42), whereas the highest prevalence (82.5%) of fecal coliform contamination was reported in a study conducted in Wegeda town, Amhara Region (1). In this current systematic review and meta-analysis study, six Ethiopian regions were represented. Six studies were from Amhara, two from SNNPR and Tigrai, and one from Somalia, Gambella, and Harari. No studies were reported from Benishangul Gumiz, Addis Ababa, Dire Dawa, Afar, or Oromia. All the water samples investigated were only from drinking water either at households, reservoirs, or sources (1, 11, 12, 26, 27, 41-48). The average quality score of included studies ranges from 5 to 8 as per the GBI quality score adapted for cross-sectional studies (Table 2).

Table 2: Descriptive summary of 13 studies included in the meta-analysis of the prevalence and associated factors of fecal coliform contaminations of drinking water in Ethiopia 2024.

Id	Author	Publication Year	Source	Region	Study design	Study setting	Duration	Sample size	No of samples tested +(	Prevale e((%)	QA/QC measures	GBI score

									FC)			
1	Sitotaw et al.	2023	published	Amhara	Cross sectional	Community based	6 Month	180	47	26.1	Yes	6
2	Mekonnen et al.	2019	published	Gambella	Cross sectional	Community based	4 Month	357	201	56.3	Yes	7
3	Gebrewahd et al.	2020	published	Tigrai	Cross sectional	Community based	12 Month	290	84	29	Yes	7
4	Getachew et al.	2021	published	Amhara	Cross sectional	Community based	3 Month	736	534	72.6	Yes	8
5	Berihun et al.	2023	published	Amhara	Cross sectional	Community based	2 Month	412	272	66	Yes	7
6	Ashuro et al.	2021	published	SNNPR	Cross sectional	Community based	2 Month	213	107	50.2	Yes	6
7	Getachew et al.	2018	published	Amhara	Cross sectional	Community based	4 Month	736	416	56.5	Yes	8
8	Gebremedhn et.al.	2019	unpublished	Tigrai	Cross sectional	Community based	6 Month	145	63	43.5	Yes	5
9	Asfaw et. al.	2016	published	Somali	Cross sectional	Community based	4 Month	125	65	52	Yes	5
10	Birhan et.el.	2022	unpublished	Amhara	Cross sectional	Community based	3 Month	675	420	62.2	Yes	7
11	Alemeshet Asefa et al.	2021	published	Harari Region	Cross sectional	Community based		448	359	80	Yes	5
12	Sitotaw et al.	2021	published	Amhara	Cross sectional	Community based	8 Month	120	99	82.5	Yes	6
13	Gizachew et al.	2020	published	SNNPR	Cross sectional	Community based	1 Month	93	76	81.7	Yes	6

3.3. Prevalence of fecal coliform contamination of drinking water in Ethiopia

The study showed that the pooled prevalence of fecal coliform contamination from drinking water in Ethiopia was 55% (95% CI: 34, 77) (Figure 2). There was no heterogeneity observed in the included studies ($I^2 = 0.0$, $p = 0.999$). Therefore, a fixed-effect meta-analysis model was computed to estimate the pooled prevalence of fecal coliform contamination from drinking water in Ethiopia. We used inverse variance to run the analysis of the data in a fixed effect model. No subgroup analysis, meta-regression, or sensitivity test was done due to the lack of heterogeneity.

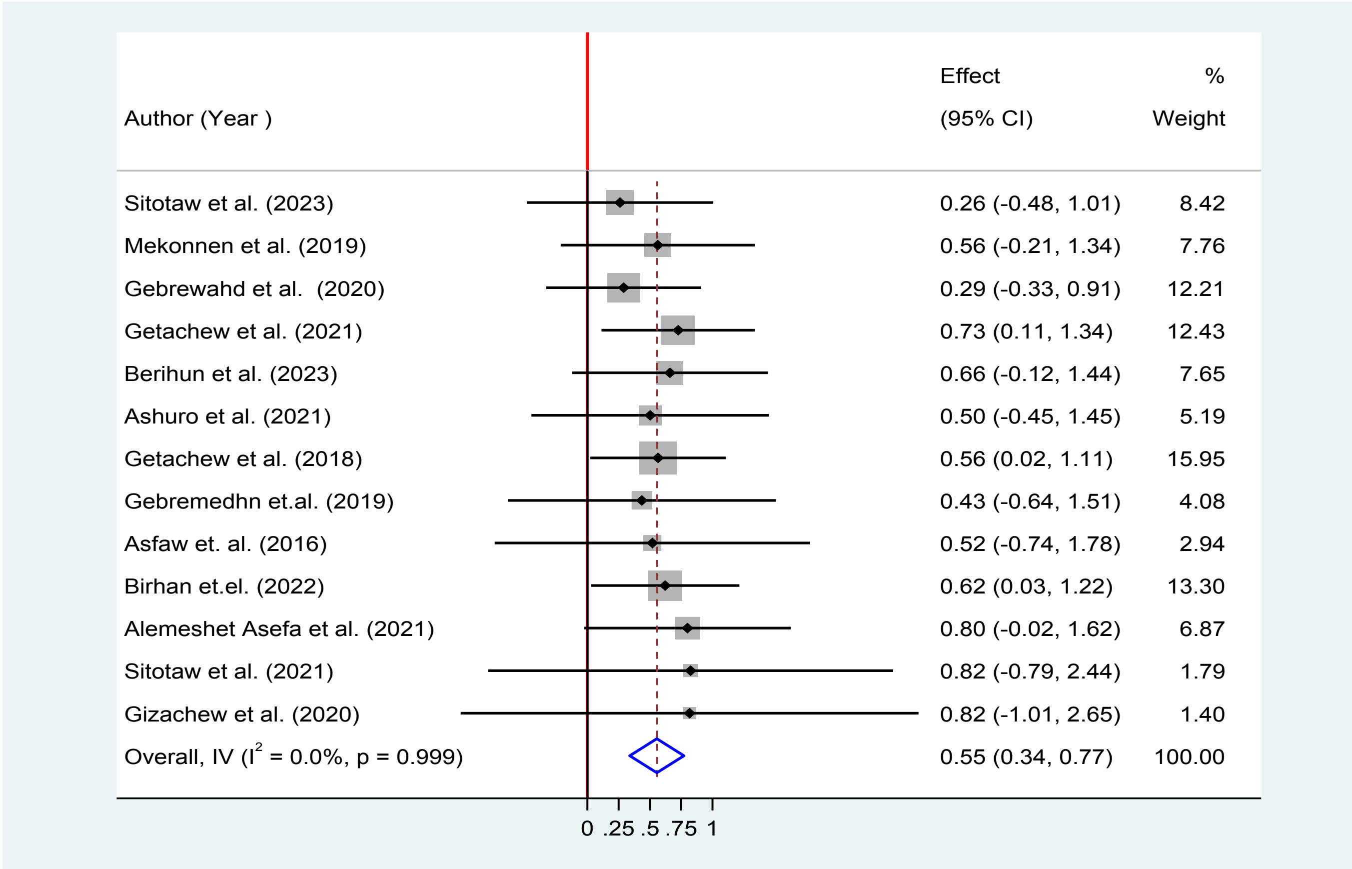

Figure 2: Forest plot of the pooled prevalence of fecal coliform contamination of drinking water in Ethiopia.

3.4. Risk of bias

Funnel plot symmetry was used to check the absence of publication bias (Figure 3). The finding of the funnel plot presented that there was a symmetrical distribution in the study. The funnel plot showed that there were no publication biases in the included studies. To confirm this symmetry, we conducted objective-based (Begg's and Egger's) tests. The results of Begg's and Egger's tests showed that there was no statistically significant publication bias in estimating the prevalence of fecal coliforms from drinking water in Ethiopia (Begg's test, $p = 0.951$; Egger's test, $p = 0.657$). The finding revealed that there was no small study effect or influence on the pooled effect size.

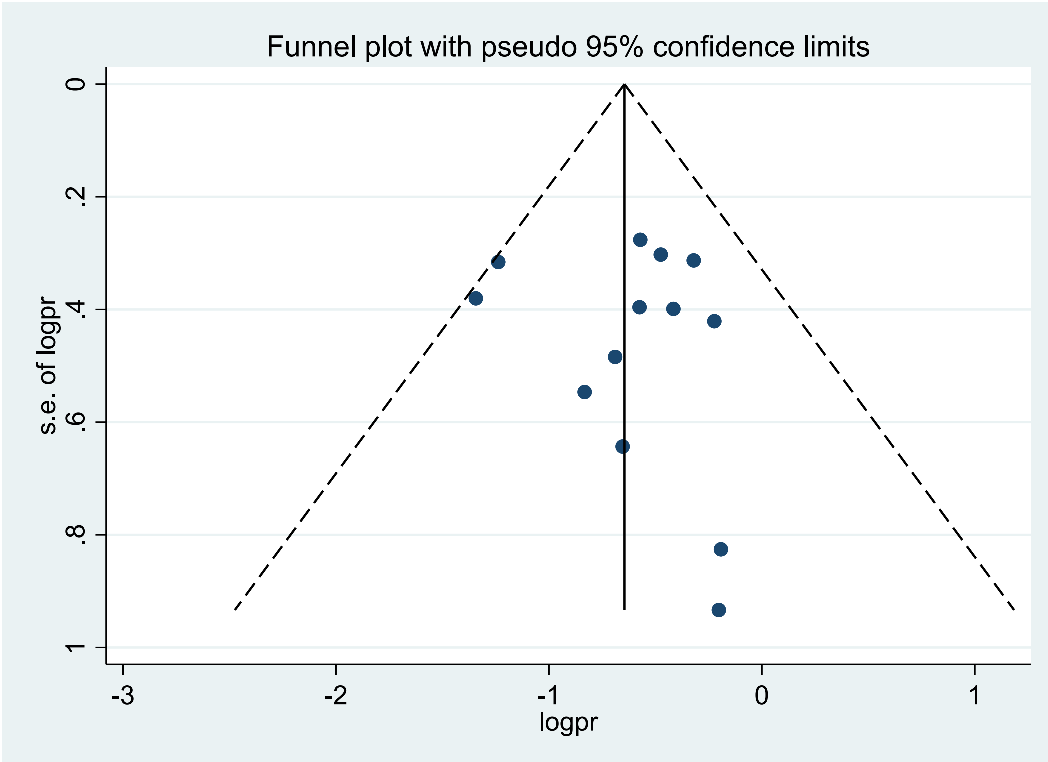

Figure 3: Funnel plot with 95% confidence limits of the pooled prevalence of fecal coliform from drinking water in Ethiopia.

3.5. Associated factors for fecal coliform contamination of drinking water in Ethiopia

The association between the availability of toilet facilities and fecal coliform contamination

In the current meta-analysis, we evaluated the association between availability of toilet facilities and fecal contamination of drinking water from five included studies (12, 26, 27, 44, 45). The findings from these five studies found that the availability of toilet facilities in households was not significantly associated with fecal coliform contamination of drinking water (OR: 0.68, 95% CI: 0.25, 1.79). The result of the test statistics indicated that significant heterogeneity (I^2 = 95.1% and $p < 0.000$) was presented across the included studies. Therefore, a random effect meta-analysis model was used to assess the association (Fig. 4).

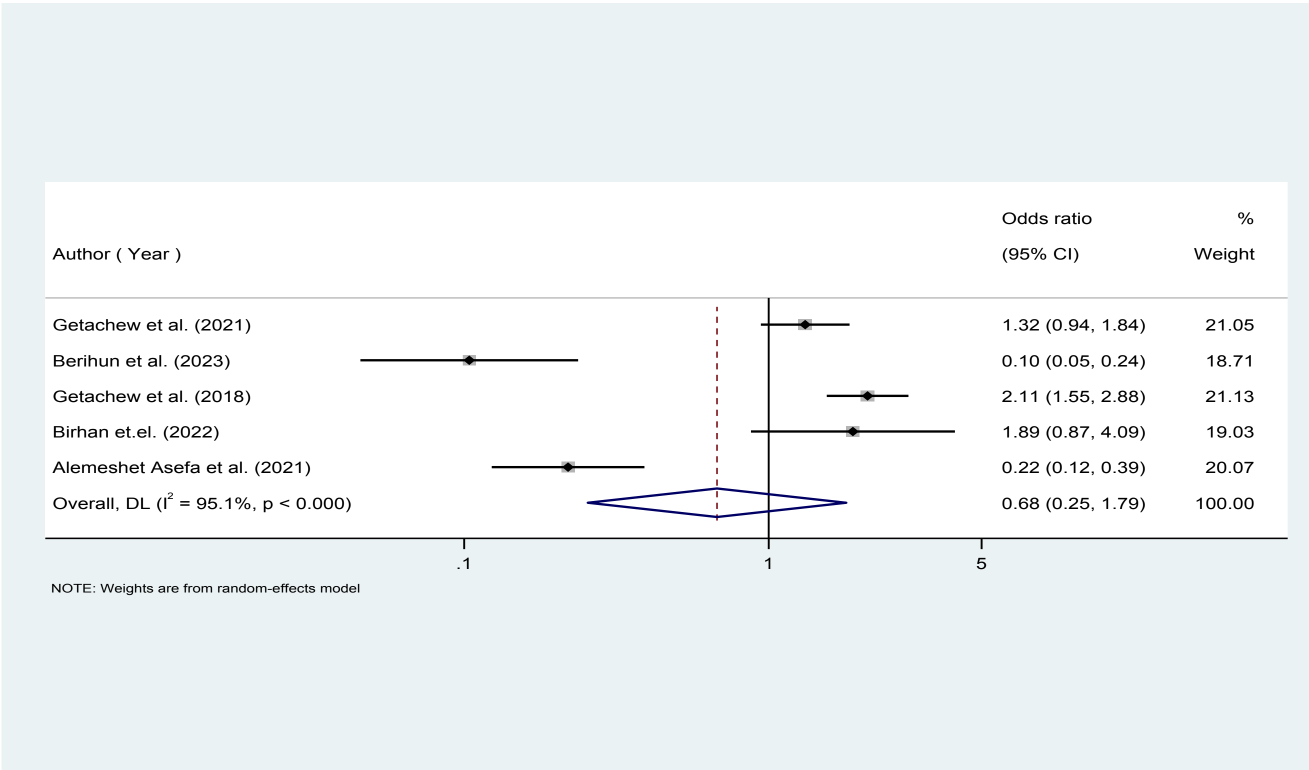

Figure 4 shows the pooled odd ratio of the association between the availability of toilet facilities and fecal coliform contamination in drinking water in Ethiopia.

Association between types of water sources and fecal coliform

The association between types of water sources and fecal coliform contamination of drinking water was inspected using four studies (12, 26, 44, 46). Three of the included studies reported that types of water sources are significantly associated with fecal coliform contamination of drinking water(12, 44, 46), whereas one study of the included studies didn't show an association between types of water sources and fecal contamination of drinking water(26). The findings of the current meta-analysis showed that types of water sources were significantly associated with fecal coliform contamination. This result found that water fetched from protected water sources was 68% less likely to be contaminated by fecal coliform than water fetched from unprotected water sources (OR: 0.32, 95%; CI: 0.14, 0.71) (Fig. 5). The included studies showed considerable heterogeneity (I2 = 88.5% and p< 0.000), hence a random effect meta-analysis model was employed.

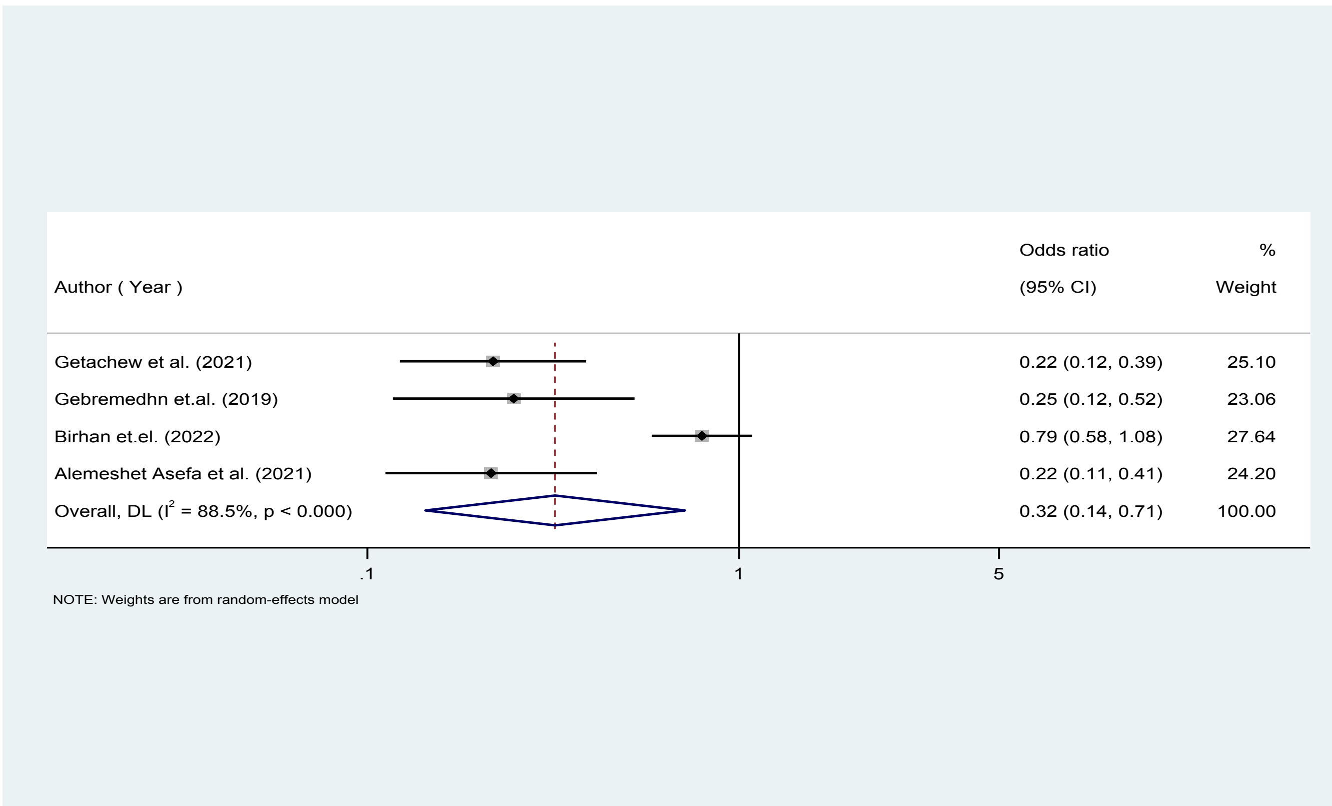

Figure 5: The pooled odd ratio of the association between types of water sources and fecal coliform contamination of drinking water in Ethiopia

Shared houses with animals

To examine the association between humans sharing the same house with animals and fecal coliform contamination of drinking water, studies that observed the association between animal access to the same house with humans and fecal coliform contamination of drinking water were included(12, 26, 44). All of these included studies showed that shared houses by both animals and humans were positively associated with fecal coliform contamination of drinking water. The result of the current meta-analysis indicated that human beings shared the same house with animals, which was positively associated with fecal coliform. This result found that human beings who shared their house with animals were 2.11 times more likely to contaminate drinking water with fecal coliforms than their counterparts (OR: 2.11, 95%; CI: 1.39, 3.19) (Fig. 6). The included studies showed high heterogeneity (I2 = 54.8% and p = 0.109), hence a random effect meta-analysis model was computed.

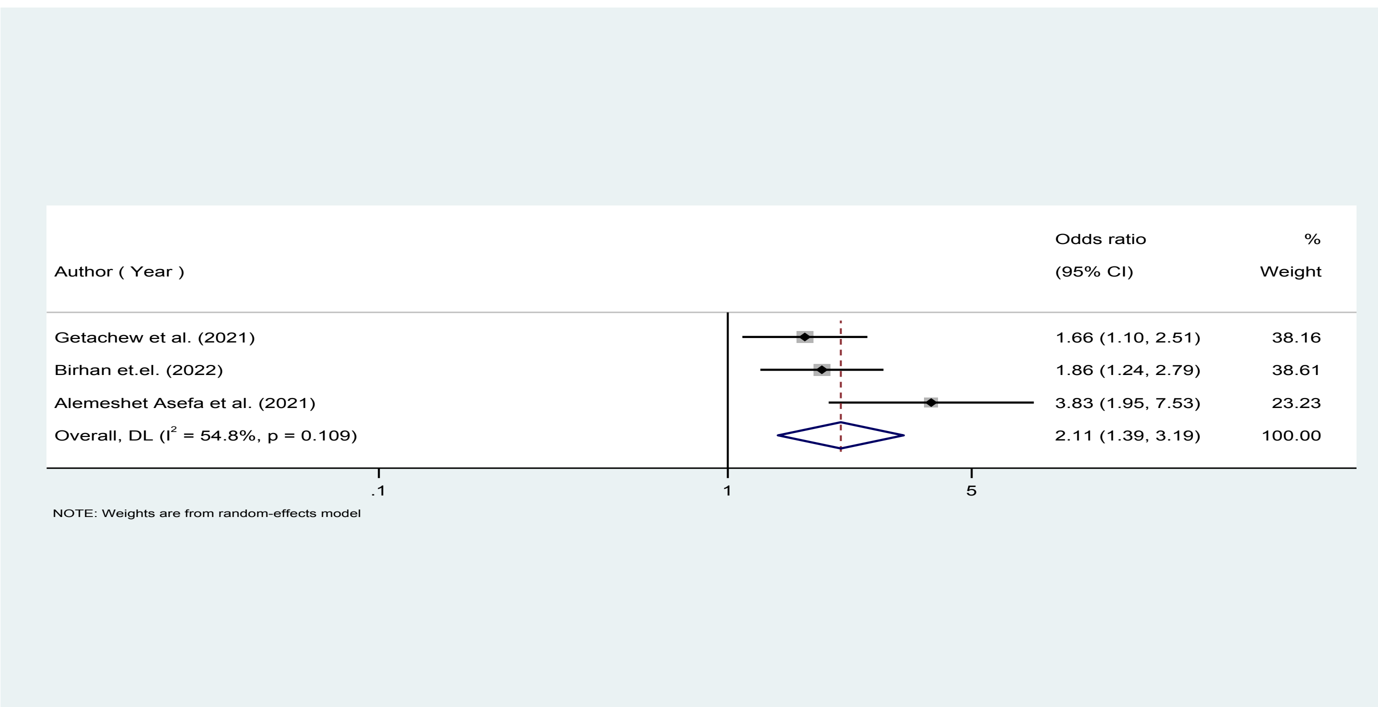

Figure 6: The pooled odd ratio of the association between animals sharing the same house with humans and fecal coliform contamination of drinking water in Ethiopia

Shortage of water

To evaluate the association between water shortages in households and fecal coliform contamination of drinking water. Three studies examined the association between fecal coliform contamination of drinking water and water shortages, and all studies showed that water shortages were significantly associated with fecal contamination (27, 44, 45). The overall study showed that a shortage of water was 3.3 times more likely to be contaminated by fecal coliforms than their counterparts (OR: 3.30, 95%CI: 2.18, 4.99) (Fig 7). The included studies showed that there was significant heterogeneity (I2 = 74.9%; p-value = 0.019); hence, a random effect meta-analysis model was computed to estimate the final analysis.

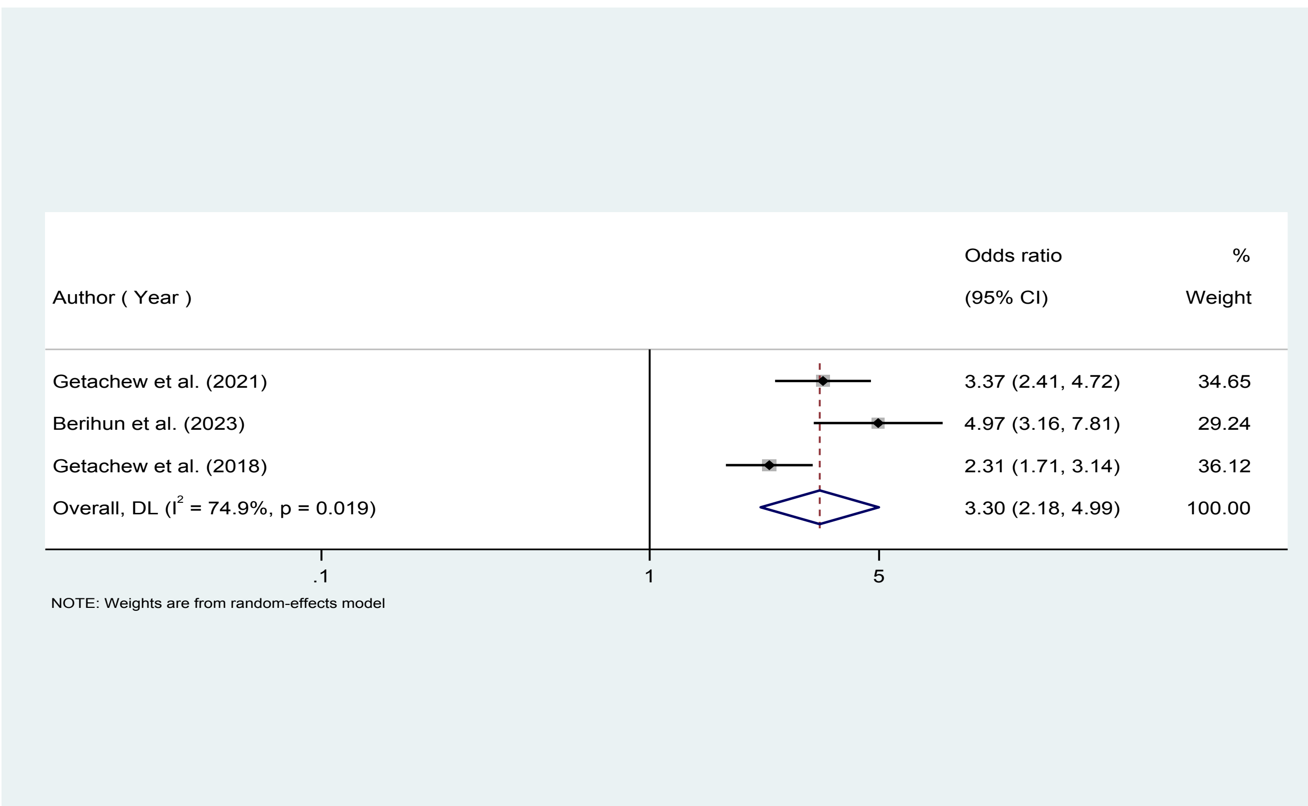

Figure 7: The pooled odd ratio of the association between water shortage experience and fecal coliform contamination of drinking water in Ethiopia

Educational status

Finally, in this meta-analysis, we evaluate the association between the educational status of the respondents and the fecal contamination of drinking water. We included three studies in this meta-analysis; two of them were significantly associated with fecal coliform contamination (12, 27) , and one of them was not significantly associated with fecal coliform contamination of drinking water (26). The pooled odd ratio of this meta-analysis directed that respondents who are educated were 39% less likely to contaminate their drinking water as compared to their illiterate counterparts (OR: 0.61, 95%CI: 0.43, 0.85) (Fig 8). In this meta-analysis, the included studies were presented with high heterogeneity (I^2 = 57.9%; p = 0.093), and then we employed a random effect meta-analysis model to determine the association.

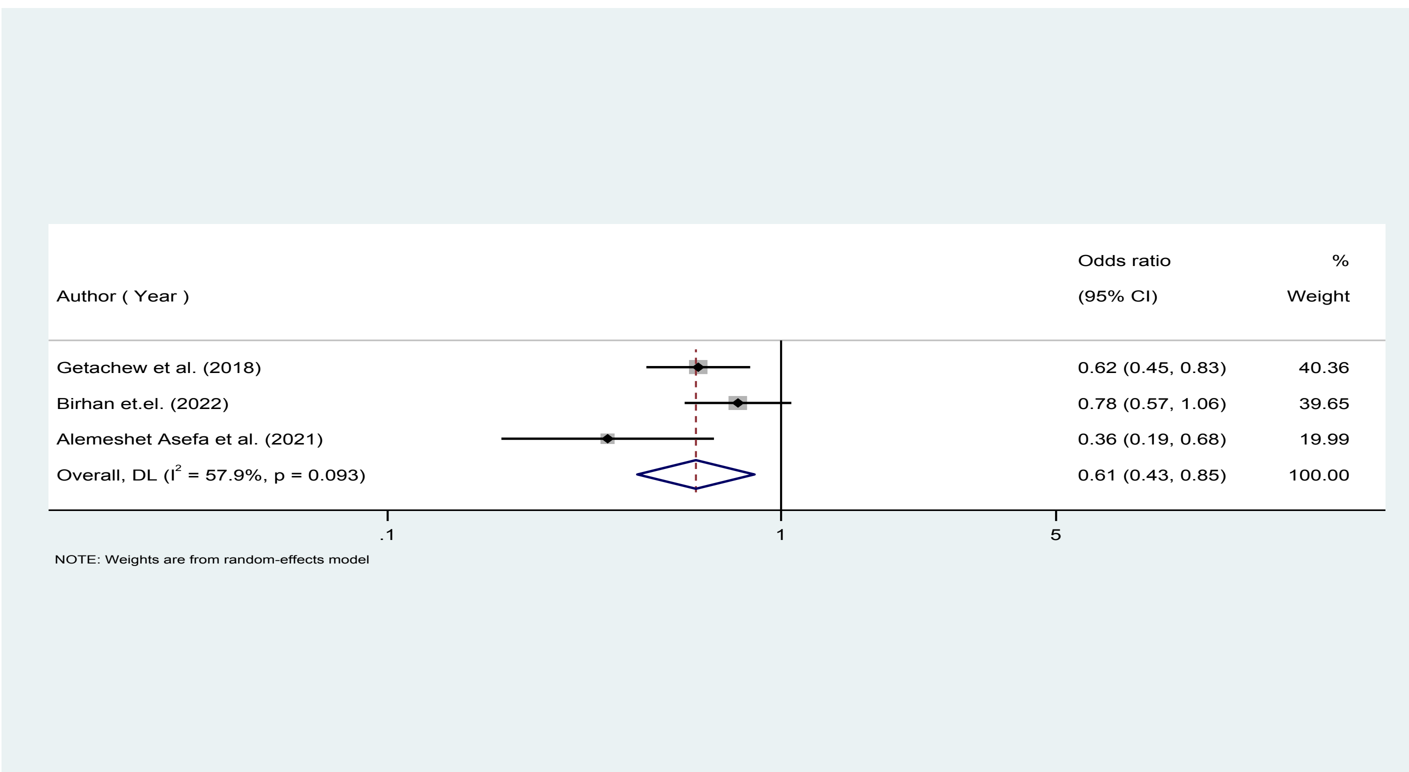

Figure 8: The pooled odd ratio of the association between the educational status of respondents and fecal coliform contamination of drinking water in Ethiopia

4. Discussion

Water quality is one of the most neglected public health problems in the world. The condition is worsening in the rural areas of many of the developing countries, including Ethiopia (49, 50). Estimating the pooled prevalence of fecal coliform contamination and its contributing factors in Ethiopia may inform decision-makers in the country to design effective intervention. To the best of our knowledge, this systematic review and meta-analysis is the first study to assess the pooled prevalence of fecal coliform contamination and its associated factors in drinking water in Ethiopia.

The current meta-analysis study revealed that more than half (55% (95% CI: 34, 77)) of drinking water samples in the study area was contaminated with fecal coliforms, which is in line with the systematic review and meta-analysis study conducted in low and middle-income countries (38%) (22), study conducted in Africa (53%) (51), in South-East Asia (35%) (51), Rwanda (75%) (52), and a study done in Pakistan (64.11%) (53), Pakistan (58%) (54), Pakistan (37%) (16). However, the prevalence of fecal coliform in the present study was lower than those studies conducted in Myanmar (94%) (55), Western Kenya (95%) (56), and Nepal (94%) (57). This difference might be due to differences in socioeconomic status, sample size, laboratory quality, trained manpower, study period, hand washing, and hygiene practices. All these factors may be contributed to microbial contamination of drinking water. The current study was not complying with WHO and Ethiopian standard agency guidelines for drinking water quality 0 CFU/100ml water sample for fecal coliform (19-21) , which call for urgent intervention to safeguard the health of the community. On the contrary, the pooled prevalence of fecal coliform in the current study was higher than studies conducted in Pakistan (23.8%) (58), Virginia USA (6.6%) (59), and Maryland USA (15.3%) (60). This might be due to the discrepancy in limited access to water treatment, knowledge and attitude towards water safety, availability and accessibility of safe drinking water, socioeconomic status, educational status, and types of water samples tested. This study finding indicates that many rural areas of Ethiopia rely on unimproved drinking water sources like unprotected wells, springs, rivers, or any other surface water sources that are potentially liable for contamination by environmental pollutants, including human and animal wastes as well as agricultural residues in the area. This situation significantly contributes to microbial contamination of drinking water at the source that threatens public health. The other possible reason that could have contributed to microbial contamination of drinking water in the study area is poor water handling at the household level, where the actual contamination occurred and significantly elevated the bacterial contamination of drinking water.

The current study was also aimed at identifying the associated factors of fecal coliform contamination of drinking water in the study area. In this study, the types of water sources, human beings sharing the same house with animals, water shortage, and educational status of the respondents were significantly associated with fecal coliform contamination of drinking water.

The likelihood of fecal coliform contamination of drinking water was 39% less likely to occur among households that can read and write as compared to their counterparts. The findings of this study are consistent the study conducted in Ghana (62%) (61). Even if the magnitude differs, education is a protective factor for fecal contamination of drinking water. The high prevalence of fecal coliform contamination of drinking water in households was higher in illiterate people. This might be due to a lack of awareness about water handling practices, hand washing habits, and infection transmission, as well as a poor awareness about pollution prevention and water treatment (62). In addition, education has a great impact on changing behaviors and attitudes at the household level that reduce microbial contamination of drinking water. Moreover, education may increase consciousness about methods of transmission and prevention of fecal coliform contamination that ultimately minimize microbial contamination of drinking water.

Households that used improved water sources for drinking purposes were 68% less likely to be exposed to contaminated water by fecal coliforms than their counterparts, which align with the study conducted in Ethiopia (63), Kenya (56), and Zimbabwe (64). This could be because of protected water sources are less exposed to contaminants like human and animal feces, plant leaves, floods and water runoff, higher rainfall, higher stream discharges, suspended sediment loads, microorganisms, soil dust, and particles (65-67). This contributes to less contamination of drinking water by fecal coliforms (68). On the other hand drinking water from unprotected water sources may have the chance of drinking water contamination by fecal coliform that endanger the health of the population.

Shortage of water was 3.3 times more likely to expose the household to fecal coliform contaminated water than those households that didn't face a water shortage. This finding corresponds with the study conducted in the Gaza Strip (69). This means that fecal coliform contamination of drinking water occurred as a result of intermittent water supply. This might be due to distribution line crust and spoilage, low attention to hand washing practices, and unsanitary activities in the household level (70), which facilitates contamination of drinking water by fecal coliforms.

Participants who shared their house with animals were 2.11 times more likely to exposed to drinking water contaminated by fecal coliforms as compared to their counterparts. This finding is in agreement with the study conducted in Uganda (71), Bangladesh (71), Nepal (72), Bangladesh (73), and Kenya (74). This might be due to close contact of animal feces with water, the household may not keeping its cleanliness, a lack of knowledge about animal feces removal, and poor hand washing practices. All these reasons could contribute to contamination of drinking water by fecal coliforms, since animal wastes are full of fecal coliforms (75, 76).

4.1. Strengths and Limitations of the Study

This systematic review and meta-analysis study had the following strength: first, the review used different databases to search all the relevant studies. Second, all the studies included in this meta-analysis were laboratory-based, which gives the findings better validity. Lastly, this systematic review and meta-analysis study follows the updated PRISMA guidelines. This systematic review and meta-analysis study had several limitations. First, most of the studies present the status of water quality in terms of risk level (low, medium, and high) and association with hygiene practice, and only a few studies used the percentage and proportion of fecal coliforms. Secondly, only a few microbial water quality studies were conducted in the country, which makes it difficult to obtain sufficient risk factors to make a pooled odds ratio of association. Thirdly, this study included only English articles. Fourth, all of the studies included in this review were cross-sectional; as a result, the outcome variable might be affected by other confounding variables. Some of the studies included in this review had a relatively small sample size, which could affect the estimated prevalence reported. Finally, this meta-analysis represented only studies reported from six regions of the country, which may reflect underrepresentation due to the limited number of available studies.

5. Conclusion

In this study, the pooled prevalence of fecal coliform contamination in drinking water samples was considerably high and failed to comply with WHO guidelines and Ethiopian standard agency guidelines for drinking water. The result for this systematic review and meta-analysis showed that using drinking water from improved water sources, shortage of drinking water, shared houses with animals, and the educational status of respondents were significantly associated with fecal coliform contamination of drinking water, which could increase the risk of infectious disease and may lead to waterborne outbreaks in the country unless appropriate measures are taken. Hence, the minister of health, along with the water and energy minister, ought to provide due attention to strengthen the quality and accessibility of safe drinking water. Moreover, strengthen and incorporate regular water quality monitoring programs into the surveillance system. Further, health education about household hygiene and sanitation practices, safe storage and handling of drinking water, proper disposal of animal excreta, including the separation of houses for humans and animals, and strengthening the existing health extension program were necessary to address the problem.

Abbreviations

CI: Confidence interval

GBI: Goanna Bridging Institute

OR: odd ratio

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SNNPR: South Nation Nationalities Peoples Region

TTC: Thermo-tolerant coliforms

USA: United States of America

WHO: World Health Organization

Declaration

Acknowledgment

Not applicable

Conflict of interest

The authors have declared that no competing interests exist.

Funding

There is no funding for this systematic review and meta-analysis.

Availability of data and materials

All the data and materials used in and/or analyzed during the study were included in the manuscript.

Authors' contributions

AD contributed to the conceptualization, methodology, analysis, validation, writing the original draft, writing the final version, and editing. BM contributed to providing support and guidance and helped with the methodology, analysis, validation, writing the original draft, writing the final version, and editing. SA and AM contributed to providing support and guidance and helped with the data extraction and analysis, validation, writing the original draft, writing the final version, and editing. All authors have read and approved the final manuscript.

Ethical approval and consent to participate

Not applicable because no primary data were collected.

Consent to publication

Not applicable

Clinical trial number

Not applicable

6. Reference

1. Sitotaw B, Melkie E, Temesgen DJJoe, health p. Bacteriological and physicochemical quality of drinking water in Wegeda Town, Northwest Ethiopia. 2021;2021.
2. Soboksa NE, Gari SR, Hailu AB, Alemu BMJPo. Association between microbial water quality, sanitation and hygiene practices and childhood diarrhea in Kersa and Omo Nada districts of Jimma Zone, Ethiopia. 2020;15(2):e0229303.
3. Nsoh FA, Wung BA, Atashili J, Benjamin PT, Marvlyn E, Ivo KK, et al. Prevalence, characteristics and correlates of enteric pathogenic protozoa in drinking water sources in Molyko and Bomaka, Cameroon: a cross-sectional study. 2016;16:1-9.
4. Abuzerr S, Nasseri S, Yunesian M, Yassin S, Hadi M, Mahvi AH, et al. Microbiological quality of drinking water and prevalence of waterborne diseases in the Gaza strip, Palestine: a narrative review. 2019;7(4):122-38.
5. Spijkers O. The sustainable human right to water as reflected in the sustainable development goals. Utrecht Law Review. 2020;16(2):18-32.
6. Cala-Wacinkiweicz E. Right to Water-Considerations in the Context of International Protection of Human Rights. US-China L Rev. 2014;11:1302.
7. Ibrahim IA. Water as a human right, water as a commodity: can SDG6 be a compromise? The International Journal of Human Rights. 2022;26(3):469-93.
8. Resolution U. The human right to water and sanitation. A/64/L. 63/Rev. 1*, 26 July; 2010.
9. Eman K, Meško G. Access to safe and affordable drinking water as a fundamental human right: The case of the Republic of Slovenia. The emerald handbook of crime, justice and sustainable development: Emerald Publishing Limited; 2020. p. 465-84.
10. Oliveira CMd. Sustainable access to safe drinking water: fundamental human right in the international and national scene. Revista Ambiente & Água. 2017;12(6):985-1000.
11. Ashuro Z, Aregu MB, Kanno GG, Negassa B, Soboksa NE, Alembo A, et al. Bacteriological quality of drinking water and associated factors at the internally displaced people Sites, Gedeo zone, Southern Ethiopia: a cross-sectional study. 2021;15:11786302211026469.
12. Alemeshet Asefa Y, Alemu BM, Baraki N, Mekbib D, Mengistu DAJPO. Bacteriological quality of drinking water from source and point of use and associated factors among households in eastern Ethiopia. 2021;16(10):e0258806.
13. Sari SYI, Faisal M, Raksanagara AS, Agustian D, Rusmil K. Water quality and factors associated with compliance of drinking water refilling stations as a choice for middle–low urban households in developing countries. Journal of Water and Environment Technology. 2020;18(1):27-36.
14. Daniel D, Diener A, van De Vossenberg J, Bhatta M, Marks SJ. Assessing drinking water quality at the point of collection and within household storage containers in the hilly rural areas of mid and far-western Nepal. International journal of environmental research and public health. 2020;17(7):2172.
15. Myint SLT, Myint T, Aung WW, Wai KT. Prevalence of household drinking-water contamination and of acute diarrhoeal illness in a periurban community in Myanmar. WHO South-East Asia journal of public health. 2015;4(1):62-8.
16. Khan K, Lu Y, Saeed MA, Bilal H, Sher H, Khan H, et al. Prevalent fecal contamination in drinking water resources and potential health risks in Swat, Pakistan. Journal of Environmental Sciences. 2018;72:1-12.
17. Kifayatullah Khan KK, Lu YongLong LY, Saeed M, Hazrat Bilal HB, Hassan Sher HS, Hizbullah Khan HK, et al. Prevalent fecal contamination in drinking water resources and potential health risks in Swat, Pakistan. 2018.

18. Daud M, Nafees M, Ali S, Rizwan M, Bajwa RA, Shakoor MB, et al. Drinking water quality status and contamination in Pakistan. BioMed research international. 2017;2017(1):7908183.

19. Edition FJWc. Guidelines for drinking-water quality. 2011;38(4):104-8.

20. Bain R, Cronk R, Hossain R, Bonjour S, Onda K, Wright J, et al. Global assessment of exposure to faecal contamination through drinking water based on a systematic review. Tropical Medicine & International Health. 2014;19(8):917-27.

21. Heasley C, Sanchez JJ, Tustin J, Young I. Systematic review of predictive models of microbial water quality at freshwater recreational beaches. PloS one. 2021;16(8):e0256785.

22. Bain R, Cronk R, Wright J, Yang H, Slaymaker T, Bartram JJPm. Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. 2014;11(5):e1001644.

23. Fakhr AE, Gohar MK, Atta AH. Impact of Some Ecological Factors on Fecal Contamination of Drinking Water by Diarrheagenic Antibiotic-Resistant Escherichia coli in Zagazig City, Egypt. International Journal of Microbiology. 2016;2016(1):6240703.

24. Bain R, Cronk R, Wright J, Yang H, Slaymaker T, Bartram J. Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. PLoS medicine. 2014;11(5):e1001644.

25. Tegen D, Damtie D, Hailegebriel TJJopr. Prevalence and associated risk factors of human intestinal protozoan parasitic infections in Ethiopia: a systematic review and meta-analysis. 2020;2020.

26. Birhan TA, Destaw B, Dagne H, Eyachew D, Azanaw J, Andualem Z, et al. Quality of household drinking water and its associated risk factors in ood-prone settings of Northwest Ethiopia: a cross-sectional community-based study. 2022.

27. Getachew A, Tadie A, Chercos DH, Guadu TJEjohs. Level of faecal coliform contamination of drinking water sources and its associated risk factors in rural settings of north Gondar Zone, Ethiopia: a cross-sectional community based study. 2018;28(2):227-34.

28. Tiku S, Legesse W, Endale H, Faris KJEjohs. Factors affecting drinking water quality from source to home in Tehuledere Woreda, Northeast Ethiopia. 2003;13(2).

29. Kahale LA, Piechotta V, McKenzie JE, Dorando E, Iannizzi C, Barker JM, et al. Extension of the PRISMA 2020 statement for living systematic reviews (LSRs): protocol. 2022;11:109.

30. Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. 2015;349.

31. Cohen A, Cui J, Song Q, Xia Q, Huang J, Yan X, et al. Bottled water quality and associated health outcomes: a systematic review and meta-analysis of 20 years of published data from China. 2022;17(1):013003.

32. Hormel L, Wardropper CB, Scott CB, Gallardo MVI, Roon D, Armijos CIJCSitE. Factors influencing water quality perceptions in an urban and rural watershed in southern Ecuador: a case study of applied interdisciplinary research training in Ecuador. 2021;5(1):1434937.

33. Olatunde K, Patton SK, Cameron L, Stankus T, Milaham PJJAJoWR. Factors affecting the quality of drinking water in the United States of America: a ten-year systematic review. 2022;10(1):24-34.

34. Schenck D, editor Bayesian time series in Stata 17. Swiss Stata Conference 2022; 2022: Stata Users Group.

35. Fidler V, Nagelkerke NJPO. The Mantel-Haenszel procedure revisited: models and generalizations. 2013;8(3):e58327.

36. Soboksa NE, Gari SR, Hailu AB, Donacho DO, Alemu BMJSR. The effectiveness of solar disinfection water treatment method for reducing childhood diarrhea: a systematic review and meta-analysis protocol. 2020;9:1-5.

37. Soboksa NE, Gari SR, Hailu AB, Donacho DO, Alemu BMJBo. Effectiveness of solar disinfection water treatment method for reducing childhood diarrhoea: a systematic review and meta-analysis. 2020;10(12):e038255.

38. Desye B, Tesfaye AH, Berihun G, Sisay T, Daba C, Berhanu LJPo. Household water treatment practice and associated factors in Ethiopia: A systematic review and meta-analysis. 2023;18(6):e0285794.

39. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. bmj. 2021;372.

40. Boers M. Graphics and statistics for cardiology: designing effective tables for presentation and publication. Heart. 2018;104(3):192-200.

41. Sitotaw B, Teferi D, Wossen Z, Tadesse BJJoW, Sanitation, Development Hf. Drinking water quality and associated factors in Bahir Dar City and the surrounding rural areas, Northwest Ethiopia: a community-based cross-sectional study. 2023;13(8):584-94.

42. Gebrewahd A, Adhanom G, Gebremichail G, Kahsay T, Berhe B, Asfaw Z, et al. Bacteriological quality and associated risk factors of drinking water in Eastern zone, Tigrai, Ethiopia, 2019. 2020;6:1-7.

43. Mekonnen GK, Mengistie B, Sahilu G, Mulat W, Kloos HJJoW, Sanitation, Development Hf. Determinants of microbiological quality of drinking water in refugee camps and host communities in Gambella Region, Ethiopia. 2019;9(4):671-82.

44. Getachew A, Tadie A, Chercos DH, Guadu T, Alemayehu M, Gizaw Z, et al. Bacteriological quality of household drinking water in North Gondar Zone, Ethiopia; a community-based cross-sectional study. 2021;11(12):189.

45. Berihun G, Abebe M, Hassen S, Gizeyatu A, Berhanu L, Teshome D, et al. Drinking water contamination potential and associated factors among households with under-five children in rural areas of Dessie Zuria District, Northeast Ethiopia. 2023;11:1199314.

46. Gebremedhn G, Berhe AA, Desta AA, Legesse L. Is Drinking Water Sources Safe for Drink? A Multicenter Assessment of Fecal Contamination of Drinking Water Sources in Tigray Region, Ethiopia. 2019.

47. Asfaw HS, Reta MA, Yimer FGJEJoHD. High enteric bacterial contamination of drinking water in Jigjiga city, Eastern Ethiopia. 2016;30(3):118-28.

48. Gizachew M, Admasie A, Wegi C, Assefa EJIJoM. Bacteriological contamination of drinking water supply from protected water sources to point of use and water handling practices among beneficiary households of boloso sore woreda, wolaita zone, Ethiopia. 2020;2020.

49. Wen X, Chen F, Lin Y, Zhu H, Yuan F, Kuang D, et al. Microbial indicators and their use for monitoring drinking water quality—A review. 2020;12(6):2249.

50. Osiemo MM, Ogendi GM, M'Erimba CJEhi. Microbial quality of drinking water and prevalence of water-related diseases in Marigat Urban Centre, Kenya. 2019;13:1178630219836988.

51. Bain R, Cronk R, Hossain R, Bonjour S, Onda K, Wright J, et al. Global assessment of exposure to faecal contamination through drinking water based on a systematic review. 2014;19(8):917-27.

52. Kirby MA, Nagel CL, Rosa G, Iyakaremye L, Zambrano LD, Clasen TFJSotTE. Faecal contamination of household drinking water in Rwanda: A national cross-sectional study. 2016;571:426-34.

53. Fatima A, Urooj S, Mirani ZA, Abbas T, Khan MNJPM. Fecal coliform contamination of drinking water in Karachi, Pakistan. 2021;6(2):42-8.

54. Nabeela F, Azizullah A, Bibi R, Uzma S, Murad W, Shakir SK, et al. Microbial contamination of drinking water in Pakistan—a review. 2014;21:13929-42.

55. Myint SLT, Myint T, Aung WW, Wai KTJWS-EAjoph. Prevalence of household drinking-water contamination and of acute diarrhoeal illness in a periurban community in Myanmar. 2015;4(1):62-8.

56. Opisa S, Odiere MR, Jura WG, Karanja DM, Mwinzi PNJWS, Technology. Faecal contamination of public water sources in informal settlements of Kisumu City, western Kenya. 2012;66(12):2674-81.

57. Sarkar B, Mitchell E, Frisbie S, Grigg L, Adhikari S, Byanju RMJJoE, et al. Drinking water quality and public health in the Kathmandu Valley, Nepal: coliform bacteria, chemical contaminants, and health status of consumers. 2022;2022.

58. Shoaib M, Asad MJ, Aziz S, Usman M, Rehman A, Zafar MM, et al. Prevalence of pathogenic microorganisms in drinking water of Rawalpindi and Islamabad. 2016;8(1):14-21.

59. Smith T, Krometis L-AH, Hagedorn C, Lawrence AH, Benham B, Ling E, et al. Associations between fecal indicator bacteria prevalence and demographic data in private water supplies in Virginia. 2014;12(4):824-34.

60. Murray RT, Rosenberg Goldstein RE, Maring EF, Pee DG, Aspinwall K, Wilson SM, et al. Prevalence of microbiological and chemical contaminants in private drinking water wells in Maryland, USA. International journal of environmental research and public health. 2018;15(8):1686.

61. Opryszko MC, Guo Y, MacDonald L, MacDonald L, Kiihl S, Schwab KJJTAjotm, et al. Impact of water-vending kiosks and hygiene education on household drinking water quality in rural Ghana. 2013;88(4):651.

62. Sharma B, Singh P, Dobhal RJAJoER. Education on Drinking Water Quality and Its Health Impacts among Students and Community People. 2017;5(4):400-8.

63. Mengesha A, Wubshet M, Gelaw BJTEJoHD. A survey of bacteriological quality of drinking water in North Gondar. 2004;18(2).

64. Munyebvu F. Variations in groundwater quality in protected and unprotected water sources of Murehwa district. 2014.

65. Hrudey SE, Hrudey EJ. Safe drinking water: IWA publishing; 2004.

66. Ten Veldhuis J, Clemens F, Sterk G, Berends BJWr. Microbial risks associated with exposure to pathogens in contaminated urban flood water. 2010;44(9):2910-8.

67. Sirajul Islam M, Brooks A, Kabir M, Jahid I, Shafiqul Islam M, Goswami D, et al. Faecal contamination of drinking water sources of Dhaka city during the 2004 flood in Bangladesh and use of disinfectants for water treatment. 2007;103(1):80-7.

68. Pal M, Ayele Y, Hadush M, Panigrahi S, Jadhav VJAWBD. Public health hazards due to unsafe drinking water. 2018;7(1000138):2.

69. Amr SA, Yassin MMJPh. Microbial contamination of the drinking water distribution system and its impact on human health in Khan Yunis Governorate, Gaza Strip: seven years of monitoring (2000–2006). 2008;122(11):1275-83.

70. Boithias L, Choisy M, Souliyaseng N, Jourdren M, Quet F, Buisson Y, et al. Hydrological regime and water shortage as drivers of the seasonal incidence of diarrheal diseases in a tropical montane environment. 2016;10(12):e0005195.

71. Ercumen A, Pickering AJ, Kwong LH, Arnold BF, Parvez SM, Alam M, et al. Animal feces contribute to domestic fecal contamination: evidence from E. coli measured in water, hands, food, flies, and soil in Bangladesh. 2017;51(15):8725-34.

72. Malla B, Ghaju Shrestha R, Tandukar S, Bhandari D, Inoue D, Sei K, et al. Identification of human and animal fecal contamination in drinking water sources in the Kathmandu Valley, Nepal, using host-associated Bacteroidales quantitative PCR assays. 2018;10(12):1796.

73. Ferdous J, Rashid RB, Sultana R, Saima S, Jahan Prima M, Begum A, et al. Is It Human or Animal? The Origin of Pathogenic E. coli in the Drinking Water of a Low-Income Urban Community in Bangladesh. 2021;6(4):181.

74. da Silva DTG, Ebdon J, Okotto-Okotto J, Ade F, Mito O, Wanza P, et al. A longitudinal study of the association between domestic contact with livestock and contamination of household point-of-use stored drinking water in rural Siaya County (Kenya). 2020;230:113602.

75. do Amaral LAJBJoPS. Drinking water as a risk factor to poultry health. 2004;6:191-9.

76. Dufour A, Bartram J. Animal waste, water quality and human health: IWA publishing; 2012.