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Prevalence of bacterial eye infections and multidrug resistance patterns among eye infection suspected patients in Ethiopia: a systematic review and meta-analysis

Mihret Tilahun[1*], Alemu Gedefie[1], Bekele Sharew[2], Habtu Debash[1] and Agumas Shibabaw[1]

Abstract

Background Bacterial eye infections are major global health issue in developing countries like Ethiopia, poor hygiene, limited healthcare infrastructure, and inadequate treatment options contribute to the increased burden of these infections, leading to significant ocular morbidity and potential blindness. Major bacterial pathogens, including *Staphylococcus aureus*, *Haemophilus influenzae*, *Streptococcus pneumoniae*, and *Pseudomonas aeruginosa*, are responsible for these infections. The objective of this systematic review and meta-analysis is to synthesize existing literature on the prevalence of bacterial eye infections in Ethiopia, identify common bacterial pathogens, and analyze antibiotic resistance patterns.

Methods Comprehensive search were performed across electronic databases and grey literature using specific search terms. Eligible studies were organized in MS Excel and imported into STATA version 14 for statistical analysis. The pooled prevalence of bacterial eye infections and multidrug resistance patterns was calculated using a random-effects model, with heterogeneity assessed via the I^2 statistic. Publication bias was evaluated through funnel plots and Egger's test. A sensitivity analysis was conducted to assess the influence of individual studies on the overall effect size.

Result The systematic review and meta-analysis of 19 studies conducted in Ethiopia revealed significant regional variations in the prevalence of bacterial eye infections and multidrug resistance (MDR). The overall pooled prevalence of bacterial eye infections was 54.07%, with substantial heterogeneity ($I^2 = 99.2\%$). Prevalence rates varied across regions, with the highest in Oromia (62.98%) and the lowest in SNNPR (34.3%). *Staphylococcus aureus* was the most common pathogen (45.47%), followed by coagulase-negative *Staphylococci* (36.14%). The pooled prevalence of MDR was 66.06%, with the highest rates in Somali (87.7%) and the lowest in Tigray (37.9%). Subgroup analysis showed higher prevalence in studies before 2020 and with smaller sample sizes.

Conclusion In conclusion, the study highlights a high prevalence of bacterial eye infections and multidrug resistance in Ethiopia, with significant regional variation. These findings highlight the urgent need for targeted interventions and antimicrobial stewardship programs to address the growing challenge of antibiotic resistance in Ethiopia.

*Correspondence:
Mihret Tilahun
tilahunmihret21@gmail.com

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

Keywords Bacterial eye infections, Ocular infections, Multidrug resistance, Ethiopia, And prevalence, Systematic review and meta-analysis

Introduction

Bacterial eye infections, also known as ocular infections, are a significant public health concern globally. If left untreated, they can lead to potential visual impairment and blindness [1]. Various bacterial pathogens cause these infections and can manifest in different forms, including conjunctivitis, keratitis, and endophthalmitis. Numerous factors, including environmental conditions, healthcare access, socioeconomic status, and underlying health conditions influence the prevalence of these infections [2].

Bacterial eye infections are a common global health concern, with incidence rates varying depending on geographic location, healthcare access, and other factors. These infections can range from mild conjunctivitis to more severe conditions like corneal ulcers and endophthalmitis, which, if left untreated, can lead to permanent vision impairment or blindness [3]. The infections are caused by a variety of bacteria, some of which are more prevalent in certain populations or settings. In the United States, bacterial conjunctivitis, or pink eye, is one of the most frequently reported eye infections, affecting about 135 cases per 10,000 people annually [4].

It spreads easily through direct contact with infected secretions or contaminated surfaces and is particularly common in children. In contrast, in developing countries, bacterial eye infections pose a significant public health challenge and are a leading cause of blindness and ocular morbidity [3]. These infections are often exacerbated by poor hygiene, limited healthcare resources, and inadequate treatment. Bacterial infections such as trachoma, caused by *Chlamydia trachomatis*, contribute to widespread vision impairment in these regions, with conditions that are treatable in developed countries potentially leading to chronic or severe damage in low-resource settings [5].

Several types of bacteria are known to cause ocular infections, including *Staphylococcus aureus*, *Coagulase-negative Staphylococci (CoNS)*, *Haemophilus influenzae*, *Streptococcus pneumoniae*, *Klebsiella pneumoniae*, *Streptococcus pyogenes*, and *Pseudomonas aeruginosa* [6]. *Staphylococcus aureus* is one of the most common causes of conjunctivitis and more severe infections like keratitis, often linked to trauma, surgery, or contact lens use [7]. *Coagulase-negative Staphylococci* are less virulent but still implicated in eye infections, particularly in immunocompromised patients or contact lens Wears [8].

Haemophilus influenzae is a frequent cause of conjunctivitis and keratitis, especially in children, and can lead to more severe conditions like orbital cellulitis. *Streptococcus pneumoniae* causes various ocular infections, including conjunctivitis and endophthalmitis [9]. *Klebsiella pneumoniae*, an opportunistic pathogen, can lead to serious infections in immunocompromised individuals, while *Streptococcus pyogenes* can cause rapid and severe eye infections [10]. *Pseudomonas aeruginosa* is a particularly concerning pathogen due to its resistance to multiple antibiotics and its association with serious infections in contact lens wears, such as corneal ulcers [11].

Several factors can increase the risk of bacterial eye infections. Children are more susceptible to bacterial conjunctivitis due to their exposure to contaminated environments like schools or daycare centers [12]. Gender may also play a role, with some studies suggesting females might be at a higher risk due to makeup use or more frequent touching of the eyes [2]. The incidence of bacterial eye infections tends to rise in certain seasons, particularly spring and fall, when allergens and irritants compromise the eye's defense mechanisms [13, 14]. Contact lens use, especially improper lens hygiene or sleeping with lenses in, increases the risk of eye infections like keratitis or conjunctivitis. Eye injuries, ocular surgeries, dry eye conditions, chronic nasolacrimal duct obstruction, and previous ocular infections can all make the eyes more vulnerable to bacterial invasion [15].

Antibiotic resistance is an emerging concern in the treatment of bacterial eye infections. Many bacteria that cause these infections have developed resistance to common antibiotics, such as ampicillin, penicillin, and tetracycline, largely due to overuse or misuse of these medications [16]. Despite this, many bacterial isolates remain susceptible to more potent antibiotics like ciprofloxacin, gentamicin, and chloramphenicol, which are effective against a wide range of ocular pathogens [17]. Proper diagnosis, timely treatment, and good hygiene practices are critical in preventing and managing bacterial eye infections, helping to reduce complications such as vision loss [18].

Despite the importance of addressing bacterial eye infections in Ethiopia, there has been no systematic effort to consolidate the available data. This gap in knowledge hampers the ability of healthcare providers and policymakers to devise effective strategies for prevention and treatment. Therefore, this systematic review and meta-analysis aim to synthesize and analyze the existing literature on bacterial eye infections in Ethiopia, focusing on prevalence rates, common bacterial pathogens, demographic variations, and antibiotic resistance patterns. By doing so, we hope to provide valuable insights that can inform public health initiatives and improve eye care services in the country.

Methods

Design and protocol registration

This systematic review and meta-analysis aimed to determine the collective prevalence of bacterial eye infections and multidrug resistance (MDR) profile among patients in Ethiopia. The study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [19]. The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42024612249.

Data source and search strategy

The review included articles published between January 1, 2010, and April 16, 2024, focusing on studies related to bacterial isolates and multidrug-resistant patterns in eye infections in Ethiopia. A comprehensive search was conducted across multiple electronic databases, including PubMed, Google Scholar, Scopus, ScienceDirect, African Index Medicus, African Journal Online (AJOL), Ethiopian Journals, and the WHO Afro Library from October 16 to December 20, 2024. To ensure thorough coverage, a supplementary search of reference lists from relevant articles was also performed. The Search was guided by the CoCoPop framework, utilizing targeted terms such as "prevalence," "epidemiology," "magnitude," "bacterial eye infections," "antimicrobial resistance," "antibiotic resistance," "antibiotic susceptibility," "conjunctivitis," "eye inflammation," ocular inflammation and "Ethiopia." These terms were systematically combined using "OR" and "AND" to enhance article retrieval efficiency.

Formulation of research question and objectives

The primary objective of this systematic review was to assess the pooled prevalence of bacterial profiles in patients with suspected bacterial eye infections in Ethiopia. The secondary objective focused on analyzing the multidrug resistance patterns of the pathogens found.

Study selection criteria

Studies were selected based on predefined inclusion and exclusion criteria. Eligible studies included laboratory-based observational research such as cross-sectional and retrospective studies, published in English, focusing on bacterial eye infections and their antimicrobial resistance profiles across all age groups. Excluded were studies that did not provide bacterial isolate data, as well as qualitative studies, reviews, commentaries, case series, case reports, conference proceedings, and abstracts.

Data extraction

Data extraction was conducted independently by three reviewers (AG, MT, HD) using a standardized format based on the Joanna Briggs Institute (JBI) data extraction template [20]. An additional group of reviewers (AS, BS) validated the extracted data, which was documented in a Microsoft Excel spreadsheet. Information extracted included the first author's name, publication Year, study period and design, geographical location, sample size, bacterial isolates, diagnostic criteria, counts of Gram-positive and Gram-negative bacteria, and multidrug resistance prevalence.

Quality assessment

The quality of the articles was assessed using the JBI quality appraisal tool by four authors (MT, AS, BS, AG). Studies scoring between 50% and 75% were considered of good quality, while those above 75% were classified as high quality. Articles meeting the good or high-quality criteria were included in the analysis [20] (Supplementary Table 1).

Data synthesis and Meta-Analysis

Data analysis was performed using STATA version 14.0. The pooled prevalence and multidrug resistance (MDR) of bacterial isolates were calculated using a random-effects model. Subgroup and meta-regression analyses were conducted to identify potential sources of heterogeneity, with heterogeneity assessed using Cochran's Q test and I^2 statistics (p-value < 0.05 indicating significant heterogeneity) [21]. A random-effects model (Der Simonian-Laired) was applied, and the results were presented in a table and forest plot [22]. Subgroup analyses were conducted based on region, study design, sample size, and population type. The results were presented in a table and a forest plot. Publication bias was assessed through funnel plot symmetry, with Egger's test statistics used. For asymmetrical funnel plots, trim-and-fill analysis was applied. Meta-regression was used to further explore sources of heterogeneity.

Result

Selection and identification of studies

The initial search across multiple databases identified a total of 1,260 articles. After removing 508 duplicates, 752 articles were available for further review. A preliminary evaluation of titles, abstracts, and study objectives led to the exclusion of 675 articles that did not meet the eligibility criteria. The remaining 77 full-text articles were thoroughly assessed based on the predefined inclusion and exclusion criteria. Following this detailed evaluation, 19 studies were considered eligible and included in the final meta-analysis on bacterial eye infections (Fig. 1).

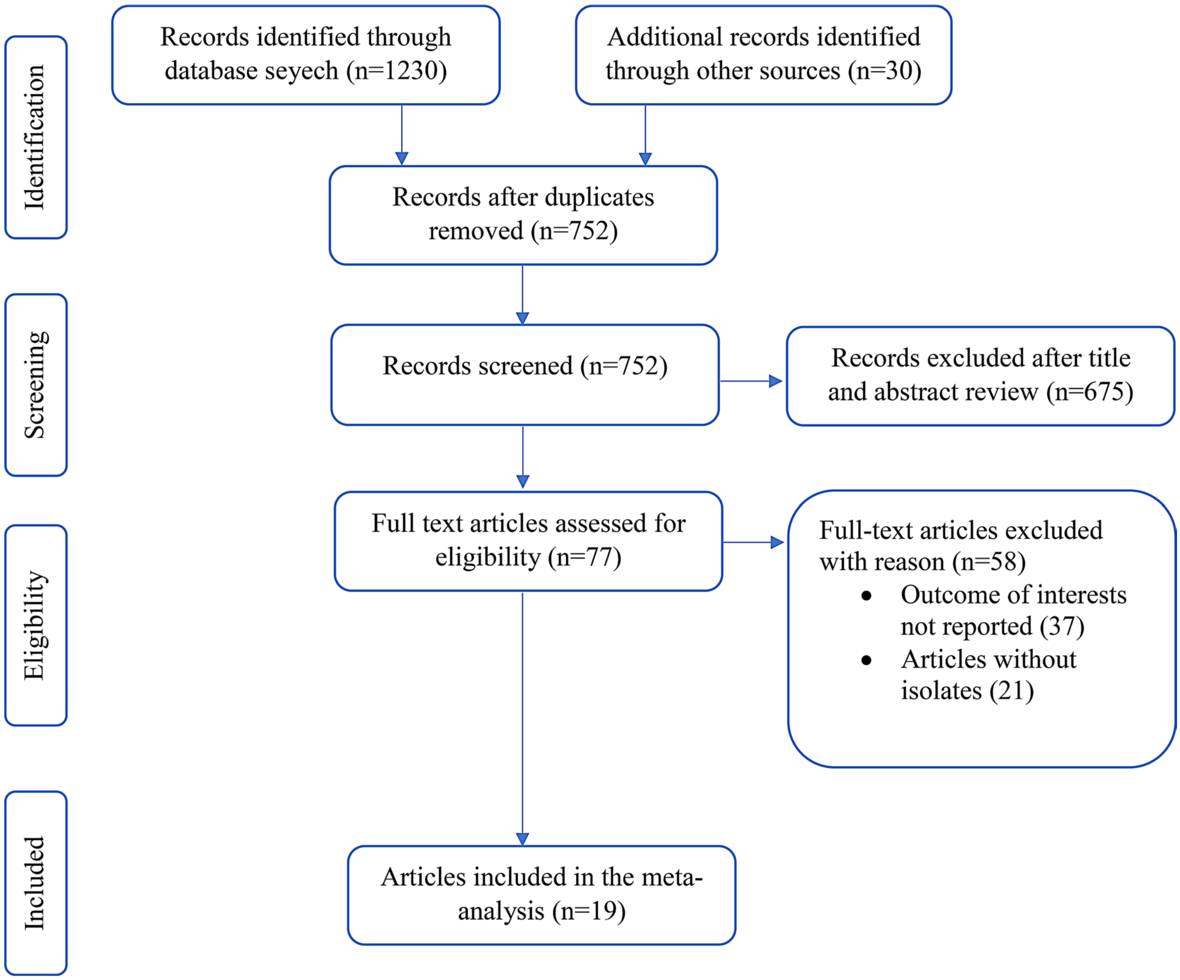

Fig. 1 PRISMA flow diagram illustrating the process of selecting eligible studies for the systematic review and meta-analysis

Characteristics of included studies

The table presents data from 19 studies conducted across various regions of Ethiopia, examining the prevalence of bacterial eye infections and multidrug resistance (MDR) rates. These studies, published between 2013 and 2024, reveal significant regional disparities in both the prevalence of bacterial eye infections and the prevalence of multidrug-resistant (MDR) pathogens. Prevalence rates range from as low as 3.13% in Gondar (Amhara) [23] to as high as 74.7% in Jimma (Oromia) [24]. Other studies also report varying prevalence, with some regions like Jijiga (Somali) [25] and Markos (Amhara) [26] showing relatively high rates of 62.2% and 62.8%, respectively. On the other hand, regions like South Omo Zone (SNNPR) [27] reported a lower prevalence of 34.3%. As for multidrug resistance, the rates also show considerable variation, ranging from a low of 37.9% in Quiha (Tigray) [28] to a high of 87.7% in Jijiga (Somali) [25]. Other regions such as Gondar (Amhara) [29, 30], Shashemene (Oromia) [31] and Jijiga (Somali) [25] reported MDR rates above 80%, indicating a severe concern for antibiotic resistance in these areas. The studies consistently show high MDR rates across most regions, with some regions exhibiting moderate resistance levels. The variation in both prevalence and MDR rates suggests regional differences in healthcare access, antibiotic usage, and infection management. These findings highlight the urgent need for targeted interventions, including antimicrobial stewardship programs, and more localized research to address the growing challenge of antibiotic resistance in Ethiopia. (Table 1).

Pooled estimate of significant bacterial eye infections

The pooled estimate of bacterial eye infections in Ethiopia, derived from 19 studies involving 2,628 bacterial isolates from 4,932 patient samples, reveals a prevalence rate of 54.07% (95% CI: 41.10–67.03). This indicates a substantial burden of bacterial eye infections, with significant variability across the studies (I^2 = 99.2%, $p<0.001$), reflecting regional differences in infection rates. The diversity in reported prevalence underscores

Table 1 Characteristics of the included studies among eye infections in Ethiopia from 2010 to 2023

Author	Study area	Region	Publication Year	Study design	Study population	Sample size	Culture Positive	Total pathogen isolated	prevalence	MDR
Amsalu et al. [32]	Hawassa	Sidama	2014	Cross-sectional	all age group	281	137	143	48.8	69.9
Muluye et al. [29]	Gondar	Amhara	2014	Retrospective	all age group	102	62	62	60.8	87.1
Fenta et al. [27]	South Omo Zone,	SNNPR	2022	Cross-sectional	all age group	347	119	119	34.3	60.5
Getahun et al. [30]	Gondar	Amhara	2017	Cross-sectional	all age group	312	168	168	58.3	87
Asfaw et al. [33]	Dessie	Amhara	2024	Cross-sectional	all age group	319	164	170	51.4	62.9
Woreta et al. [34]	Addis Ababa	Central	2022	Cross-sectional	all age group	323	175	184	54.5	73.4
Tesfaye et al. [24]	Jimma	Oromia	2013	Cross-sectional	all age group	198	148	148	74.7	75
Abebe et al. [25]	Jijiga	Somamlie	2023	Cross-sectional	all age group	288	179	179	62.2	87.7
Haile et al. [26]	Debre Markos	Amhara	2022	Cross-sectional	all age group	207	130	130	62.8	59.2
Ayehubizu et al. [2]	Bahir Dar	Amhara	2021	Cross-sectional	all age group	360	208	208	57.8	45.2
Teweldemedhin et al. [28]	Quiha	Tigray	2017	Cross-sectional	all age group	270	180	186	66.7	37.9
Assefa et al. [35]	Gondar	Amhara	2015	Cross-sectional	all age group	51	31	37	60.8	45.2
Shiferaw et al. [36]	Dessie	Amhara	2015	Cross-sectional	all age group	160	94	157	58.8	74.5
Mohammed et al. [31]	Shashemene	Oromia	2020	Cross-sectional	all age group	332	198	198	68.2	84.5
Belayhun et al. [37]	Gondar	Amhara	2018	Cross-sectional	all age group	210	131	131	62.4	45.8
Aklilu et al. [38]	Addis Ababa	Central	2018	Cross-sectional	all age group	215	118	118	54.9	71.2
Seifu et al. [39]	Gondar	Central	Pre-print	Retrospective	all age group	319	133	133	41.7	47.4
Diriba et al. [40]	Jimma	Oromia	2020	Cross-sectional	all age group	319	147	147	46.1	68.7
Wuletaw et al. [23]	Gondar	Amhara	2021	Cross-sectional	all age group	319	10	10	3.13	70

the geographical variation in the occurrence of bacterial eye infections across Ethiopia (Fig. 2).

The analysis of bacterial isolates, summarized in Table 2, shows that Gram-positive bacteria are the most commonly identified pathogens, accounting for 70.73% of the pooled prevalence. *Staphylococcus aureus* emerged as the most prevalent pathogen, found in 45.47% (95% CI: 30.85–60.08) of cases. Coagulase-negative *Staphylococci* (CONS) followed at 36.14% (95% CI: 24.71–45.78), indicating their significant role in bacterial eye infections. Other notable pathogens include *Streptococcus pneumoniae* and *Klebsiella* species, both of which were detected in 9.34% (95% CI: 6.60–12.08 and 95% CI: 5.04–13.65, respectively) of cases.

Among the Gram-negative bacteria, *Escherichia coli* (7.06%, 95% CI: 4.65–9.47), *Pseudomonas aeruginosa* (7.34%, 95% CI: 3.23–11.45), and *Proteus species* (4.45%, 95% CI: 2.06–6.84) were among the most frequently isolated. Lesser prevalent bacteria included *Citrobacter spp.*, *Enterobacter* species, and *Moraxella/Neisseria spp.*, with prevalence rates ranging from 3.69 to 9.62%. Interestingly, *Enterococcus* species was the least prevalent among the isolates, found in only 4.34% (95% CI: 1.77–6.90) of the samples.

Subgroup analysis

Subgroup analyses indicated that the prevalence of bacterial eye infections was 48.80% (95% CI: 42.96–54.64, I^2 = 0%, $p = 0.000$) in studies conducted in the Sidama region, and 52.83% (95% CI: 30.21–75.46, I^2 = 99.4%, $p < 0.001$) in the Amhara region. In Oromia showed a prevalence of bacterial eye infection was 62.98% (95% CI: 46.33–79.63, I^2 = 96.4%, $p < 0.001$). Studies from the Central region reported a prevalence of 50.27% (95% CI: 41.48–59.06, I^2 = 85.4%, $p = 0.001$), while SNNPR and Somalia regions had lower but still notable prevalence rates of 34.30% (95% CI: 29.31–39.30, I^2 = 0%, $p = 0.000$) and 62.20% (95% CI: 56.60–67.80, I^2 = 0%, $p = 0.000$), respectively (Fig. 3).

Further subgroup analysis by year of publication revealed a prevalence of 60.71% (95% CI: 55.27–66.14, I^2 = 82.2%, $p < 0.001$) in studies published before 2020, and 48.90% (95% CI: 28.37–69.42, I^2 = 99.5%, $p < 0.001$) in studies published after 2020. The pre-print studies showed a prevalence of 41.70% (95% CI: 36.29–47.11, I^2 = 0%, $p = 0.000$) (Fig. 4).

Additionally, Subgroup analyses based on sample size indicated that the prevalence of bacteria was 46.39% (95% CI: 28.43–64.35, I^2 = 99.4%, $p < 0.001$) in studies with a sample size greater than or equal to 300, and 63.02% (95% CI: 59.04–66.99, I^2 = 65.4%, $p = 0.003$) in studies with fewer than 300 samples. The overall prevalence across all studies was 54.07% (95% CI: 41.10–67.03, I^2 = 99.2%, $p < 0.001$) with higher heterogeneity in studies with a sample size of 300 or more (I^2 = 99.4%). The heterogeneity was lower in studies with smaller sample sizes (I^2 =

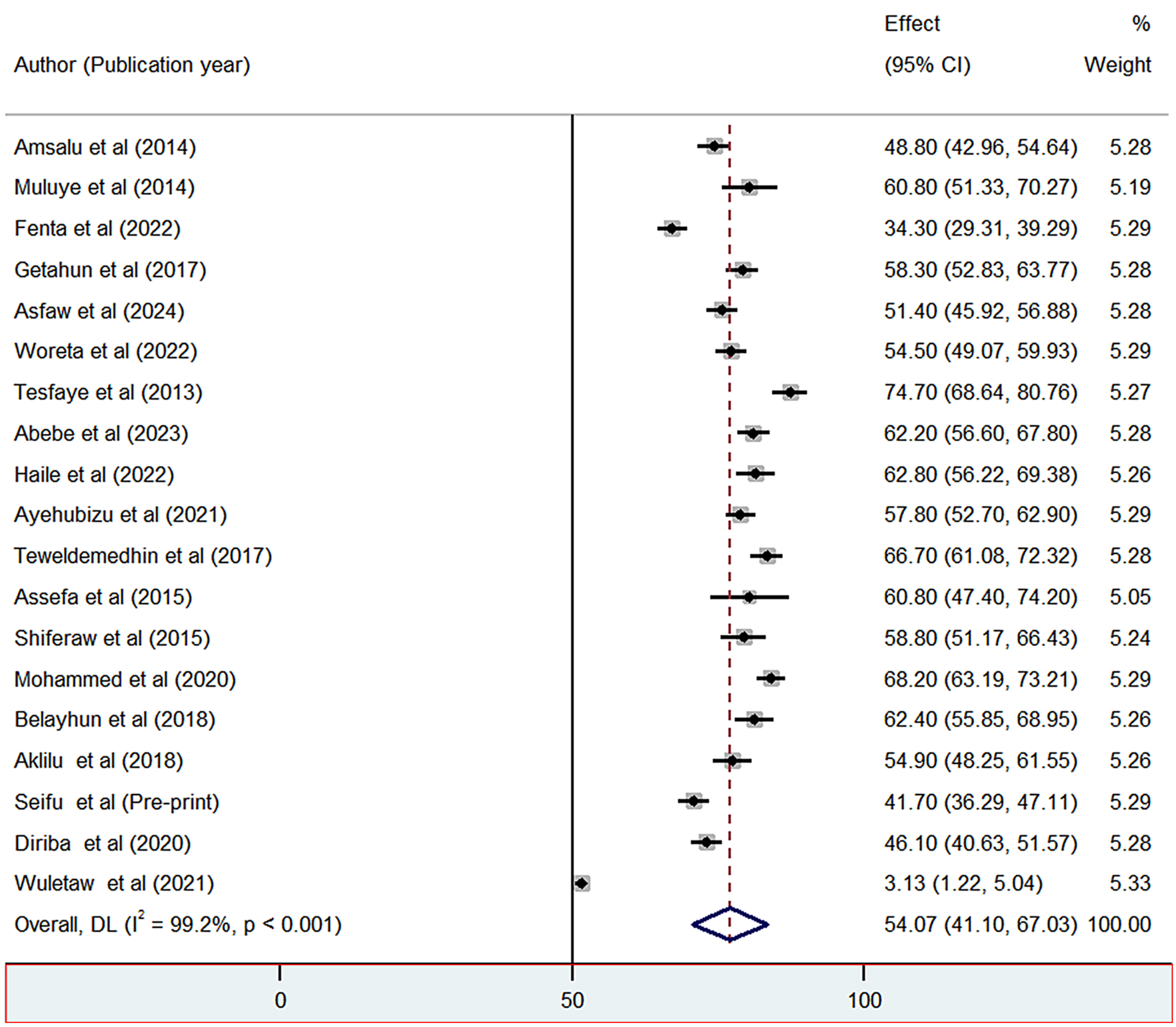

Fig. 2 Forest plot showing the pooled prevalence of bacterial eye infections in Ethiopia, 2024

Table 2 Bacterial isolates from eye-infected patients in Ethiopia

Bacteria	Number of studies	No. of bacteria isolates	Pooled pathogen isolated (95% CI)	I^2 (%)	*p*-value
S. aureus	19	862	45.47 (30.85–60.08)	99.3	< 0.001
CONS	19	685	36.14 (24.71–45.78)	98.9	< 0.001
Klebsiella spp.	14	126	9.34 (5.04–13.65)	85	< 0.001
E. coli	15	99	7.06 (4.65–9.47)	55.5	0.005
P. aeruginosa	15	109	7.34 (3.23–11.45)	89.1	< 0.001
Citrobacter spp.	10	41	4.71 (2.81–6.58)	0	0.785
Enterobacter species	8	33	3.69 (2.23–5.15)	0	0.474
H. influenzae	9	58	6.74 (4.49–8.89)	17.7	0.285
Proteus spp.	13	57	4.45 (2.06–6.84)	60.8	0.002
S. pyogenes	13	66	5.04 (3.40–6.68)	0	0.757
S. pneumoniae	17	155	9.34 (6.60-12.08)	70.8	< 0.001
S. Viridians	8	69	8.75 (5.23–12.28)	66.4	< 0.001
Enterococcus species	6	22	4.34 (1.77–6.90)	0.0	0.693
Moraxella and Neisseria spp	7	67	9.62 (1.01–18.23)	9.39	< 0.001
Other NLF	12	26	7.58 (1.36–13.80)	91.2	< 0.001
Total pathogen isolated	20	2628	138.35(101.81-174.89)	99.9	< 0.001

Other NLF = Acinetobacter, S. Mercescenes and salmonella, Moraxella (54 species) *and Neisseria spp* [13]

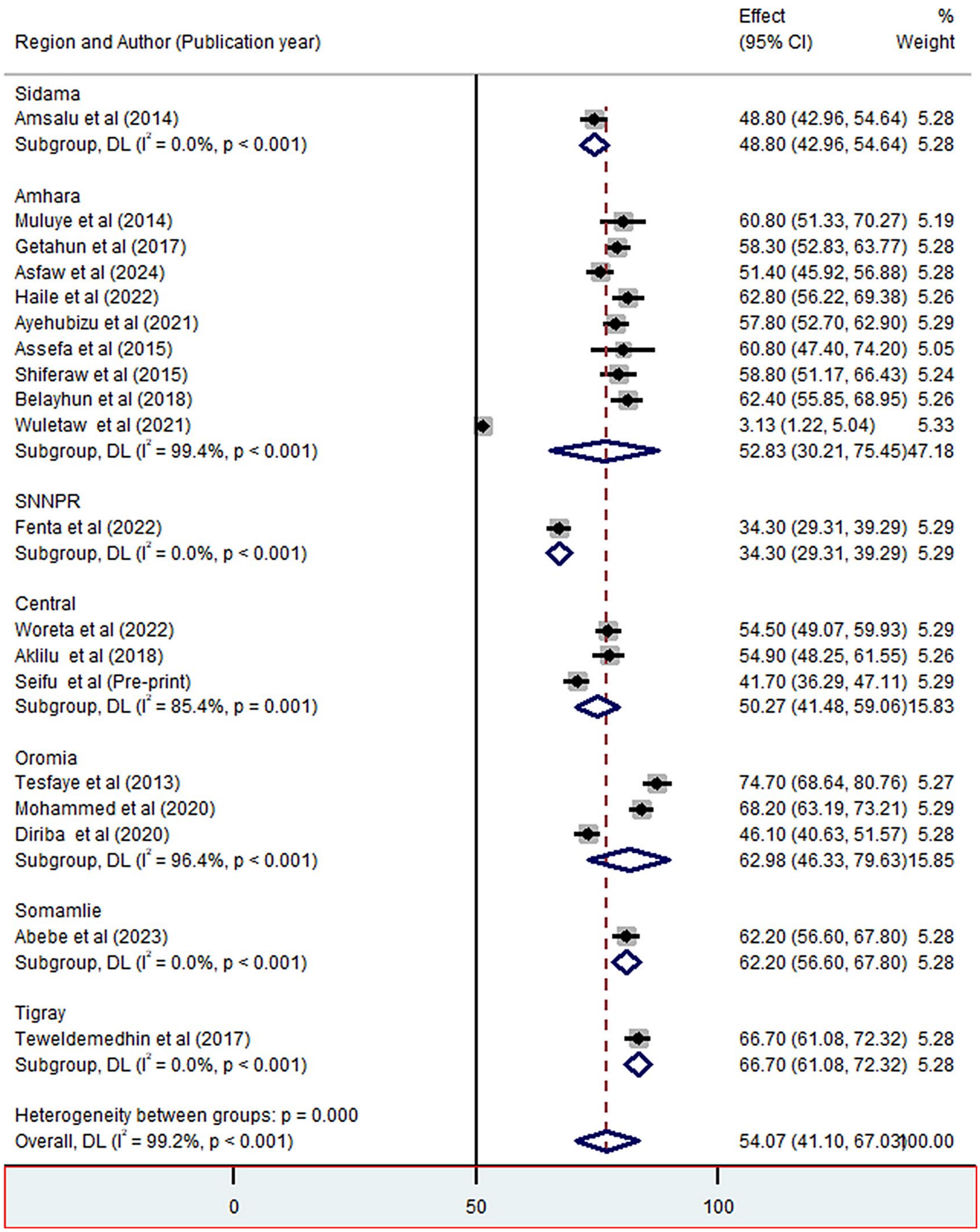

Fig. 3 Subgroup analysis by region in Ethiopia

65.4%), and no significant difference was found between the two subgroups ($p = 0.076$) (Fig. 5).

Pooled prevalence of multidrug resistance (MDR)

The prevalence of multidrug resistance (MDR) in bacterial eye infections varied between 37.9% and 87.7%. In Ethiopia, the pooled prevalence of MDR was estimated at 66.06% (95% CI: 59.82–72.30), reflecting substantial variability across studies ($I^2 = 96.3\%$, $p < 0.001$) (Fig. 6).

The MDR rates of ocular pathogens in Ethiopia are concerning. Enterococcus (90%) and Acinetobacter spp. (85%) show high resistance, complicating treatment. Other pathogens like CONS (80%), *H. influenzae* (80%), and *S. pyogenes* (75%) also present treatment challenges. Pathogens such as S. aureus (70%), *Pseudomonas spp.*

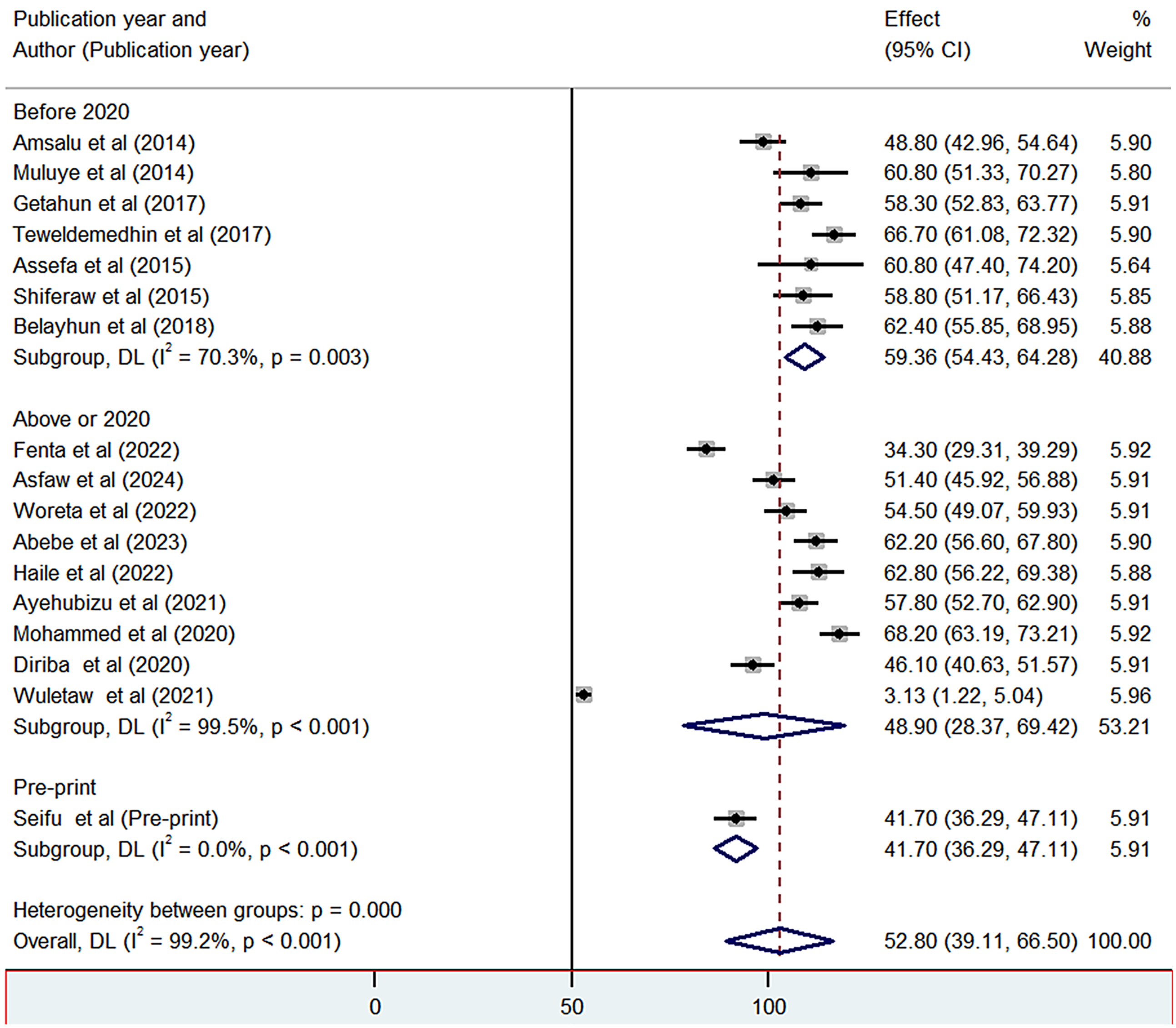

Fig. 4 Subgroup analysis by eye of publication in Ethiopia

(72%), *Citrobacter spp*. (70%), and *Serratia marcescens* (78%) have moderate resistance, requiring careful antibiotic selection. Klebsiella spp. (55%) and E. coli (50%) pose moderate concerns, while *Moraxella spp.* (63%) and Other NLF (50%) have lower but still concerning MDR rates. These trends highlight the need for susceptibility testing and tailored therapies (Table 3).

Subgroup analyses based on regions revealed significant variation in the prevalence of multidrug-resistant (MDR) bacteria across Ethiopia. In Sidama, a single study reported a prevalence of 69.90% (95% CI: 64.06–75.74). The Amhara region had a pooled prevalence of 63.47% (95% CI: 51.13–75.80), with individual studies ranging from 45.20 to 87.10%. In SNNPR, another single study showed a prevalence of 60.50% (95% CI: 55.51–65.50). The Central region had a pooled prevalence of 63.96% (95% CI: 46.91–81.01), while Oromia showed a prevalence of 68.70% (95% CI: 63.23–74.17) in one study. The Somali region exhibited a notably high prevalence of 87.70% (95% CI: 82.10–93.30), and Tigray had a lower prevalence of 37.90% (95% CI: 32.28–43.52) (Fig. 7).

Subgroup analyses based on publication Year revealed important insights into the prevalence of multidrug-resistant (MDR) bacteria. In studies published before 2020, the pooled prevalence was 64.94% (95% CI: 51.08–78.79), with individual study results ranging from 37.90 to 87.10%. In contrast, studies published after 2020 showed a slightly higher pooled prevalence of 65.36% (95% CI: 55.40–75.32), with individual studies ranging from 45.20 to 87.70%. A single pre-print study by Tesfaye et al. (Pre-print) reported a prevalence of 47.40% (95%

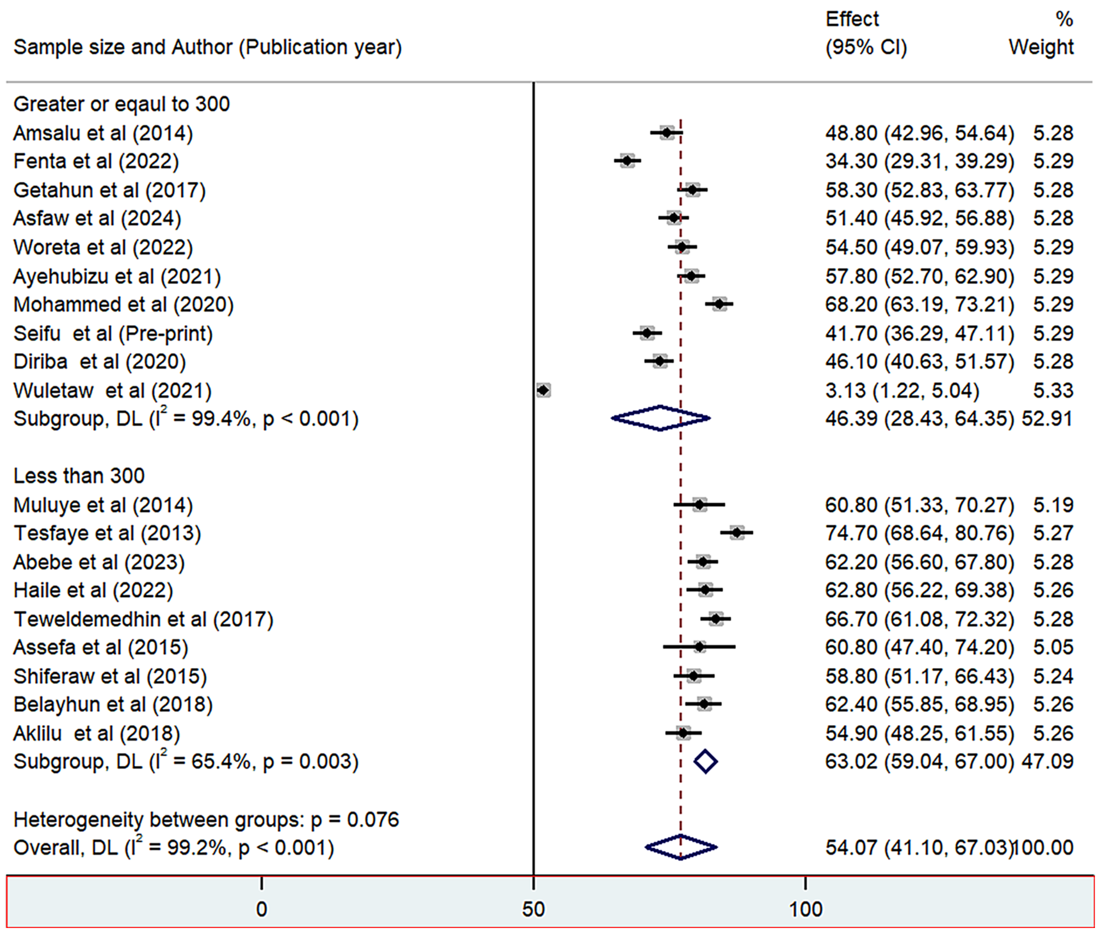

Fig. 5 Subgroup analysis by sample size in Ethiopia

CI: 41.99–52.81). Overall, the pooled prevalence from all included studies was 64.04% (95% CI: 56.19–71.89) (Fig. 8).

The subgroup analysis based on sample size revealed interesting findings about the prevalence of multidrug-resistant bacteria. For studies with sample sizes greater than or equal to 300, the pooled prevalence was 64.35% (95% CI: 54.79–73.92), with individual studies ranging from 45.20 to 87.00%. On the other hand, for studies with sample sizes less than 300, the pooled prevalence was 63.66% (95% CI: 49.52–77.80), with individual study results ranging from 37.90 to 87.70%. The overall pooled prevalence across all studies was 64.04% (95% CI: 56.19–71.89) (Fig. 9).

Sensitivity analysis

The sensitivity analysis demonstrated that excluding any single study had minimal impact on the pooled estimate, confirming the robustness of the overall result. The 19 omitted studies had prevalence estimates ranging from 52.92 to 56.83%, with most falling between 53% and 55%. The combined estimate for these studies was 54.07% (95% CI: 41.10–67.03%), showing consistency across studies. Importantly, the pooled effect size remained within the 95% confidence interval of the overall estimate, highlighting that no single study significantly influenced the prevalence of bacterial eye infections in Ethiopia and reinforcing the stability of the overall effect (Table 4).

Publication Bias

The funnel plot was employed to assess the potential influence of small-study effects and publication bias on the pooled prevalence estimate of bacterial eye infections. The observed asymmetry in the funnel plot indicated the presence of publication bias, with over 64.3% of studies concentrated on the right side of the triangular distribution (Fig. 10). Furthermore, Egger's test confirmed significant publication bias, with a p-value < 0.001 (Table 5 and Fig. 11), the regression showed a weak negative slope (-12.59), but the bias term (22.00) was highly significant, indicating potential bias in the prevalence estimates of bacterial eye infections in Ethiopia.

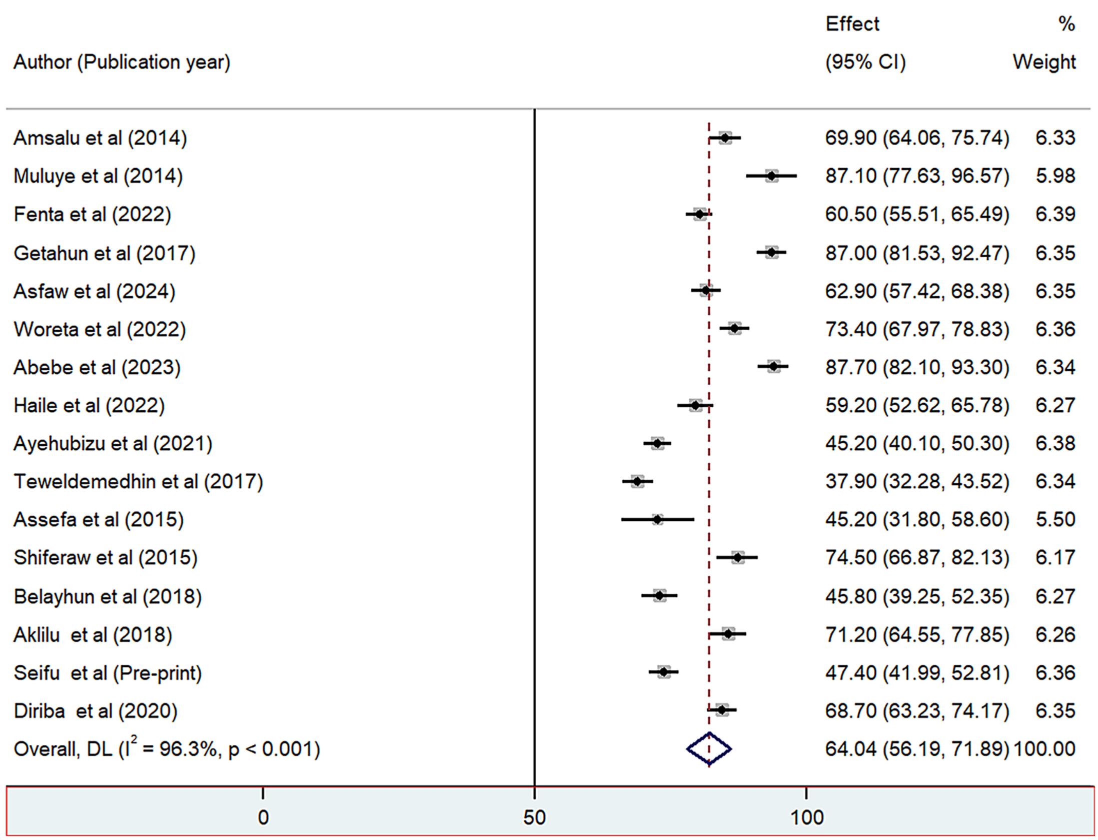

Fig. 6 Forest plot showing the overall pooled prevalence of MDR in Ethiopia

Table 3 Overall pooled MDR of bacterial pathogen of eye infection in Ethiopia

Pathogen	MDR Rate (%)	Lower Bound CI %	Upper Bound CI%
S. aureus	70%	63%	77%
CONS	80%	73%	87%
S. pneumoniae	60%	55%	65%
S. Pyogene	75%	68%	82%
S. Viridians	67%	62%	72%
Enterococcus	90%	83%	97%
Klebsiella spp	55%	50%	60%
Pseudomonas spp	72%	65%	79%
E. coli	50%	45%	55%
Citrobacter spp	70%	63%	77%
Enterobacter spp	68%	63%	73%
Proteus spp	66%	61%	71%
H. influenzae	80%	73%	87%
Acinetobacter spp	85%	78%	92%
Moraxella spp	63%	58%	68%
Other NLF	50%	45%	55%
S. Mercescenes	78%	71%	85%

Trim and fill analysis of the pooled prevalence of bacterial eye infections in Ethiopia

To account for the identified publication bias, a trim-and-fill analysis was conducted. After incorporating 10 additional studies, the adjusted pooled prevalence of bacterial eye infections in Ethiopia was found to be 31.01% (95% CI: 18.79–43.23) (Table 6).

Meta-regression

Meta-regression was conducted to investigate potential sources of heterogeneity across the studies included in the meta-analysis. Continuous study characteristics, including publication Year, sample size, and the number of bacterial isolates, were examined as covariates. However, no significant variables were identified that could account for the observed heterogeneity among the studies ($P > 0.05$) (Table 7).

Discussions

Bacterial eye infections pose a major global health threat, particularly in low- and middle-income countries, with increasing challenges due to multidrug-resistant (MDR) bacteria. These infections can lead to severe complications like vision loss, and the overuse of antibiotics, poor hygiene, and limited healthcare access contribute

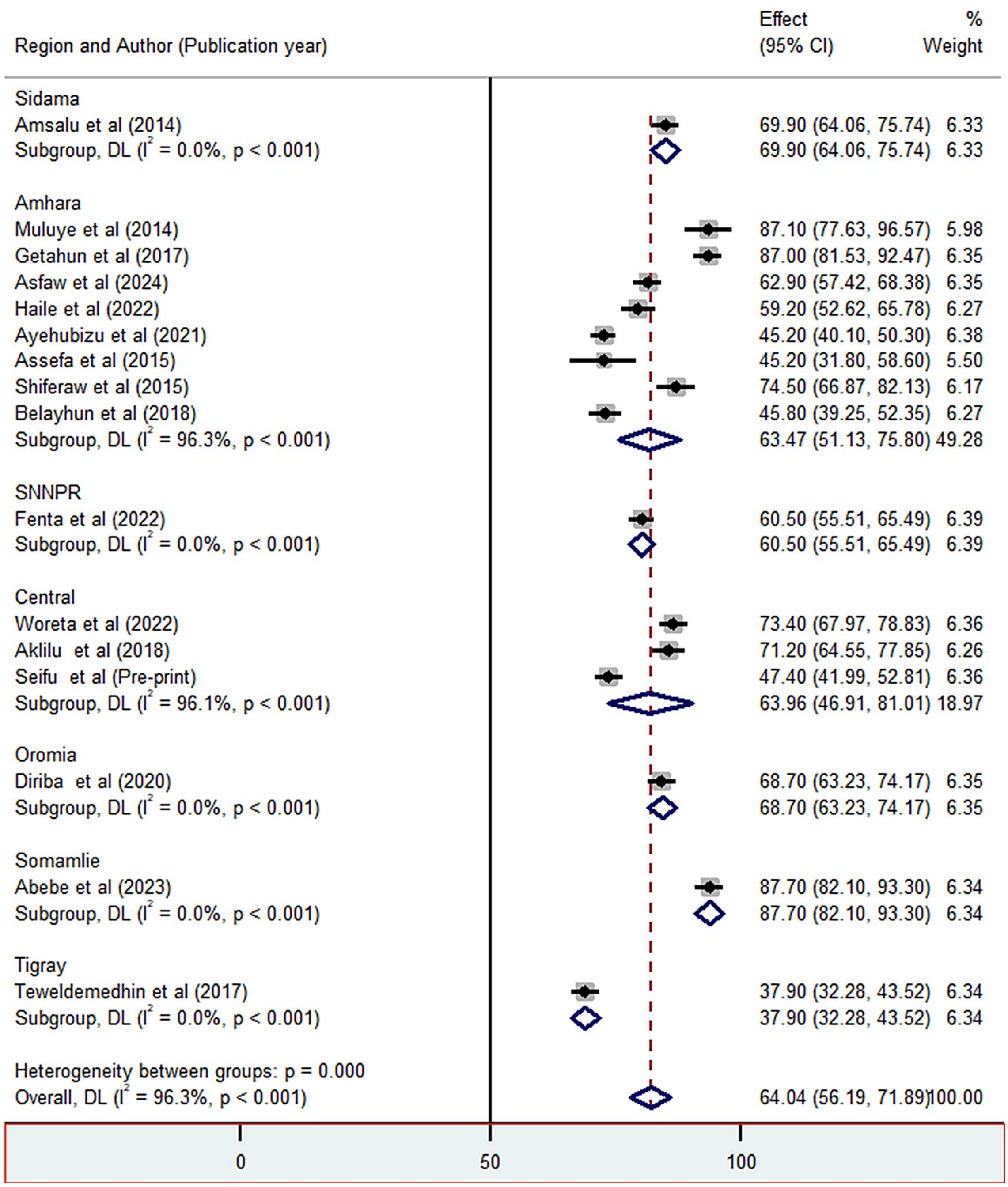

Fig. 7 Forest plot showing the Subgroup analysis of MDR by region

to the rise of resistance [41]. In Ethiopia, the situation is exacerbated by poor infrastructure and limited access to effective treatments, making the management of eye infections even more difficult. Tackling this issue requires strengthening healthcare systems, enhancing diagnostics, and promoting responsible antibiotic use to reduce both eye infections and antibiotic resistance [2].

The pooled prevalence of bacterial eye infections in Ethiopia was found to be 54.07% (95%. CI: 41.10–67.03), indicating substantial heterogeneity (I^2 = 99.2%, $p < 0.001$) across the studies reviewed. This finding is comparable to a sytematric review and meta that reported in Ghana a pooled prevalence of symptomatic dry eye was 69.3% [42]. When comparing individual study findings with this pooled prevalence, most studies report culture-positive rates within the confidence interval range of 41.10–67.03%, indicating a consistent trend across regions. For example, studies like in Gondar

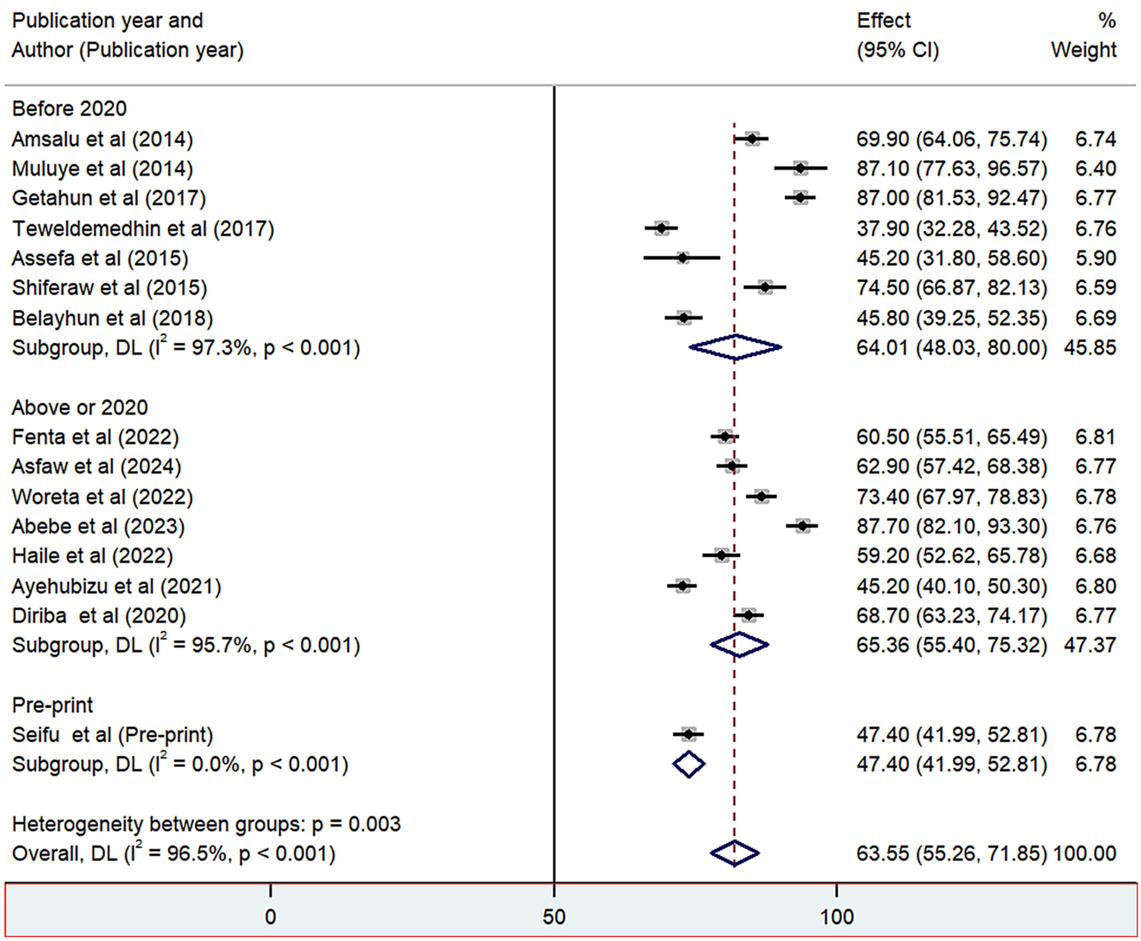

Fig. 8 Forest plot showing the subgroup analysis of MDR by Year of publication

(60.8%) [29], in Gondar (58.3%) [30], and (2013) in Jimma (74.7%) [24] report higher-than-average prevalence rates. In contrast, some studies, such as in South Omo Zone (34.3%) [27] and in Gondar (3.13%) [23], show much lower rates, indicating regional variations. Overall, while most regions fall within the pooled prevalence range, studies from areas like Jimma, Jijiga, and Gondar suggest higher infection burdens, while regions like South Omo Zone and Tigray show relatively lower prevalence rates. These findings highlight the significant heterogeneity in bacterial eye infections across Ethiopia, underscoring the need for handcrafted public health interventions based on regional patterns of infection.

In this analysis, Gram-positive bacteria are the most commonly identified pathogens, indicates that 70.73% of the pooled prevalence. Similarly, Gram-positive cocci (87.7%) were the most common isolates [25], Gondar (88%) [30], Dessie (55.6%) [36], and Jimma (52%) in Ethiopia [24], as well as Nigeria (50.3%) [43]. The most prevalent pathogen among these is *Staphylococcus aureus*, which was found in 45.47% of cases, followed by *Coagulase-negative Staphylococci* at 36.14%. Other notable pathogens include *Streptococcus pneumoniae* and *Klebsiella* species, each present in 9.34% of cases, which aligns with eyelier findings from The predominant bacterial isolate of *S. aureus* (53.1%) [25], Iran [44], Uganda [45] and the USA [46]. In the current analysis, Gram-negative bacteria such as *Escherichia coli*, *Pseudomonas aeruginosa*, and *Proteus species* were identified at lower prevalence rates (4.45–7.34%) compared to Gram-positive cocci, which were more dominant. Other Gram-negative pathogens like *Citrobacter spp*., *Enterobacter species*, and *Moraxella/Neisseria spp*. were also detected at lower levels, highlighting the diversity of bacteria involved in eye infections. Interestingly, Enterococcus species was the least prevalent, found in just 4.34% of samples. These findings emphasize the varied microbial landscape of bacterial eye infections in Ethiopia, indicating the need for comprehensive diagnostic and treatment strategies to address both Gram-positive and Gram-negative pathogens.

These findings underline the diversity of bacterial eye infections in Ethiopia, with *S. aureus* and *CONS* being the predominant isolates. The prevalence of

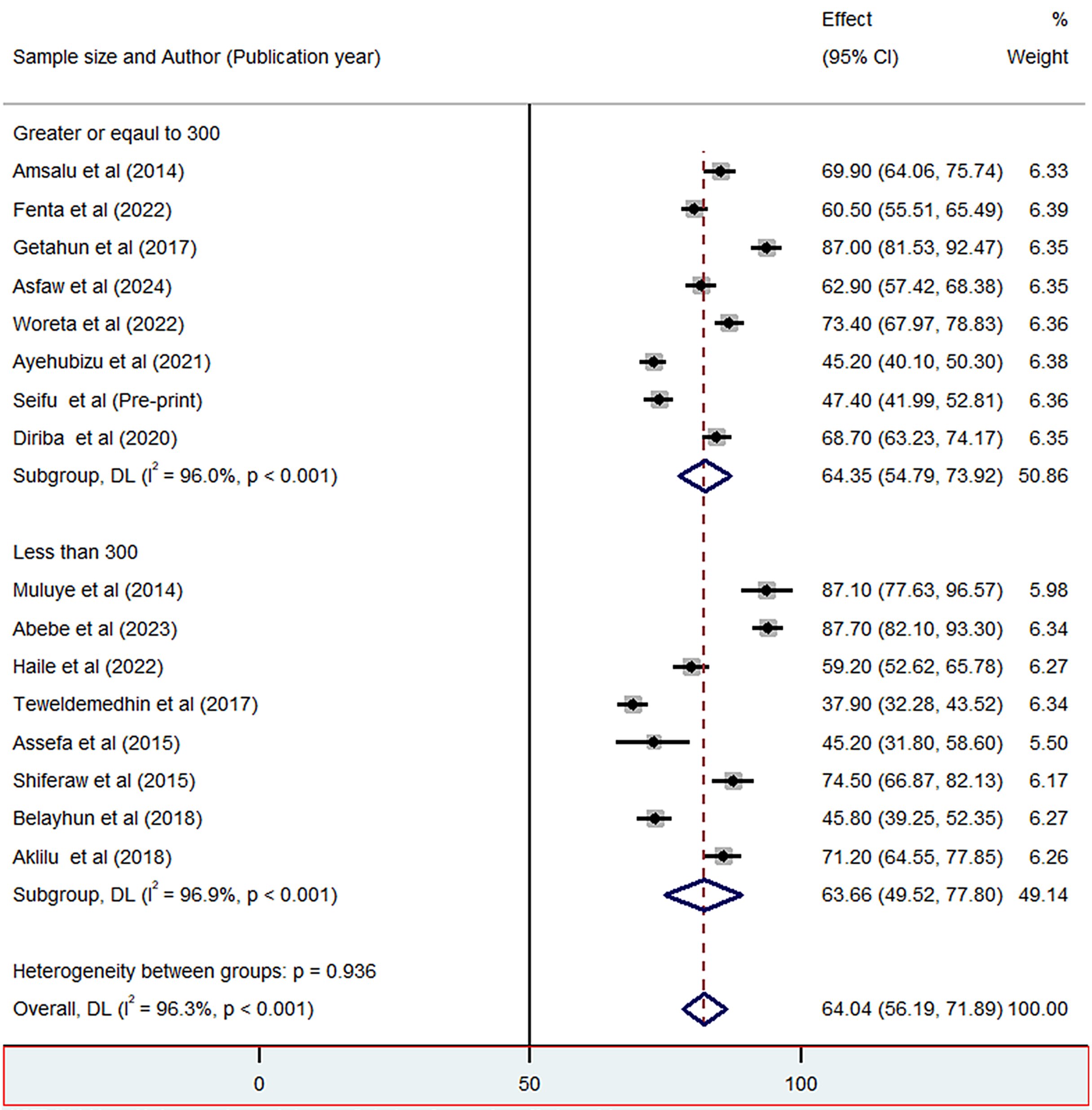

Fig. 9 Forest plot showing the subgroup analysis of MDR by sample size

Gram-positive bacteria (especially *S. aureus*) is comparable across several Ethiopian regions and internationally, but the regional variations in pathogen prevalence suggest the influence of environmental conditions, hygiene practices, and local microbial ecosystems [25]. The study also highlights the need for region-specific interventions and antimicrobial stewardship to combat the increasing threat of multidrug resistance and ensure effective treatment strategies. The substantial heterogeneity in the pooled data emphasizes the necessity for further research to understand the underlying causes of these regional differences and refine public health responses.

The pooled prevalence of multidrug-resistant (MDR) bacterial eye infections was 62.8% CI: 59.82–72.30, bring into closely with a study Dessie, Ethiopia, where the MDR rate was similarly reported at 62.4% [33] and Addis Ababa (71.2%) [47]. However, the MDR rate in this study is higher than those found in other Ethiopian regions such as Tigray (53%) [28] and some international studies like China (12.1%) [47]. Conversely, the MDR rate in this study is lower than that reported in Gondar (87%) [30]. The differences in MDR prevalence across regions in Ethiopia are likely due to variations in local antibiotic usage, healthcare infrastructure, and bacterial strains, with urban and densely populated areas facing

Table 4 Sensitivity analysis of the included studies in Ethiopia

Author	Estimate	95% CI
Amsalu et al. [32]	54.365	40.754–67.975
Muluye et al. [29]	53.701	40.332–67.071
Fenta et al. [27]	55.177	41.399–68.955
Getahun et al. [30]	53.835	40.312–67.353
Asfaw et al. [33]	54.220	40.599–67.842
Woreta et al. [34]	54.047	40.462–67.632
Tesfaye et al. [24]	52.919	39.774–66.064
Abebe et al. [25]	53.616	40.180-67.052
Haile et al. [26]	53.585	40.186–66.983
Ayehubizu et al. [2]	53.862	40.306–67.419
Teweldemedhin et al. [28]	53.365	40.031–66.699
Assefa et al. [35]	53.711	40.377–67.046
Shiferaw et al. [36]	53.808	40.389–67.228
Mohammed et al. [31]	53.279	39.999–66.559
Belayhun et al. [37]	53.607	40.202–67.012
Aklilu et al. [38]	54.024-	40.530-67.518
Seifu et al. [39]	54.762	41.055–68.469
Diriba et al. [40]	54.516	40.842–68.191
Wuletaw et al. [23]	56.828	51.848–61.807
Combined prevalence	**54.069**	**41.104–67.034**

more severe antimicrobial resistance challenges [26, 31]. The study revealed significant heterogeneity (I^2 = 96.3%, $p < 0.001$), driven by factors such as methodological differences, sample size, and target population categories. Additionally, the ongoing antibiotic resistance crisis is worsened by overuse and inappropriate use of antibiotics, complicating treatment of eye infections [48]. This high variability underscores the need for region-specific antibiotic stewardship, regular monitoring, and preventive measures to manage the growing threat of MDR. Despite being a natural phenomenon, steps can be taken to slow antibiotic resistance, with the study providing valuable insights into the epidemiology, diagnosis, and clinical implications of MDR eye infections.

Table 5 Egger's test statistics of the prevalence of bacterial eye infections in Ethiopia illustrating the publication bias

Std-Eff	Coef.	Std. Err.	T	P>|t|	95% CI
Slope	-12.594	7.164	-1.76	**0.097**	-27.710, 2.521
Bias	22.004	2.851	7.72	< 0.001	15.988, 28.019

The high rates of multidrug resistance (MDR) in ocular pathogens in Ethiopia, especially in *Enterococcus* (90%) and *Acinetobacter spp.* (85%), make treatment challenging. Other pathogens like *CONS* (80%) and *H. influenzae* (80%) also show significant resistance. Moderate resistance is seen in *S. aureus* (70%) and *Pseudomonas spp.* (72%). These trends highlight the need for careful antibiotic selection, regular susceptibility testing, and region-specific interventions to manage the growing problem of MDR and ensure effective treatment.

This study employed sensitivity analysis, subgroup analysis, and meta-regression to identify potential sources of heterogeneity in the data. The sensitivity analysis confirmed that excluding any single study had minimal impact on the pooled estimate, maintaining

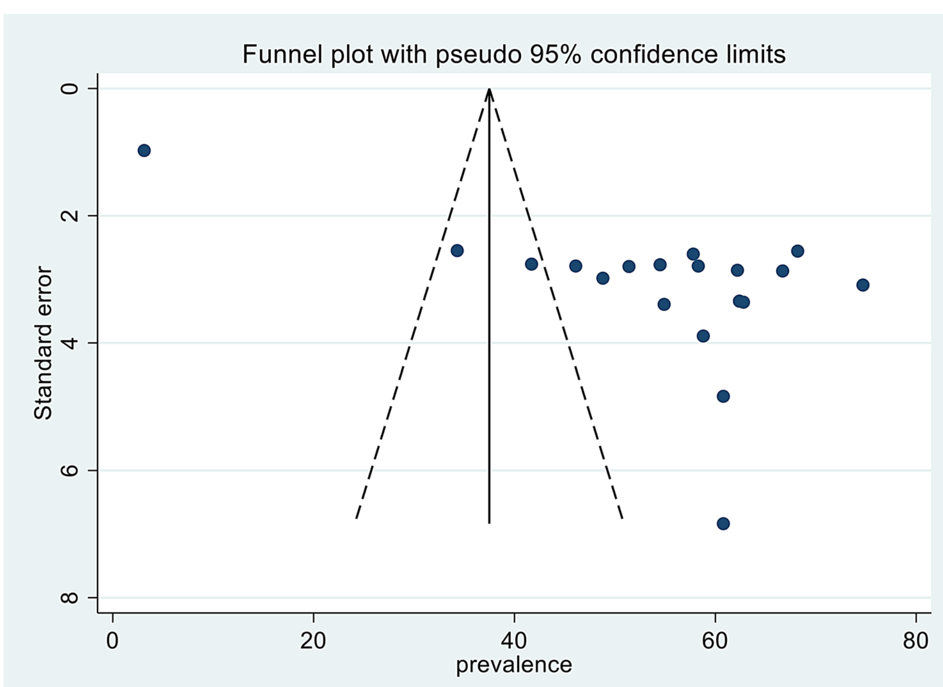

Fig. 10 Funnel plot on the prevalence of bacterial eye infections in Ethiopia illustrating the presence of publication bias

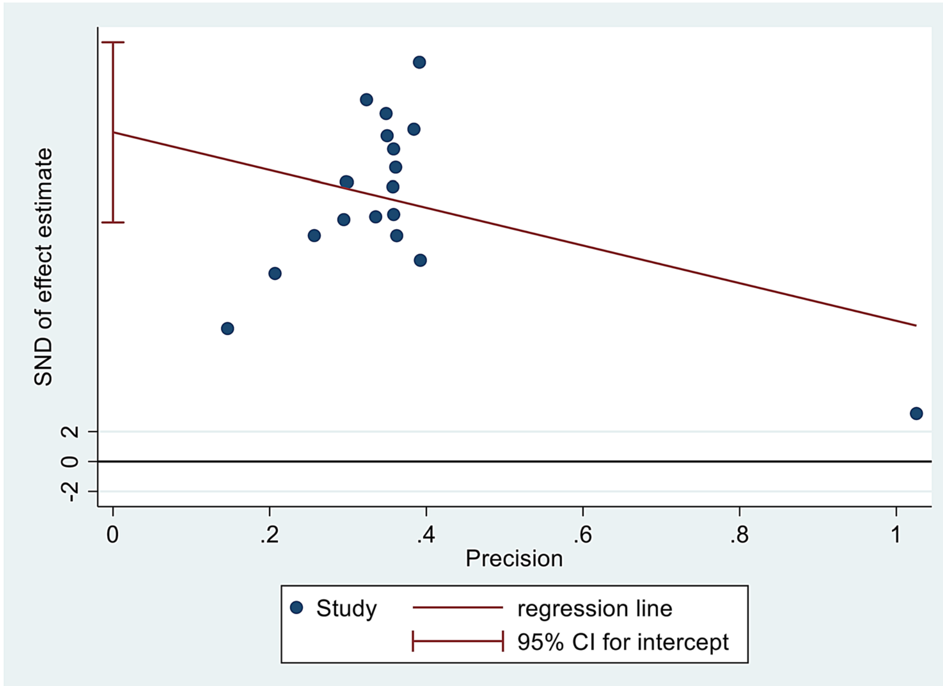

Fig. 11 Egger's test graph depicting no publication bias

Table 6 Trim and fill analysis of the prevalence of eye infections in Ethiopia **Filled**

Method	Pooled est.	95% CI		Asymptotic		No. of studies
		Lower	Upper	z-value	p-value	
Fixed	37.495	36.365	38.624	65.041	< 0.001	19
Random	54.069	41.104	67.034	8.174	< 0.001	
Test for heterogeneity: Q = 2120.205 on 18 degrees of freedom (p < 0.001)						
Moment-based estimate of between studies variance = 820.247						
Trimming estimator: Lineye						
Meta-analysis type: Fixed-effects model						
Iteration	**Estimate**	**Tn**	**# To trim**		**Diff**	
1	37.495	171	8		190	
2	28.160	184	10		26	
3	25.314	186	10		4	
4	**25.314**	**186**	**10**		**0**	
Filled						
Meta-analysis						
Method	**Pooled est.**	**95% CI**		**Asymptotic**		**No. of studies**
		Lower	**Upper**	**z-value**	**p-value**	
Fixed	25.314	24.328	26.301	50.296	< 0.001	29
Random	31.013	18.793	43.232	4.974	< 0.001	
Test for heterogeneity: Q = 4020.717 on 28 degrees of freedom (p < 0.001)						
Moment-based estimate of between studies variance = 1114.835						

estimates within the 95% confidence interval, thereby reinforcing the robustness of the overall result. The 19 omitted studies showed prevalence estimates ranging from 52.92 to 56.83%, with most falling between 53% and 55%. The combined estimate for these studies was 54.07% (95% CI: 41.10–67.03%), showing consistency across the studies and confirming that no single study significantly influenced the pooled prevalence of bacterial eye infections in Ethiopia.

Publication bias was assessed through funnel plots and Egger's test, which indicated some presence of bias, despite a seemingly symmetrical apperance. Following trim-and-fill analysis, the pooled prevalence of bacterial eye infections in Ethiopia was adjusted to 73.392% (95%

Table 7 Meta-regression analysis of prevalence and MDR pattern of bacterial eye infections by different categories of studies included in the systematic review and meta-analysis

	Type of variables	Exp(b)	SE	T	*P*>|t|	95% CI
Prevalence	Total isolates	1.020096	0.0224446	0.90	0.385	0.9718726 – 1.070712
	Publication year	0.1224026	0.1465905	-1.75	0.107	0.0087705–1.708269
	Sample size	1.010753	0.0191361	0.56	0.583	0.9694999 – 1.053761
MDR	Total isolates	1.005243	0.0180785	0.29	0.777	0.9662295 – 1.045831
	Publication year	0.2087983	0.2007601	-1.63	0.132	0.0251565- 1.733022
	Sample size	1.003603	0.0152143	0.24	0.817	0.9706692 – 1.037655

CI: 65.148–81.635), indicating some adjustments were made due to publication bias.

Limitation All studies were phenotypic, lacking genotypic analysis of antibiotic resistance, which limits understanding of resistance mechanisms. Strengthening healthcare infrastructure and establishing a national surveillance system are crucial for improving diagnosis and treatment. Antimicrobial stewardship programs and targeted interventions in high-prevalence regions should be prioritized. Future research should include both phenotypic and genotypic data to better understand resistance and standardize diagnostic methods. Public education on antibiotic use and hygiene is also essential.

Conclusion

The pooled prevalence of bacterial eye infections was found to be 54.07%, with significant regional differences. The pooled prevalence of MDR was 66.06%, with the highest rates observed in the Somali region (87.7%) and the lowest in Tigray (37.9%). The study found diverse antibiotic resistance patterns across clinical specimens and demographics, with significant variation in regional data, bacterial species, and prevalence. The main discrepancies in study design, phenotypic reliance, and inherent biases can be refined through meta-regression and subgroup analyses.Despite these limitations, the increasing threat of MDR in bacterial eye diseases is clear. Strengthening antimicrobial stewardship, combining phenotypic and genotypic data for standardized diagnostics, and improving public education on antibiotic usage and hygiene are all crucial for effective intervention.

Abbreviations

AMR	Antimicrobial resistance
CI	confidence interval
CLSI	Clinical Laboratory Standards Institute
MDR	Multidrug resistance
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
STATA	Statistics and data
WHO	World Health Organization

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Not applicable.

Author contributions
Mihret Tilahun conceived and designed the study. Habtu Debash, and Agumas Shibabaw participated in the article research and data extraction. Mihret Tilahun, and Alemu Gedefie conducted a quality assessment of the included studies and performed the statistical analysis and interpretation of the data. Mihret Tilahun, Bekele Sharew drafted the manuscript. Mihret Tilahun, and Agumas Shibabaw check the validity and monitor the overall process. Mihret Tilahun, Habtu Debash and Agumas Shibabaw critically reviewed the manuscript. All the authors read and approved the final manuscript.

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Data availability
All required data for this reseerech are available within the manuscript.

Declarations

Ethical approval and consent to participate
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Consent for publication
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Competing interests
The authors declare no competing interests.

Author details
[1]Department of Medical Laboratory Science, College of Medicine and Health Sciences, Wollo University, P.O. Box: 1145, Dessie, Ethiopia
[2]Department of Medical Laboratory Science, College of Medicine and Health Sciences, Debre Tabor University, Debre Tabor, Ethiopia

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