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Prevalence and epidemiological distribution of indicators of pathogenic bacteria in households drinking water in Ethiopia: a systematic review and meta-analysis

Ermias Alemayehu Adugna[1*], Abel Weldetinsae[1], Zinabu Assefa Alemu[1], Alemneh Kabeta Daba[1], Daniel Abera Dinssa[1], Tiruneh Tariku[2], Mesaye Getachew Weldegebriel[1], Melaku Gizaw Serte[1], Kirubel Tesfaye Teklu[1], Moa Abate Kenea[1], Gebretsadik Keleb Yehuala[3], Masresha Tessema[1] and Aderajew Mekonnen Girmay[1]

Abstract

Background Ensuring the availability of safe drinking water remains a critical challenge in developing countries, including Ethiopia. Therefore, this paper aimed to investigate the prevalence of fecal coliform and *E. coli* bacteria and, geographical, children availability, and seasonal exposure assessment through a meta-analysis.

Methods Two independent review groups extensively searched internet databases for English-language research articles published between 2013 and 2023. This systematic review and meta-analysis followed PRISMA guidelines. The methodological quality of each included study was evaluated using the STROBE guidelines. Publication bias was assessed by visual inspection of a funnel plot and then tested by the Egger regression test, and meta-analysis was performed using DerSimonian and Laird random-effects models with inverse variance weighting. Subgroup analyses were also conducted to explore heterogeneity.

Results Out of 48 potentially relevant studies, only 21 fulfilled the inclusion criteria and were considered for meta-analysis. The pooled prevalence of fecal coliform and *E. coli* was 64% (95% CI: 56.0–71.0%, $I^2=95.8\%$) and 54% (95% CI: 45.7–62.3%, $I^2=94.2\%$), respectively. Subgroup analysis revealed that the prevalence of fecal coliform bacteria increased during the wet season (70%) compared to the dry season (60%), particularly in households with under-five children (74%) compared to all households (61%), in rural (68%) versus urban (66%) areas, and in regions with high prevalence such as Amhara (71%), Gambela (71%), and Oromia (70%). Similarly, the prevalence of *E. coli* was higher in households with under-five children (66%) than in all households (46%).

Conclusions The analysis highlights the higher prevalence of fecal coliform and *E. coli* within households drinking water, indicating that these bacteria are a significant public health concern. Moreover, these findings emphasize the critical need for targeted interventions aimed at improving drinking water quality to reduce the risk of fecal contamination and enhance public health outcomes for susceptible groups, including households with under-five

*Correspondence:
Ermias Alemayehu Adugna
ermi.alex03@gmail.com

Full list of author information is available at the end of the article

children, in particular geographical areas such as the Amhara, Gambela, and Oromia regions, as well as rural areas, at point-of-use, and during the rainy season.

Registration This review was registered on PROSPERO (registration ID - CRD42023448812).

Keywords Prevalence, Fecal coliform, *E. Coli*, Ethiopia, Meta-analysis and systematic review

Introduction

An essential requirement for the health and well-being of people is access to safe drinking water. However, most of the world's population lacks access to adequate, sustainable, and safe water [1, 2]. Considering this, in 2015, the United Nations ratified different developmental goals, including the Sustainable Development Goal (SDG) 6.1, which aspires to achieve universal and equitable access to safe and affordable drinking water for all by 2030 [3]. This goal emphasizes having access to safe drinking water for every household [4]. To monitor this phenomenon, most countries, including Ethiopia, have adopted the World Health Organization's (WHO) guidelines for drinking water quality [1].

Worldwide, water-related diseases account for approximately 80% of all illnesses and diseases and, in turn, cause an estimated 505,000 diarrheal deaths each year [5]. Children are more susceptible to microbiological pollutants and develop an illness due to their immature immune systems [6]. As a result, waterborne diseases continue to be major health problems worldwide. Particularly in most developing nations where access to potable water is scarce, water-borne diseases are a serious public health concern as a result of bacterial contamination of drinking water [7]. Water-borne pathogenic bacteria could infect or harm humans by secreting toxins that could harm human tissue, living as parasites within human cells, or colonizing within the body to interfere with regular bodily processes. Numerous harmful bacteria, such as fecal coliforms, *Escherichia coli*, *Salmonella typhi*, and *Vibrio cholerae*, have been identified in water [8]. These bacteria can lead to various waterborne diseases, including cholera, typhoid, and diarrhea [5].

In developing countries, the main causes of diarrheal diseases are bacteria, protozoa, viruses, and helminths [9]. Specifically, in rural areas of most developing countries, where water sources are communally shared and exposed to several fecal-oral transmission channels within their local boundaries, *fecal* contamination of drinking water is a primary cause of water-borne diseases, including fatal diarrhea [10]. This could be detected by examining the presence of potential indicator organisms such as fecal coliforms [11, 12].

Several pathogenic bacteria can be transmitted via polluted drinking water [13, 14]. Drinking water can be polluted at the source, distribution line, and/or household level, and such polluted water can be a vehicle for several pathogens [2, 15]. In Ethiopia, poor environmental health conditions resulting from subpar water quality and inadequate hygiene and sanitation standards are responsible for more than 60% of infectious diseases [16]. Studies conducted in Ethiopia revealed that the prevalence of fecal contamination in drinking water, including *Escherichia coli* (*E. coli*), total coliforms (TC), and fecal coliforms, have been extremely high [17–22].

This could be due to many reasons, as water safety depends on various factors, from the quality of the source water to its storage and handling practices in the home [23]. Even if the source is clean, the process of collecting, transporting, storing, and drawing water in the household can all lead to fecal contamination [17]. In addition, pollutants in drinking water sources include human excreta, animal waste, effluent agricultural practices, and floods, as well as a lack of knowledge among end-users about hygiene and environmental cleanliness [17, 24]. Due to inadequate access and frequent interruptions in the piped water supply [25], drinking water is commonly stored, often for considerable lengths of time, resulting in gross contamination [26].

Therefore, understanding the extent and epidemiological variation of bacterial contamination in household drinking water is vital for policymakers and public health officials to allocate resources efficiently and target interventions effectively to reduce the burden of waterborne illnesses in Ethiopia. Despite individual studies on contamination levels, there is a notable research gap due to the lack of a national systematic review and meta-analysis. Existing research does not fully examine how contamination varies with factors such as children's availability, geographic regions, water sources, and seasonal changes. This study aims to address this gap by offering a comprehensive review and meta-analysis, providing essential insights for policymakers to effectively allocate resources and target interventions to reduce waterborne illnesses and support vulnerable groups.

Methodology

Data sources and search strategy

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [S1] and the protocol of this study was registered with the International Prospective Register of Systematic Reviews (PROSPERO), with protocol registration number CRD42023448812. With a focus on English-language materials, we conducted an exhaustive search across numerous electronic databases, including PubMed, Web of Science, Google Scholar, ScienceDirect, ProQuest, Directory of Open Access Journals, POPLINE, African Journals Online, and the Cochrane Library. The search strategy included a combination of keywords and controlled vocabulary related to Ethiopia, drinking water, and specific indicators of pathogenic bacteria. Moreover, the search strategies for Google Scholar were [Microbiological OR Microorganisms OR Organisms OR Bacteriological OR pathogens] AND ["Water quality" OR "Water contamination"] AND [household OR domestic OR residential OR home] AND ["Drinking water"] AND [intitle: Ethiopia], and those for Pubmed were ((Microbiological OR Microorganisms OR Organisms OR Bacteriological OR pathogens) AND ("Water quality" OR "Water contamination")) AND (household OR domestic OR residential OR home)) AND ("Drinking water")) AND (Ethiopia [Title]). we have provided a detailed breakdown of the query [S5].

Study selection criteria

Studies were included if they met the following criteria: (i) Original research was conducted in Ethiopia, and only peer-reviewed journal articles, as they undergo rigorous review processes and were more likely to meet high-quality standards; (ii) Focus on the prevalence of those specific indicators of pathogenic bacteria in household drinking water; (iii) Published in English; (vi) Articles with a cross-sectional study, had freely available full texts and were published between 2013 and 2023. However, articles with no clear data were excluded.

Methodological quality of the included studies

Two groups independently assessed the methodological rigor of every study included, employing the Strengthening the Reporting of Observational Studies

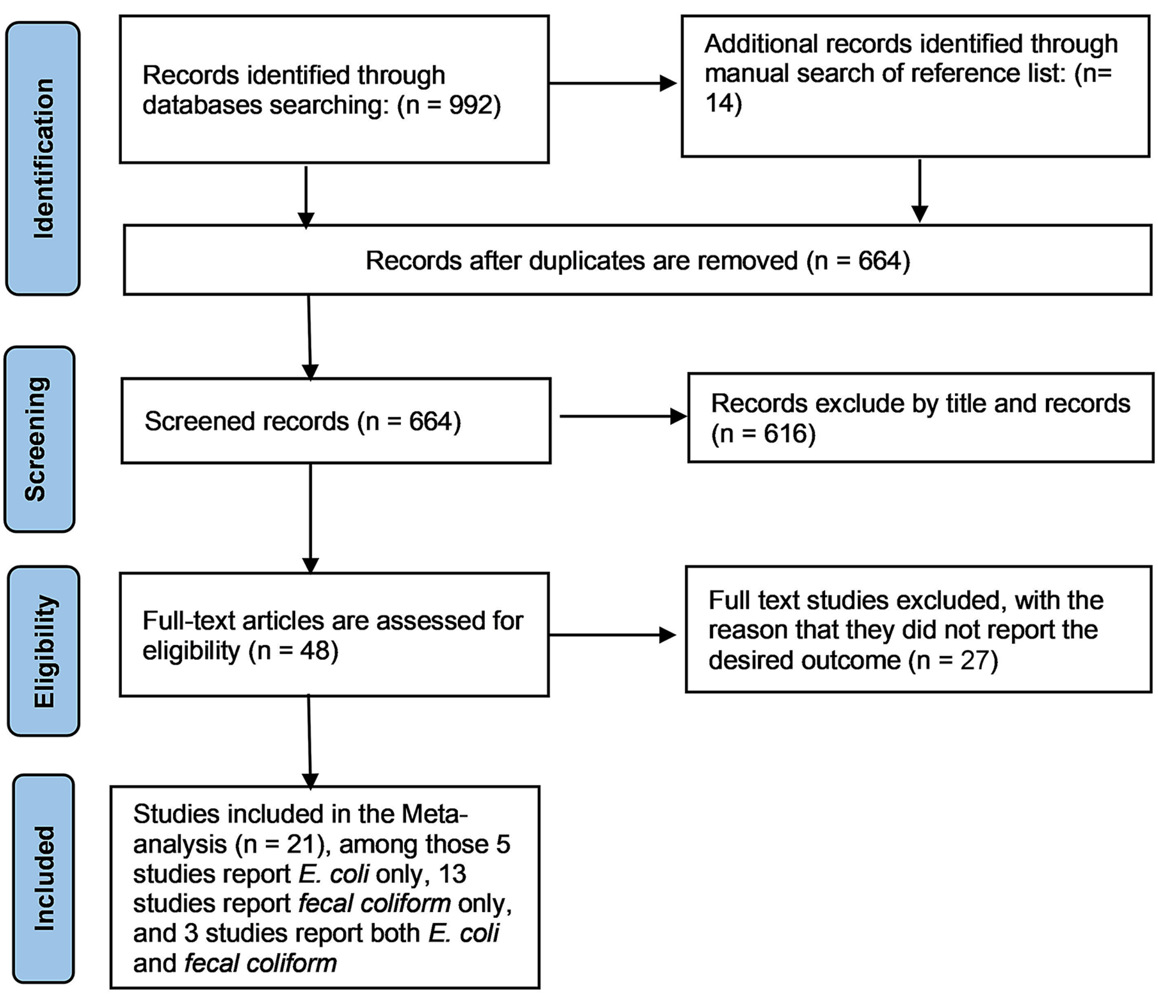

Fig. 1 Flow diagram indicating how articles were included and excluded during the meta-analysis of household drinking water contamination in Ethiopia

in Epidemiology (STROBE) guidelines [27]. Each study was then classified based on its quality: "Good" (G) if it achieved a score of at least 70% of the total points, "Fair" (F) if it scored between 50% and 69%, and "Poor" (P) if its score was below 50% [S2].

Extraction and analysis

Following the selection of pertinent articles, two investigators individually screened the titles and abstracts to determine their suitability for full-text review. Subsequently, these investigators utilized a standardized data extraction template in Microsoft Office Excel 2021 to collect study characteristics, prevalence, sample sizes, season, child availability, water sources, and geographic locations. In the event of any disagreements between the two investigators, a third investigator intervened, and their decision was considered final. The data analysis was performed using STATA 16.0 software. Random effects meta-analysis models were used to investigate the pooled prevalence of indicators of pathogenic bacterial contaminants using DerSimonian and Laird's approach with 95% confidence intervals (*CIs*) [28]. The inverse of the Freeman-Tukey double arcsine transformation was used to stabilize the variance of each study [29].

A forest plot was generated to visually assess the pooled prevalence estimates and corresponding 95% confidence intervals (*CIs*) across the included studies. For statistical heterogeneity across studies, the I^2 statistic was used [30]. Heterogeneity was considered high, moderate, or low, with I^2 values of 75, 50, and 25%, respectively. To identify potential sources of heterogeneity, subgroup analyses were conducted in under-five children's availability, seasons, residential, water sources, and regional settings. Publication bias was assessed by visual inspection of the funnel plot and tested by the Egger regression test [31, 32].

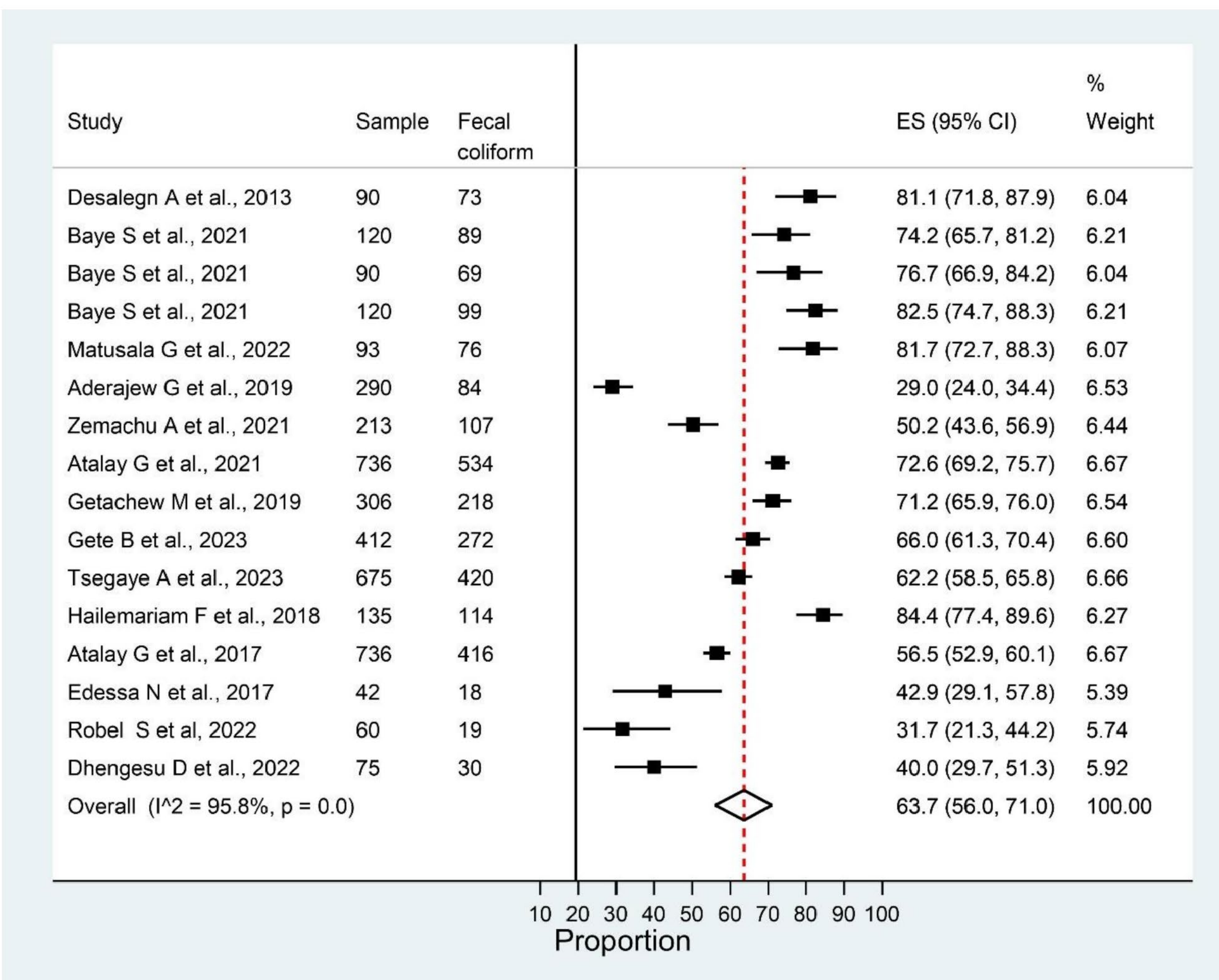

Fig. 2 Forest plot of the prevalence of fecal coliform bacteria in households drinking water in Ethiopia

Results

Search results

A total of 992 articles were identified from the nine databases, and an additional 14 articles were identified through additional manual searching. Three hundred forty-two studies were removed due to being duplicates found both within the same database and across different databases. A total of 616 studies were determined to be ineligible during title and abstract screening. At the full-text review stage, 27 articles were excluded because they did not measure microbial indicators of interest. The flow chart of the study selection process is presented in Fig. 1, generated using the PRISMA flow diagram [33].

Characteristics of the included studies

This study included 16 studies with 4,193 samples for fecal coliform [17, 34–48], and eight studies with 2,594 samples for *E. coli* analysis [38, 46, 48–53]. The main characteristics of the selected studies are summarized in the article matrix [S2]. All the articles were cross-sectional studies and followed a random sampling procedure. The articles included in the study were conducted between 2013 and 2023 and sample sizes ranged from 42 to 538 for *E. coli* and from 42 to 736 for fecal coliforms.

The data were collected from seven regions of Ethiopia. Nine studies in Amhara region [35, 36, 40, 42–45, 49, 51], one study each in Sidama [47], Somali [53] and Gambela [41] regions, two studies each in Oromia [17, 46], and Tigray [34, 38] regions, four studies in SNNPR [37, 39, 48, 52], and one study in all over Ethiopia [50] were conducted. Moreover, six studies were conducted in households with under-five children only [41, 42, 44, 49, 51, 53].

Pooled meta-analysis

The forest plot of the prevalence estimates and the corresponding 95% confidence intervals (*CIs*) of the contaminants are presented in Figs. 2 and 3. The pooled prevalence of fecal coliform was 63.7% (95% CI: 56.0–71.0%, I^2=95.8%, based on 16 studies) in a total sample of 4193 households. Additionally, the pooled prevalence of *E. coli* was 54.0 (95% CI: 45.7–62.3%, I^2=94.2%, based on 8 studies) in a total sample of 2,594 households. The funnel plot [S3] showed almost no publication bias, which was confirmed by the Egger regression test for

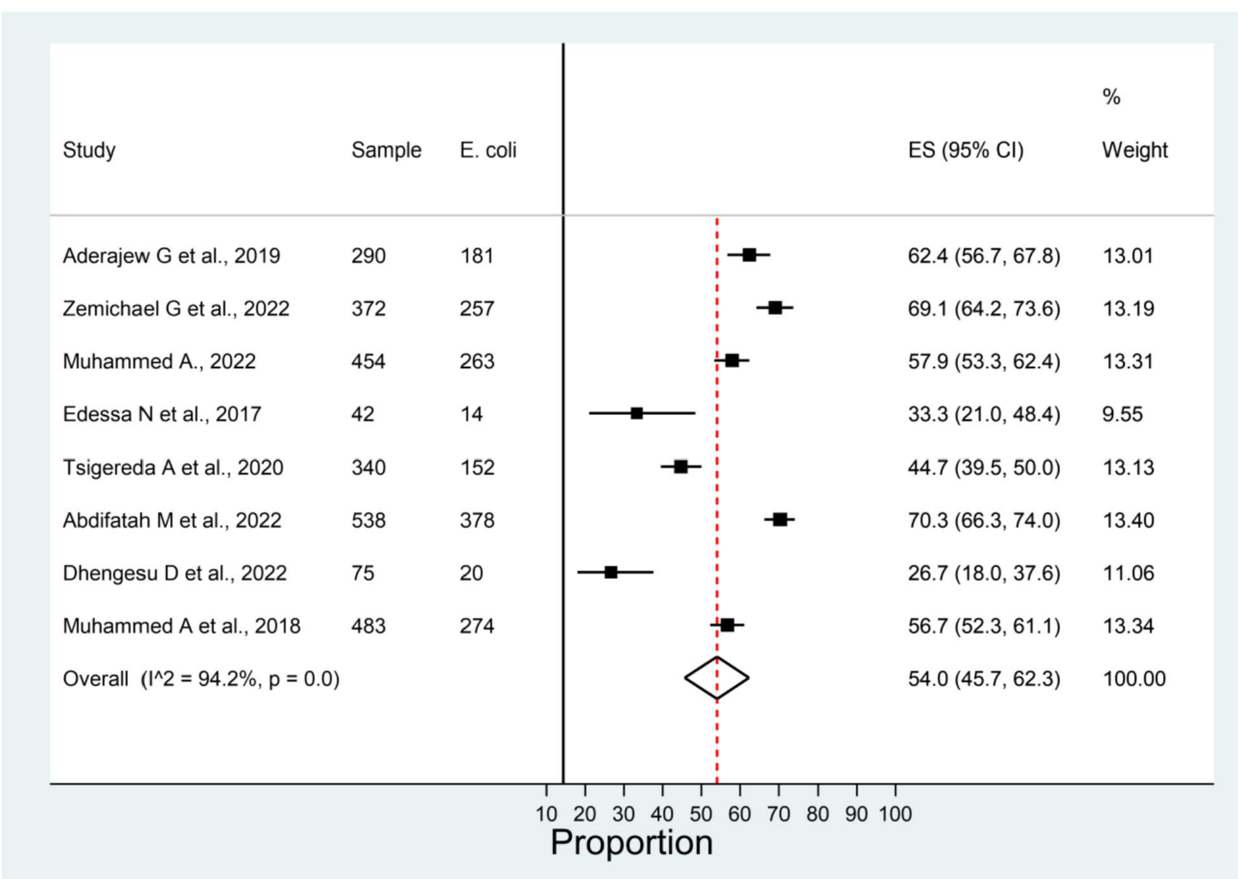

Fig. 3 Forest plot of the prevalence of *E. coli* in households drinking water in Ethiopia

both fecal coliform (p=0.10) and *E. coli* (p=0.18). Moreover, no publication bias was confirmed by the 'Trim and Fill' sensitivity analysis, as we did not find any hypothetical missing studies. A leave-one-out sensitivity analysis found that excluding any single study resulted in an average variation of 1% in the pooled prevalence of fecal coliforms and 1.93% for *E. coli*, indicating no substantial impact on the overall results.

Heterogeneity and subgroup analysis

The pooled prevalence of fecal coliform among the dry seasons samples was 60.1% (95% CI: 47.4–72.1), while for the wet seasons samples, it was 70.3% (95% CI: 63.8–76.3). When stratified by residence, the pooled prevalence in rural and urban areas were 68.0% [95%CI: 59.0–76.3] and 66.4% [95%CI: 49.1–81.7], respectively. Specifically, households with under-five children had a higher prevalence of fecal coliform (73.8% [95% CI: 63.9–82.7%]) than all households without any restrictions (61.0% [95% CI: 51.8–69.8]). When stratified by regions, the prevalence of fecal coliform was highest (71.4%) in Amhara, 71.2% in Gambela, and 70.1% in Oromia, compared with 58.1% in SNNP, 31.7% in Sidama, and 42.0% in Tigray. Regarding sample collection sources, the prevalence of fecal coliform is higher at the point of use (66.4% [95% CI: 57.3–74.9]) compared to the point of source (57.8% [95% CI: 42.0-72.3]). No significant publication bias was observed in any of the subgroup analyses (Table 1).

The pooled prevalence of *E. coli* (Fig. 4) among only households with under-five children was 65.9% (95% CI: 57.9–73.4), while for all households, it was 45.9% (95% CI: 35.2–56.9). The detailed distribution of the pooled prevalence of *E. coli* in household drinking water is shown in a table [S4].

Discussion

This systematic review and meta-analysis aimed to compile all available data reporting the prevalence and epidemiological distribution of indicators of pathogenic bacteria in households' drinking water in Ethiopia. The study findings help enhance public health interventions in Ethiopia by identifying vulnerable groups and suggesting appropriate measures to reduce the impact of waterborne diseases. This knowledge enables more targeted interventions to mitigate the effects of such diseases effectively. The findings of this systematic review and meta-analysis revealed that the pooled prevalence of fecal coliforms in households' drinking water in the 16 cross-sectional studies with 4193 samples was 63.7% (95% CI: 56.0, 71.0%).

This is lower than that found in a similar systematic review and meta-analysis in developing countries, where the fecal contamination of household drinking water was 75% (95% CI: 64, 84%) [54]. Differently, this is comparably high compared to the pooled prevalence in Africa (53%, 95% CI: 42, 63%); and also, significantly higher than the study conducted in South-East Asia (35%, 95%

Table 1 Pooled prevalence of fecal coliform and its risk factors in households' drinking water

Characteristics	studies	Sample	Fecal coliform	Prevalence, % (95%CI)	I^2, %	Heterogeneity	*P*-Egger test
Season							0.1007
Dry season	8	1953	1140	60.1[47.4, 72.1]	0.965	< 0.0001	
Wet season	2	210	144	70.3[63.8, 76.3]	.	.	
Both seasons	6	2030	1354	68.4[59.1, 76.9]	0.935	< 0.0001	
Target groups							.
All households	13	2394	2034	61.0[51.8, 69.8]	0.961	< 0.0001	
Households with under-five children	3	853	604	73.8[63.9, 82.7]	.	.	
Residence							0.0976
Rural	6	2109	1389	68.0[59.0, 76.3]	0.932	< 0.0001	
Urban	6	480	420	66.4[49.1, 81.7]	0.946	< 0.0001	
Both	4	1484	829	53.3[35.7, 70.4]	0.977	< 0.0001	
Region							0.1122
Amhara	7	2168	1924	71.4[64.2, 78.0]	0.936	< 0.0001	
Gambela	1	306	218	71.2[65.9, 76.0]	.	.	
Oromia	2	132	91	70.1[61.9, 77.7]	.	.	
SNNP	3	381	213	58.1[34.4, 80.0]	.	.	
Sidama	1	60	19	31.7[21.3, 44.2]	.	.	
Tigray	2	410	173	42.0[37.3, 46.9]	.	.	
Sources of sample collection by point							0.1005
Point-of-source	5	1635	898	57.8[42.0, 72.3]	0.973	< 0.0001	
Point-of-use	5	2033	1370	66.4[57.3, 74.9]	0.936	< 0.0001	
Both point-of-source and point-of-use	6	525	370	66.5[50.5, 80.8]	0.928	< 0.0001	

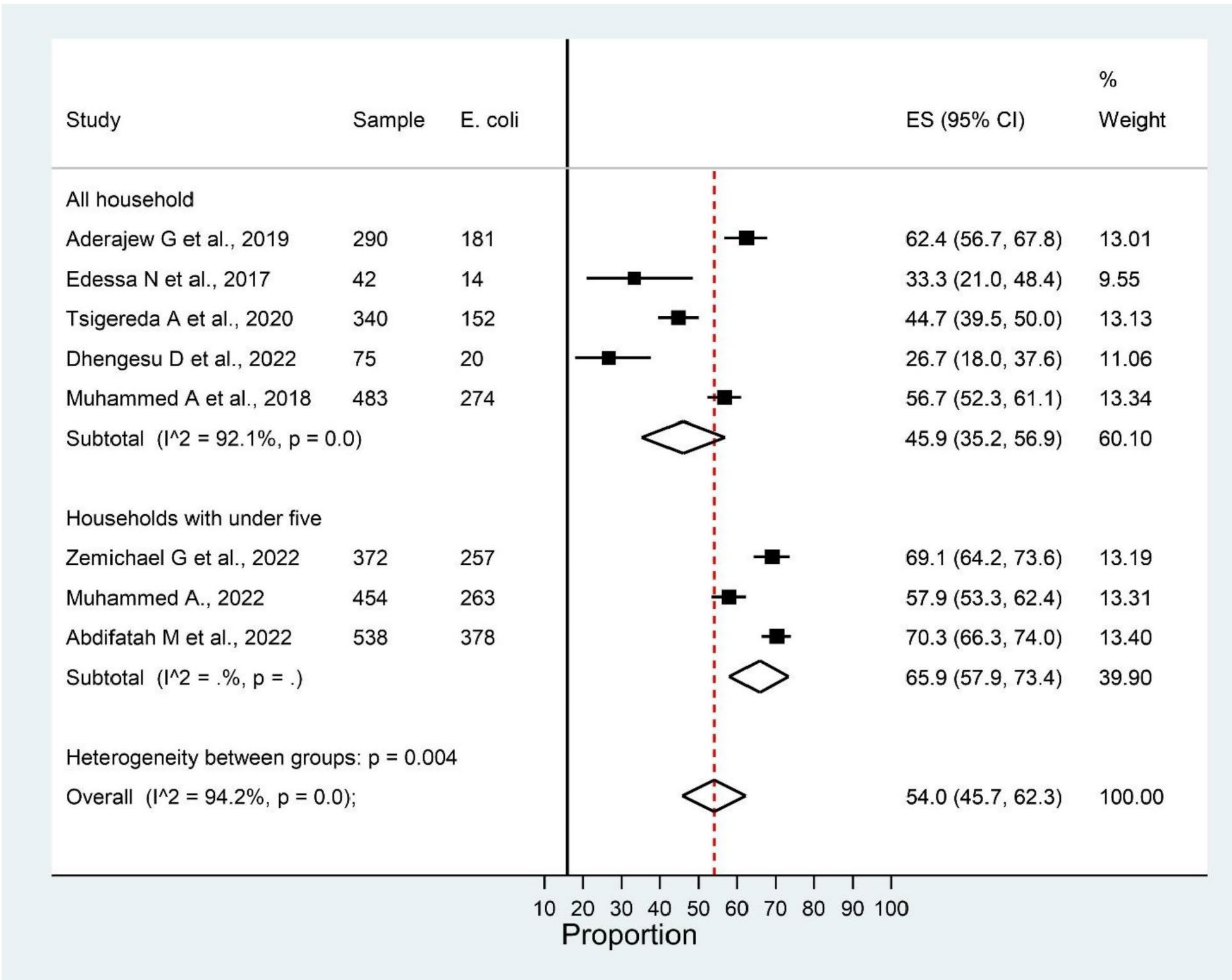

Fig. 4 Forest plot of *E. coli* prevalence distribution in all households and only households with under-five children drinking water in Ethiopia

CI: 24, 45%) [55]. This variation might come from differences in how samples are collected and could also be because South-East Asia has better water quality rules and improvements compared to Ethiopia. In addition, the pooled prevalence of *E. coli* in households' drinking water in the 8 cross-sectional studies with a total of 2,594 samples was 54% (95% CI: 45.7, 62.3%). This pooled prevalence is lower than a systematic review and meta-analysis conducted in Africa (2000–2021) where the pooled prevalence of *E. coli* in drinking water was 71.7% (95% CI: 56.2, 83.3%) [56]. Regional variations in water contamination in Ethiopia, compared to other African countries, can be influenced by factors like the types of water sources, the effectiveness of sanitation and water treatment practices, local environmental conditions, and differences in public health standards.

In this study, the prevalence of fecal coliform in households drinking water in the wet season was higher (70.3%) than in the dry season (60.1%). Similarly, a study conducted in Ghana found that the proportion of the population at risk of fecal contamination in the rainy season (41.5%) was higher compared to the dry season (33.1%) [57]. Furthermore, the pooled prevalence of fecal coliform was higher (73.8%) among households with only under-five children than in other households, this might be because of improper disposal of child feces. The pooled prevalence of fecal coliform was lower (66.4%) among urban households than rural (68%). Similarly, a systematic review and meta-analysis study on fecal contamination of drinking water globally, and in low-and-middle-income countries found that drinking water is more contaminated in rural areas than in urban areas [55, 58]. This might be because urban areas have better infrastructure, like improved water sources and improved sanitation, which help to keep lower contamination levels.

Finally, the pooled prevalence of fecal coliform was higher at the point of use (66.4%) compared to the source point (57.8%). Similarly, a study conducted in Bangladesh found a lower contamination rate of 28% in water samples taken from the source compared to a significantly higher contamination rate of 73.96% in samples from stored household sources (point of use) [59]. The higher pooled prevalence of contamination observed in stored household water, compared to source water, is likely due to poor storage conditions, inadequate hygiene practices, and exposure to environmental contaminants. Future research should explore how Ethiopian water management practices and infrastructure impact fecal coliform and *E. coli* prevalence to identify effective interventions. Longitudinal studies could track changes in water quality over time. Additionally, more research in underrepresented regions is needed to understand water contamination patterns and improve policies for safer drinking water in Ethiopia.

Conclusion

The findings of this systematic review and meta-analysis point to a higher prevalence of *E. coli* and fecal coliform in Ethiopia, raising serious concerns about public health that require attention. There are variations within the country by season, residence, region, sources of sample collection and availability of under-five children. Subgroup assessments revealed an increased risk during the wet season, among only households with under-five children, at point-of-use, residing in rural areas, notably in the Amhara, Gambella, and Oromia regions. These findings emphasize the critical necessity for targeted interventions in vulnerable populations and specific geographic areas to address the risks posed by drinking water contamination and improve public health outcomes promptly.

Strengths and limitations of this study

We employed appropriate methods to stabilize variability across studies and enhance the reliability of our overall findings. The generalizability of our study might be constrained because of the restricted regional coverage within the country.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20067-x.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Author contributions

EAA, AW, AMG, ZAA, TT, and AKD conceived, designed the review, and did the data collection and analysis for the study. EAA, AW, and AMG drafted the manuscript. MGW, MGS, KTT, MAK, and GKY reviewed the manuscript. EAA, AW, AMG, MT, and DAD checked the final analysis and revised the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable here, as this is a systematic review and meta-analysis.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Ethiopian Public Health Institute, Addis Ababa, Ethiopia
[2]Action Against Hunger, Addis Ababa, Ethiopia
[3]Ministry of Planning and Development, Addis Ababa, Ethiopia

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