Advances in Microbiology, 2026, 16(6), 237-257
https://www.scirp.org/journal/aim
ISSN Online: 2165-3410
ISSN Print: 2165-3402

Prevalence of Ocular Infections and the Burden of Multidrug-Resistant Bacteria in Africa: A Systematic Review and Meta-Analysis

Mahirou Garba Sounna[1*], Lamine Mahaman Moustapha[1], Abdourahamane Yacouba[2], Ounoussa Tapha[2], Ousmane Sani[3], Laouali Laminou[4], Amza Abdou[2], Zoubeirou Alzouma Mayaki[1,3]

[1]Laboratory of Ecology and Management of Sahelo-Saharan Biodiversity, Faculty of Science and Technology, André Salifou University of Zinder, Zinder, Niger
[2]Faculty of Health Sciences, Abdou Moumouni University of Niamey, Niamey, Niger
[3]Tropical Microbiology Laboratory, Faculty of Science and Technology, Abdou Moumouni University of Niamey, Niamey, Niger
[4]Clinical Research and Health System Laboratory, Faculty of Health Sciences, André Salifou University of Zinder, Zinder, Niger
Email: *labspromotion@gmail.com

How to cite this paper: Garba Sounna, M., Mahaman Moustapha, L., Yacouba, A., Tapha, O., Sani, O., Laminou, L., Abdou, A. and Alzouma Mayaki, Z. (2026) Prevalence of Ocular Infections and the Burden of Multidrug-Resistant Bacteria in Africa: A Systematic Review and Meta-Analysis. *Advances in Microbiology*, **16**, 237-257.
https://doi.org/10.4236/aim.2026.166013

Received: April 14, 2026
Accepted: June 19, 2026
Published: June 22, 2026

Abstract

Ocular infections represent a major public health challenge in Africa, where data on their epidemiology and antimicrobial resistance (AMR) remain fragmentary. This study aimed to synthesize available data on the prevalence, microbial aetiology, and antimicrobial resistance profiles of ocular infections in Africa. This systematic review and meta-analysis were conducted via PubMed, Google Scholar, and AJOL (2000-2025). Pooled prevalence was estimated using a random-effects model. Heterogeneity was assessed using the I^2 statistic. Fifteen studies (5004 specimens) from five African countries were included. The pooled prevalence of ocular infections was 65% (95% CI: 58% - 71%), with significant heterogeneity ($I^2 = 97\%$). Regional prevalence was 61% in East Africa and 74% in West Africa. Gram-positive cocci predominated (69.6%), with *Staphylococcus aureus* (39.6%) and coagulase-negative staphylococci (CoNS) (18.6%). Multidrug resistance (MDR) rates were high: CoNS (63.5%; 95% CI: 58.7% - 68.1%), *Klebsiella pneumoniae* (76%; 95% CI: 56.6% - 88.5%), *Escherichia coli* (60.6%), and *S. aureus* (54.7%). Temporal analysis revealed a decline in *S. aureus* and the emergence of CoNS and *K. pneumoniae*. Ocular infections in Africa exhibited high prevalence and alarming multidrug resistance rates, exceeding global estimates, particularly for CoNS and *K. pneumoniae*. These findings underscore the urgency of continental surveillance programs and targeted interventions.

Keywords

Ocular Infections, Antimicrobial Resistance, Africa, Meta-Analysis, Multidrug Resistance

1. Introduction

Ocular infections represent a significant global public health concern, posing a substantial risk of severe vision impairment and blindness when diagnosis and treatment are delayed. This spectrum of conditions, encompassing viral, bacterial, fungal, and parasitic aetiologies, includes conjunctivitis, keratitis, blepharitis, and endophthalmitis, with bacterial pathogens being the most frequently implicated [1]. Globally, infectious keratitis is a leading cause of preventable blindness, affecting millions each year. The burden of this disease is disproportionately high in low- and middle-income countries, where access to ophthalmic care and antimicrobials may be limited [2]. The scientific literature demonstrates that a limited bacterial spectrum primarily causes ocular infections: *Staphylococcus aureus*, coagulase-negative staphylococci (CoNS), *Pseudomonas aeruginosa*, *Streptococcus pneumoniae*, and *Haemophilus influenzae*. These pathogens predominate in international systematic reviews and in North American and European surveillance networks [3]-[5]. Nevertheless, the epidemiological distribution and prevalence of these pathogens vary considerably across regions, influenced by factors such as regional climate, local hygiene practices, and patterns of antibiotic use [4]. There is a marked deficit of standardized, representative data on ocular infections in Africa, unlike in other regions, where epidemiological surveillance provides clear measures of the importance of pathogens, as is the case with keratitis [6] [7]. These findings underscore the persistent global burden of bacterial ocular infections and highlight a particularly high frequency in certain African regions, where access to specialized ophthalmic care and appropriate antibiotics constitutes a major public health challenge. Concurrently, the rapid emergence and spread of antimicrobial resistance (AMR) represent one of the most critical global health challenges of the 21st century. Ocular pathogens are not exempt from this concerning trend. A 2023 Ethiopian study documented high rates of resistance to ampicillin, tetracycline, and ciprofloxacin among key ocular isolates, including *Staphylococcus aureus* and *Pseudomonas aeruginosa* [8]. Furthermore, researchers have highlighted a significant paucity of data concerning the prevalence of ocular infections and local bacterial susceptibility patterns across diverse African settings [9]. This review is the first to offer a continent-wide overview over such a long period (2000-2025). Confronted with this substantial burden on ocular health, generating contemporary epidemiological data is essential to inform effective clinical decision-making. This systematic review, therefore, aims to synthesize available evidence to provide a comprehensive overview of the prevalence, microbial profiles, and antibiotic susceptibility patterns of ocular infections across the African continent.

2. Methods

2.1. Study Design

This systematic review and meta-analysis were conducted to synthesize published data on the prevalence and antimicrobial resistance of ocular infections in Africa. The study protocol was registered prospectively on the International Prospective Register of Systematic Reviews (PROSPERO) under the registration number: CRD420251127675. The review is reported in accordance with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and methodological rigor [10].

2.2. Inclusion Period

To capture contemporary microbial profiles and recent trends in antimicrobial susceptibility among ocular isolates, this review considered data published over the last quarter-century. Consequently, studies published between January 2000 and November 2025 were eligible for inclusion.

2.3. Information Sources

To ensure comprehensive literature coverage, searches were conducted across multiple electronic databases: PubMed/MEDLINE, Google Scholar, and African Journals Online (AJOL). Additional searches targeted relevant scientific society websites in microbiology and ophthalmology. Furthermore, institutional reports from the World Health Organization (WHO), the Global Action Fund for Fungal Infections (GAFFI), and the Centers for Disease Control and Prevention (CDC) were consulted.

2.4. Search Strategy

The search strategy employed a combination of Medical Subject Headings (MeSH) terms and keywords, utilizing Boolean operators (AND, OR). For PubMed, the following representative strings were used:

- ((((((Eye Infections [MeSH]) OR (Conjunctivitis [MeSH])) OR (Keratitis [MeSH])) AND (Microbial Sensitivity Tests [MeSH])) OR (Drug Resistance, Microbial [MeSH])) AND Africa [MeSH]).
- ((((Eye Infections [MeSH]) AND (Diagnosis, Microbial [MeSH])) OR (Anti-Bacterial Agents/Pharmacology [MeSH])) AND Africa [MeSH]).

For AJOL and Google Scholar, broader terms such as "*eye infections AND microbiological analysis AND Africa*" were applied to capture regional publications.

2.5. Eligibility Criteria

The studies were included if they met the following criteria: 1) conducted in an African setting, 2) patients with clinically manifest ocular infections characterized by inflammatory signs, purulent discharge, or symptomatic distress, and 3) reported primary data on microbial prevalence, profile, or antibiotic susceptibility.

Exclusion criteria involved: 1) non-primary research (systematic reviews, editorials, conference abstracts), 2) primarily measuring bacterial colonization of the ocular surface (e.g., routine preoperative screenings in asymptomatic surgical patients), 3) studies on non-ocular specimens, 4) data published before 2000, and 5) systemic infections with only secondary ocular involvement.

2.6. Study Selection and Quality Assessment

Reference management and initial de-duplication were performed using Zotero. Records were then imported into the Rayyan platform for blinded screening. Two independent reviewers (M.G.S. and G.S.M.) assessed the methodological quality of the included studies using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Prevalence Studies. Discrepancies were resolved through discussion or by a third reviewer (M.L.). Potentially relevant articles underwent full-text review. Finally, the methodological quality of included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal tool for analytical cross-sectional studies [11].

2.7. Study Data Extraction

A standardized form was used to extract publication year, country, type of ocular infection, sample source, sample size, number of positive cultures, and antimicrobial resistance rates. We specifically recorded whether resistance was defined according to CLSI or EUCAST guidelines to ensure comparability.

2.8. Statistical Analysis

Meta-analysis was performed using RStudio (version 4.5.2) with the meta package (version 7.0 or higher). Pooled prevalence and resistance rates were estimated using a random-effects model (if $I^2 > 50\%$) or a fixed-effects model (if $I^2 \leq 50\%$). Effect sizes are presented with their 95% confidence intervals (CI). Subgroup analyses were conducted by African region (East, West, North, South, Central) and by bacterial species to address the geographical variations mentioned in the introduction. The primary outcome was the bacterial culture positivity rate among clinically suspected cases. To ensure rigor, denominators were standardized by analysis: 1) total samples for overall positivity; 2) identified isolates for pathogen distribution; and 3) specific strains tested for resistance and multidrug-resistance (MDR) rates.

3. Results

3.1. Study Selection Flow

The literature search initially identified 1978 studies. Duplicates were removed using the Rayyan tool. After this step, 1947 unique studies were retained for screening. Following the title and abstract screening, twenty-three (n = 23) studies were deemed fully eligible. Finally, fifteen (n = 15) quality studies were retained. The PRISMA flow diagram (**Figure 1**) documents the entire process.

3.2. Characteristics of Included Studies

This systematic review included 15 cross-sectional studies [12]-[26] published between 2003 and 2024. Ethiopia led research production with 9 publications, followed by Nigeria (n = 3), while Egypt, Eritrea, and Tanzania each had one study. Diagnostic methodology relied primarily on standard microbiological culture. Antibiotic susceptibility was tested primarily by disk diffusion. The Clinical and Laboratory Standards Institute (CLSI) guidelines were the most frequently reported. The main characteristics of the studies are detailed in **Table 1**.

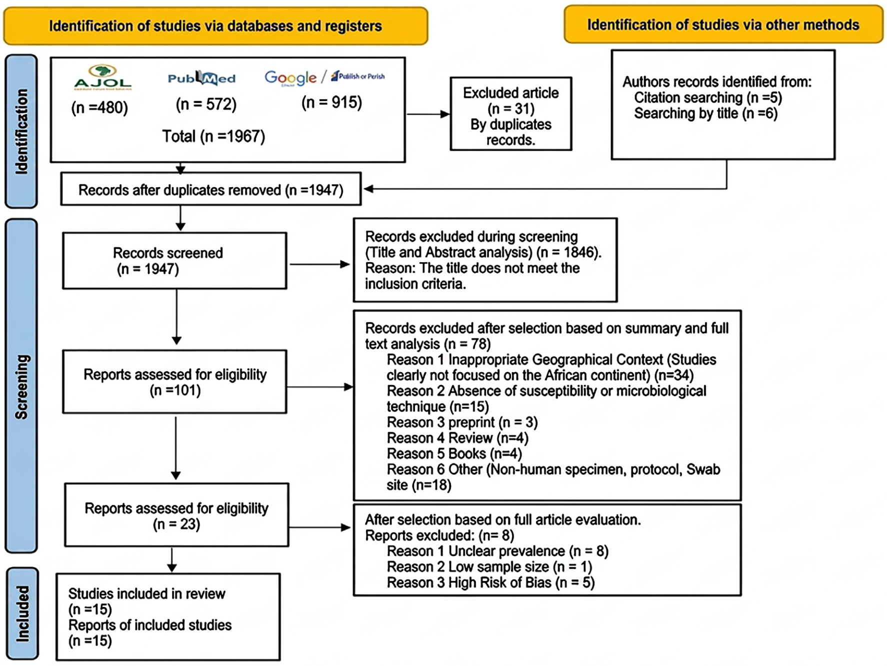

Figure 1. PRISMA flow diagram of study selection.

Table 1. Characteristics of eligible research papers.

Author	Country	Year	Study Design	Sampling Site	Sample Size (N)	Positive n (%)	Predominant Pathogens (n)	Diagnostic Method	Susceptibility Testing	Interpretive Criteria	Reference
Abebe *et al.*	Ethiopia	2023	Cross-sectional	Conjunctiva	288	179 (62.2)	*S. aureus* (95), CoNS (58), *E. coli* (11)	Microbiological culture	Disk diffusion	CLSI	[12]
Adeyaba *et al.*	Nigeria	2010	Not specified	Conjunctiva	210	158 (75.2)	*S. aureus* (72), *S. albus* (42), *P. aeruginosa* (20)	Microbiological culture	Disk diffusion	Not specified	[13]
Ahmed *et al.*	Eritrea	2022	Cross-sectional	Cornea	330	220 (66.7)	*S. aureus* (110), CoNS (66), *S. pneumoniae* (33)	Microbiological culture	Disk diffusion	CLSI	[14]
Ayehubizu *et al.*	Ethiopia	2021	Cross-sectional	Conjunctiva	360	208 (57.8)	*S. aureus* (77), CoNS (48), *K. pneumoniae* (28)	Microbiological culture	Disk diffusion	CLSI	[15]
Barakat *et al.*	Egypt	2019	Cross-sectional	Cornea	843	277 (32.9)	*A. flavus* (93), *A. niger* (68), *A. fumigatus* (51)	Culture + PCR	Not applied	Not applied	[16]

Continued

Belyhun *et al.*	Ethiopia	2018	Cross-sectional	Conjunctiva	210	131 (62.4)	CoNS (36), *S. aureus* (35), *Pseudomonas* spp. (14)	Microbiological culture	Disk diffusion	CLSI	[17]
Getahun *et al.*	Ethiopia	2017	Cross-sectional	Conjunctiva	312	182 (58.3)	*S. aureus* (96), CoNS (64), *Klebsiella* spp. (9)	Microbiological culture	Disk diffusion	CLSI	[18]
Iyamu and Enabulele	Nigeria	2003	Cross-sectional	Conjunctiva	330	248 (75.2)	*S. aureus* (150), *E. coli* (31), *P. aeruginosa* (19)	Microbiological culture	Disk diffusion	Not specified	[20]
Diriba *et al.*	Ethiopia	2020	Cross-sectional	Conjunctiva	319	147 (46.1)	*S. aureus* (29), CoNS (41), *P. aeruginosa* (10)	Microbiological culture	Disk diffusion	CLSI	[22]
Mohammed *et al.*	Ethiopia	2020	Cross-sectional	Conjunctiva	332	198 (59.6)	*S. aureus* (74), CoNS (57), *E. coli* (17)	Microbiological culture	Disk diffusion	CLSI	[24]
Neway *et al.*	Ethiopia	2019	Cross-sectional	Not specified	288	171 (59.4)	*S. aureus* (63), CoNS (54), *E. coli* (18)	Microbiological culture	Disk diffusion	CLSI	[21]
Okesola and Salako	Nigeria	2011	Cross-sectional	Conjunctiva	365	342 (93.7)	*S. aureus* (256), CoNS (35), *P. aeruginosa* (22)	Microbiological culture	Disk diffusion	NCCLS	[26]
Teweldemedhin *et al.*	Ethiopia	2017	Cross-sectional	Conjunctiva	270	180 (66.7)	*S. aureus* (40), CoNS (31), *P. aeruginosa* (21)	Microbiological culture	Disk diffusion	CLSI	[19]
Woreta *et al.*	Ethiopia	2022	Cross-sectional	Conjunctiva	323	175 (54.2)	CoNS (76), *S. aureus* (67), *Streptococcus viridans* (16)	Microbiological culture	Disk diffusion	CLSI	[23]
Rukyaa *et al.*	Tanzania	2024	Cross-sectional	Conjunctiva	224	175 (78.1)	*S. epidermidis* (85), *S. aureus* (43), *P. aeruginosa* (28).	Microbiological culture	Disk diffusion	CLSI	[25]

3.3. Methodological Quality Assessment

The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal checklist for analytical cross-sectional studies. The results are presented in Table 2. Overall, all 15 included studies demonstrated moderate to high methodological quality, with scores ranging from 7 to 9 out of a possible 9.

Abbreviations: JBI: Joanna Briggs Institute; Q1 - Q9: quality assessment criteria.

Q1: Was the sampling frame appropriate to address the target population?

Q2: Were study participants recruited in an appropriate way?

Q3: Was the sample size adequate? Q4: Were the study subjects and the setting described in detail? Q5: Was the data analysis conducted with sufficient coverage of the identified sample? Q6: Were valid methods used for the identification of the condition? (Identification of bacterial/fungal pathogens) Q7: Was the condition measured in a standard, reliable way for all participants?

Q8: Was appropriate statistical analysis used? Q9: Was the response rate adequate, and if not, was the low response rate managed appropriately? 1 = Yes, 0 = No.

Table 2. Quality assessment of included studies using the JBI checklist.

Authors and Year	Study Design	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Score
Diriba *et al.*; 2020	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Ayehubizu *et al.*; 2021	Not specified	1	1	1	1	1	1	1	1	1	9
Barakat *et al.*; 2019	Cross-sectional	1	1	1	1	1	1	0	1	1	8
Ahmed *et al.*; 2022	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Okesola and Salako; 2011	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Abebe *et al.*; 2023	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Iyamu et Enabulele; 2023	Cross-sectional	1	1	1	1	1	1	0	1	1	8
Mohammed *et al.*; 2020	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Getahun *et al.*; 2017	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Woreta *et al.*; 2022	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Teweldemedhin *et al.*; 2017	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Belyhun *et al.*; 2018	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Adeyaba *et al.*; 2010	Cross-sectional	1	0	1	1	1	1	0	1	1	7
Neway *et al.*; 2016	Cross-sectional	1	1	1	1	1	1	1	1	1	9
Rukyaa *et al.*; 2024	Cross-sectional	1	1	1	1	1	1	1	1	0	8

3.4. Meta-Analysis of the Global Prevalence of Ocular Infections

The pooled analysis of 15 cross-sectional studies comprising 5004 samples estimated an overall ocular infection prevalence of 65% (95% CI: 58% - 71%), with substantial heterogeneity ($I^2 = 97\%$; $p < 0.0001$) justifying the use of a random-effects model. Individual study prevalences ranged widely from 33% (95% CI: 30% - 36%) in the study by Barakat *et al.* [16] to 94% (95% CI: 91% - 96%) in that by Okesola and Salako [26]. The 95% prediction interval (34% - 87%) confirms the considerable dispersion of potential effects (**Figure 2**).

3.5. Subgroup Analysis by Geographical Region

The pooled prevalence was 61% (95% CI: 56% - 66%) in East Africa [12] [14] [15] [17]-[19] [21]-[25] compared to 74% (95% CI: 42% - 92%) in West Africa [13] [16] [19] [20], with corresponding heterogeneity of 86% and 99.2%, respectively. Despite these disparities, the test for subgroup differences was not significant ($p = 0.40$). The very high overall heterogeneity ($I^2 = 97\%$) and the prediction interval confirm the substantial dispersion of potential effects (Figure 3).

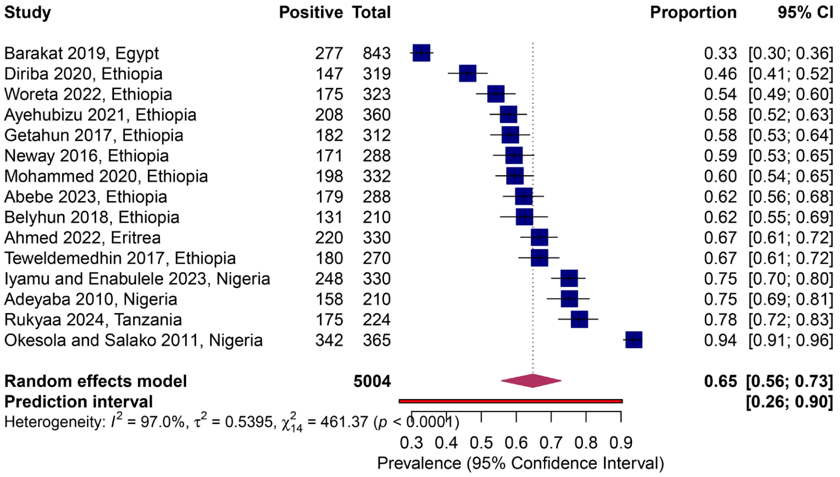

Figure 2. Forest plot of the pooled prevalence of ocular infections with 95% confidence intervals.

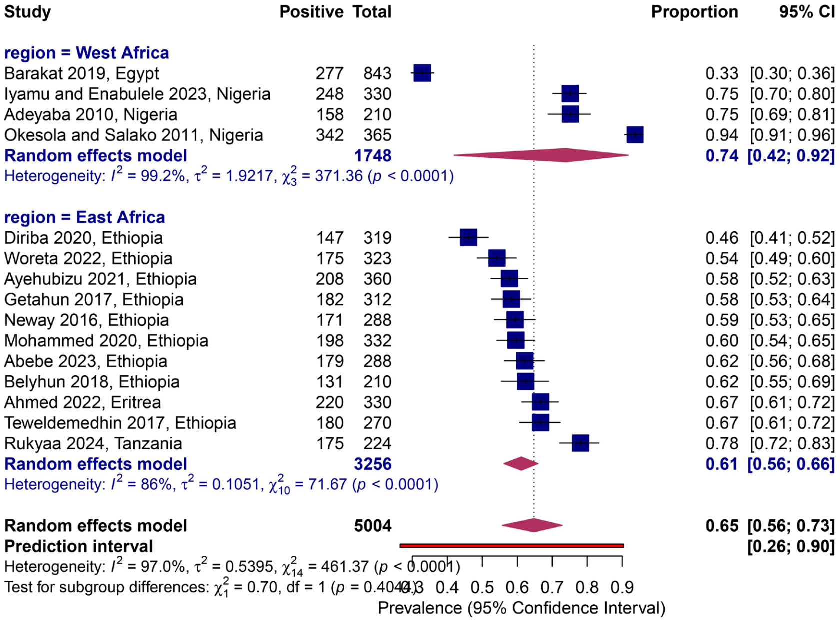

Figure 3. Forest plot of the pooled prevalence in East and West Africa.

3.6. Sensitivity Analysis and Heterogeneity According to Sample Size

The stratified analysis by sample size shows pooled prevalences of 72% (95% CI: 62% - 81%) for small studies (<250), 61% (95% CI: 55% - 67%) [13] [17] [25] for medium-sized studies (250 - 350) [12] [14] [18]-[24], and 68% (95% CI: 23% - 94%) for large studies (>350) [15] [16] [26], with very high heterogeneity across all subgroups (I^2 = 86.4% to 99.2%). The test for subgroup differences was not significant (χ^2 = 3.70; p = 0.155), indicating that sample size does not explain the observed variability. Overall heterogeneity remains very high (I^2 = 97%), confirming the substantial dispersion of results (Figure 4).

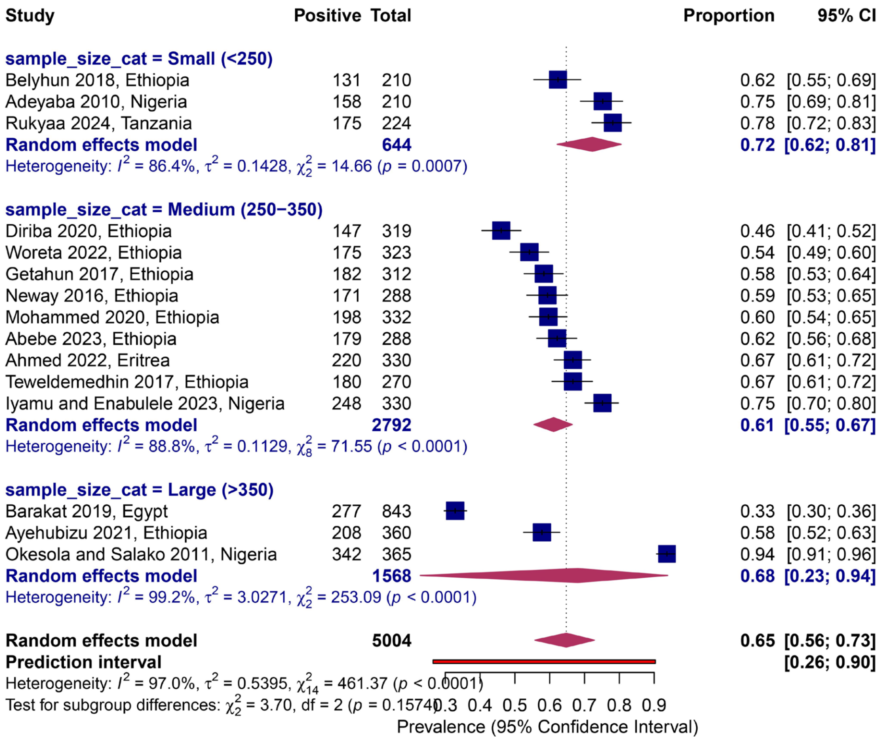

Figure 4. Forest plot of the pooled prevalence stratified by study size.

3.7. Prevalence According to the Nature of the Ocular Infection

The stratified analysis by type of infection showed a prevalence of 62% (95% CI: 55% - 68%) for external eye infections (13 studies, n = 3831) [12] [15] [18]-[24] [26], compared to 50% (95% CI: 20% - 80%) for keratitis (2 studies, n = 1173) [14] [16]. The test for subgroup differences is significant (p = 0.0025), indicating that infection type explains part of the observed variability (Figure 5).

3.8. Microbiological Profile

Analysis of the microbiological profile of ocular isolates (n = 3047) revealed a marked predominance of Gram-positive cocci (n = 2122, 69.64%), mainly *Staphylococcus aureus* (n = 1207, 39.6%) and coagulase-negative staphylococci (n = 566, 18.57%). Gram-negative bacilli constituted the second major pathogenic group (n = 597, 19.59%), dominated by *Escherichia coli* (n = 134, 4.4%) and *Pseudomonas aeruginosa* (n = 129, 4.2%), whereas Gram-negative cocci were rare (n = 48, 1.6%). The fungal component (n = 277, 9.09%) was characterized by the predominance of the genus Aspergillus, notably *Aspergillus flavus* (n = 93, 3.05%) (Table 3).

3.9. Temporal Evolution of Isolated Pathogens

Analysis of trends over the 2003-2024 period reveals a significant recomposition of the microbiological landscape of ocular infections. This evolution is characterized by a marked decline in *Staphylococcus aureus*, with its prevalence decreasing

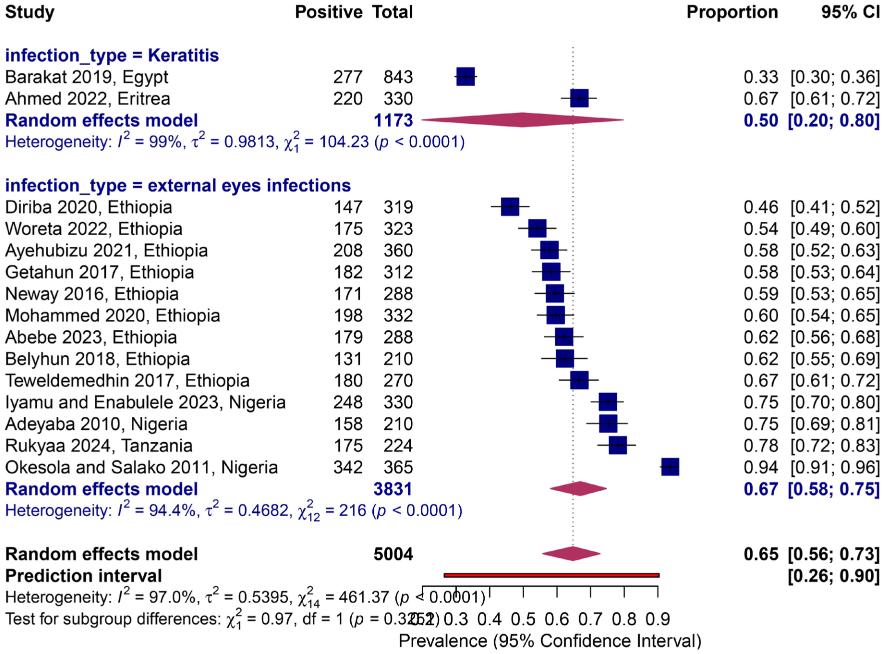

Figure 5. Forest plot of the pooled prevalence stratified by type of infection.

Table 3. Microbial profile of pathogens isolated from ocular infections.

Microbial Isolates	Frequencies and Percentage	
	n	%
Gram-positive cocci	**2122**	**69.64**
Staphylococcus aureus	1207	39.61
Coagulase-negative *Staphylococcus*	566	18.57
Streptococcus pneumoniae	91	2.99
Staphylococcus epidermidis	85	2.79
Viridans group *Streptococcus*	46	1.51
Staphylococcus albus	42	1.38
Streptococcus spp.	42	1.38
Streptococcus pyogenes	24	0.79
Enterococcus spp.	13	0.43
Streptococcus agalactiae	5	0.16
β-hemolytic *Streptococci*	1	0.03
Gram-negative cocci	**48**	**1.58**
Moraxella spp.	23	0.75
Neisseria gonorrhoeae	17	0.56
Neisseria meningitidis	8	0.26
Gram-negative bacilli	**597**	**19.59**
Escherichia coli	134	4.4
Pseudomonas aeruginosa	129	4.23

Continued

Klebsiella spp.	83	2.72
Klebsiella pneumoniae	68	2.23
Haemophilus influenzae	36	1.18
Citrobacter spp.	31	1.02
Enterobacter spp.	23	0.75
Proteus spp.	22	0.72
Pseudomonas spp.	19	0.62
Proteus mirabilis	15	0.49
Serratia marcescens	10	0.33
Proteus vulgaris	6	0.2
Acinetobacter spp.	5	0.16
Providencia stuartii	4	0.13
Citrobacter freundii	4	0.13
Klebsiella rhinoscleromatis	2	0.07
Aeromonas spp.	2	0.07
Plesiomonas shigelloides	1	0.03
Others GNB	3	0.1
Gram-positive bacilli	**3**	**0.1**
Fungi	**277**	**9.09**
Aspergillus flavus	93	3.05
Aspergillus niger	68	2.23
Aspergillus fumigatus	51	1.67
Alternaria spp.	26	0.85
Mucor species	12	0.39
Fusarium spp.	8	0.26
Candida albicans	6	0.2
Non-albicans Candida	5	0.16
Aspergillus terreus	3	0.1
Aspergillus nidulans	3	0.1
Dematiaceous fungi	2	0.07

from 45% to 27%, paralleled by a dramatic increase in coagulase-negative staphylococci (CoNS), whose isolation rate increased from 0.0% to 24.5%, as well as a notable increase in *Klebsiella pneumoniae*. Furthermore, the appearance of fungal pathogens, with the emergence of the genus *Aspergillus* during the 2019-2021 period, further complicates this evolving picture (Figure 6).

3.10. Resistance Profiles of Key Clinical Isolates

Analysis of the heatmap reveals distinct resistance profiles according to species.

Staphylococcus aureus presents a very high level of resistance to *β*-lactams (approximately 75%) and moderate resistance to macrolides (less than 50%). *Pseudomonas aeruginosa* displays variable resistance, ranging from 30% to cephalosporins to 100% to macrolides and 75% to *β*-lactams. *Escherichia coli* develops a profile comparable to *P. aeruginosa*, except for cephalosporins, where resistance is very low. Resistance remains moderate against aminoglycosides and fluoroquinolones, with *Streptococcus* escaping the latter family (Figure 7).

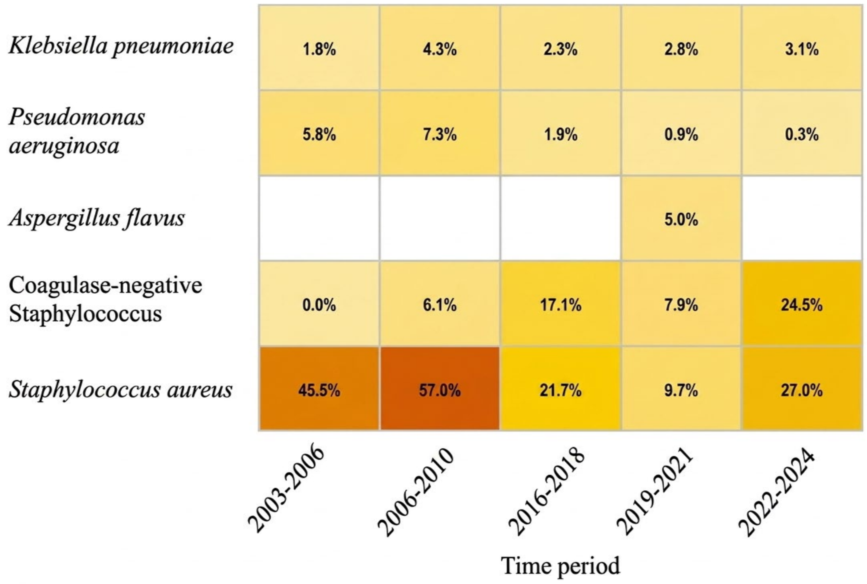

Figure 6. Evolution of the frequency of isolated germs over the years.

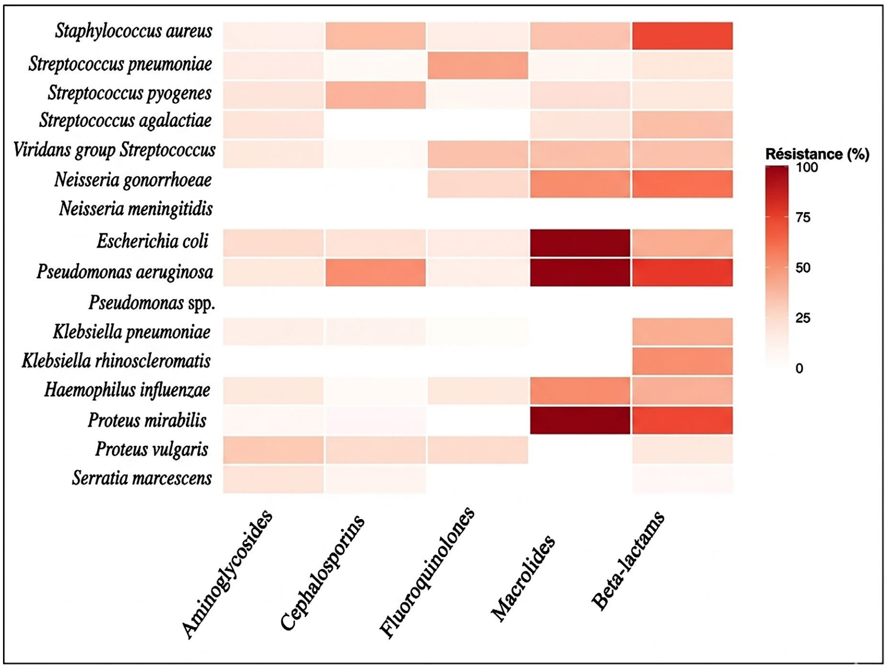

Figure 7. Antibiotic susceptibility testing results: percentages of resistant strains isolated from ocular infections, based on multiple studies in Africa.

3.11. Multidrug-Resistant Bacterial Isolates from Ocular Infections

Among the fifteen studies included in this analysis, eight (comprising 1324 bacterial isolates) [12] [15] [17]-[19] [21]-[23] reported concerning levels of multidrug resistance (MDR). The overall prevalence of multidrug resistance was 53.5% (95% CI: 50.8% - 56.1%). The coagulase-negative staphylococci (CoNS) and *Klebsiella pneumoniae* displayed the highest MDR rates, reaching 63.5% (95% CI: 58.7% - 68.1%) and 76% (95% CI: 56.6% - 88.5%), respectively. *Escherichia coli* (60.6%) and *Staphylococcus aureus* (54.7%) also showed significant resistance (**Table 4**).

Table 4. Distribution of multidrug resistance profiles among bacterial isolates from ocular infections in 8 African studies.

Bacterial Species	Number and Percentage of Antibiotic Classes to Which Isolates Are Resistant							
	(n)	R0 n (%)	R1 n (%)	R2 n (%)	R3 n (%)	R4 n (%)	≥R5 n (%)	MDR % [95% CI]
Staphylococcus aureus	503	13 (2.6)	52 (10.3)	114 (22.7)	124 (24.7)	86 (17.1)	65 (12.9)	54.7 [50.3 - 59]
*CoNS**	408	15 (3.7)	28 (6.9)	63 (15.4)	74 (18.1)	91 (22.3)	94 (23)	63.5 [58.7 - 68.1]
Escherichia coli	71	9 (12.7)	8 (11.3)	11 (15.5)	20 (28.2)	14 (19.7)	9 (12.7)	60.6 [48.9 - 71.1]
Streptococcus pneumoniae	45	4 (8.9)	9 (20)	15 (33.3)	7 (15.6)	10 (22.2)	0 (0)	37.8 [25.1 - 52.4]
Pseudomonas aeruginosa	42	10 (23.8)	9 (21.4)	10 (23.8)	5 (11.9)	2 (4.8)	6 (14.3)	31 [19.1 - 46]
Proteus spp.	37	3 (8.1)	7 (18.9)	13 (35.1)	9 (24.3)	1 (2.7)	4 (10.8)	37.8 [24.1 - 53.9]
Klebsiella spp.	28	1 (3.6)	2 (7.1)	5 (17.9)	7 (25)	7 (25)	4 (14.3)	64.3 [45.8 - 79.3]
Viridans streptococci	26	3 (11.5)	10 (38.5)	6 (23.1)	5 (19.2)	2 (7.7)	0 (0)	26.9 [13.7 - 46.1]
Klebsiella pneumoniae	25	4 (16)	2 (8)	3 (12)	12 (48)	6 (24)	1 (4)	76 [56.6 - 88.5]
Enterobacter spp.	23	2 (8.7)	4 (17.4)	8 (34.8)	4 (17.4)	5 (21.7)	0 (0)	39.1 [22.2 - 59.2]
Citrobacter spp.	22	4 (18.2)	6 (27.3)	4 (18.2)	5 (22.7)	2 (9.1)	1 (4.5)	36.4 [19.7 - 57]
Haemophilus influenzae	22	3 (13.6)	7 (31.8)	8 (36.4)	3 (13.6)	1 (4.5)	0 (0)	18.2 [7.3 - 38.5]
Streptococcus pyogenes	22	5 (22.7)	12 (54.5)	1 (4.5)	2 (9.1)	1 (4.5)	1 (4.5)	18.2 [7.3 - 38.5]
Serratia marcescens	10	3 (30)	2 (20)	2 (20)	2 (20)	1 (10)	0 (0)	30 [10.8 - 60.3]
Streptococcus agalactiae	7	2 (28.6)	1 (14.3)	1 (14.3)	1 (14.3)	1 (14.3)	1 (14.3)	42.9 [15.8 - 75]
GLOBAL MDR	708	-	-	-	-	-	-	53.5 [50.8 - 56.1]

*CoNS: Coagulase-negative staphylococci; MDR: Multidrug-resistant (resistant to ≥3 antibiotic classes); R0 - R5: Number of antibiotic classes to which isolates are resistant.

3.12. Egger's Test of Publication Bias

Egger's regression test revealed no significant funnel plot asymmetry ($p > 0.05$), and the symmetrical distribution of studies around the pooled estimate suggests no major publication bias. Trim-and-fill analysis confirmed the robustness of the findings, with an adjusted estimate nearly identical to the original. However, the limited number of studies (n = 15) reduces the power of these tests, although the comprehensive search strategy minimizes the risk of bias (**Figure 8**).

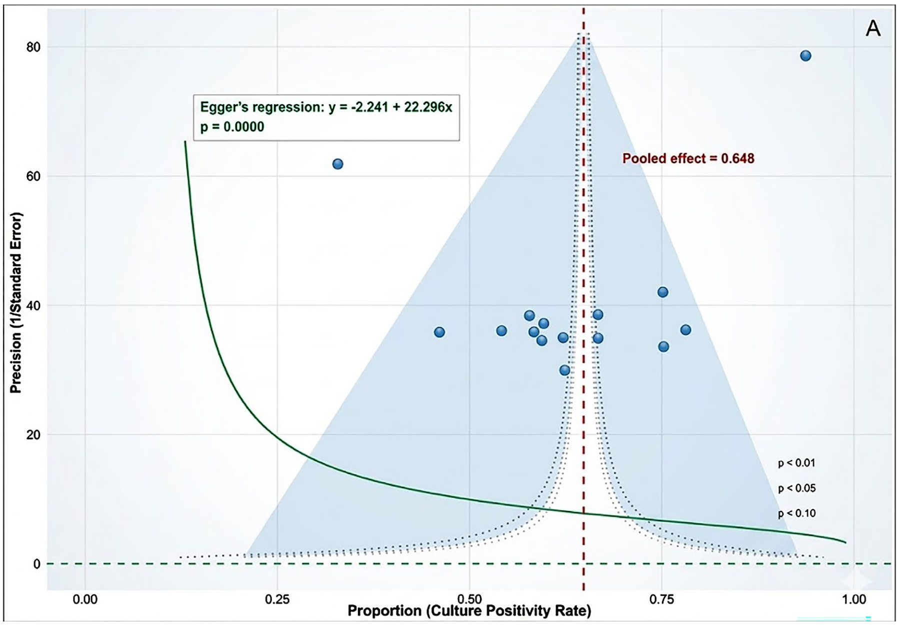

Figure 8. Funnel plot of ocular infection prevalence for publication bias assessment.

4. Discussion

The meta-analysis revealed a pooled weighted prevalence of positive cultures of 65% (95% CI: 58% - 71%). This estimate was derived using a random-effects model, necessitated by the substantial inter-study heterogeneity ($I^2 = 97.0\%$, $p < 0.0001$). This significant variability is reflected in the wide range of individual prevalence rates, varying from 33% (95% CI: 30% - 36%) reported in Egypt by Barakat *et al.* [16] to 94% (95% CI: 91% - 96%) observed in Nigeria by Okesola and Salako [26]. The notably low prevalence in the Egyptian study is primarily attributable to its specific focus on fungal keratitis, which typically has a lower incidence than bacterial conjunctival infections [16]. Conversely, the extremely high prevalence reported in Nigeria (averaging 83% across Nigerian studies) may result from the interplay of environmental factors, behavioral determinants, and barriers to accessing specialized eye care, phenomena frequently documented in resource-limited settings [13] [20] [26]. More broadly, this variation can be attributed to differences in study populations [27] [28], diagnostic techniques [29], geographic locations [30], and clinical settings [27].

The overall prevalence identified in this review (65%) differs from the national estimates reported in other African syntheses, such as the study by Tilahun *et al.* in Ethiopia (54.07%) [31]. Nevertheless, our findings corroborate those of Lottie Brown *et al.*, highlighting a high incidence of ocular infections in developing regions of Africa and Asia, compared with the lower rates observed in Europe [32]. These geographical and temporal variations are multifactorial; they arise from methodological divergences, climatic disparities influencing pathogen survival, and socio-economic determinants related to healthcare infrastructure accessibility.

The extreme heterogeneity observed in this meta-analysis ($I^2 = 97\%$; $p < 0.0001$) reflects the vast diversity of clinical and microbiological contexts across Africa. Clinically, the predominance of global external infections (62%) over isolated keratitis (50%) may be explained by the limited number of studies on keratitis, of which only two were included, one being specifically focused on fungal keratitis. Nevertheless, this difference is consistent with the literature, which highlights the severity and diagnostic specificity of corneal involvement, thereby naturally limiting its statistical prevalence in favor of clinical precision [33]. The regional analysis revealed a higher prevalence in West Africa (74%) compared to East Africa (61%). This trend may reflect variations in healthcare infrastructure, population density, and climatic conditions. Environmental and socio-economic factors are well-established factors in the transmission of ocular infections [34] [35]. The lack of statistical significance suggests that intra-regional variability outweighs inter-regional differences, highlighting the multifactorial nature of ocular infections [36]. Regarding the aetiological profile, *Staphylococcus aureus* was confirmed as the predominant bacterial pathogen in ocular infections across Africa during the study period, followed by coagulase-negative staphylococci (CoNS). However, this hierarchy of predominance was not uniform across all included studies, revealing notable epidemiological variability. For instance, in Nigeria, the works of Iyamu and Enabulele, and Adeyeba *et al.* reported no CoNS isolates, suggesting either a distinct local microbial ecology or differences in laboratory identification methods [13] [20]. More drastically, the study by Barakat *et al.* in Egypt, which focused on mycotic keratitis, isolated no bacterial species [16]. These disparities underscore the critical need for standardized microbiological diagnostic protocols to refine epidemiological surveillance across the continent. This systematic review and meta-analysis (n = 3047) corroborates the predominance of Gram-positive cocci (69.64%) reported by Zhang *et al.* in 2022 [2] [37], and primarily *Staphylococcus aureus* (39.61%), in agreement with the international literature [38] [39]. The proportions of Gram-negative bacilli (19.59%) and filamentous fungi (9.09%) validate established aetiological profiles of severity [40] [41], while highlighting the critical emergence of multidrug resistance in ophthalmology [38]. The decline of *Staphylococcus aureus* in favor of coagulase-negative staphylococci (CoNS) and *Klebsiella pneumoniae* marks a major epidemiological transition in ocular infections in Africa. Several recent studies, particularly in Ethiopia and Malawi, confirm the emergence of CoNS as the predominant pathogen, now ranking first or second among isolates in cases of conjunctivitis and keratitis [31] [36]. Concurrently, the emergence of *K. pneumoniae* is all the more concerning as this pathogen exhibits alarming multidrug resistance profiles [42], complicating current therapeutic strategies on the continent. The high resistance levels observed in *S. aureus* and *P. aeruginosa*, two major ocular pathogens, illustrate the growing challenge of antimicrobial resistance (AMR) in ocular infections. For *S. aureus*, our results align with African data showing the ineffectiveness of simple penicillins (>80% resistance) [43] [44]. Regarding *P. aeruginosa*, the alarming multidrug-resistance (MDR) profiles reported in Sub-Saharan Africa echo our findings [45], confirming the circulation of resistant strains and the need for enhanced surveillance. The overall prevalence of multidrug resistance (MDR) observed in this review is part of a concerning global trend for ocular health. The 63.5% MDR rate for coagulase-negative staphylococci (CoNS) represents an urgent clinical challenge, comparable to systemic medicine data where MDR rates reach 66% [46]. Our estimate significantly exceeds the global pooled prevalence of 25% reported by a recent meta-analysis covering 214 studies and sits markedly above the averages observed in Europe (30%) and Asia (21%) [47]. These disparities may be explained by limited access to last-line antibiotics, frequent antibiotic prescriptions without prior microbiological examination, and inadequate logistical support for adequate analyses. Furthermore, the 64.2% rate observed for *Klebsiella pneumoniae* aligns with global concerns about the emergence of hypervirulent, multidrug-resistant strains, whose potential to cause devastating endogenous endophthalmitis is well documented [48].

While this global trend suggests a concerning shift in the ocular microbiological landscape, the scope of our findings must be interpreted in light of several inherent methodological limitations. First, restricted access to major subscription-based databases, such as EMBASE, Scopus, or Web of Science, may have constrained the exhaustiveness of the literature retrieval process. Second, extreme heterogeneity ($I^2 = 97\%$) persisted despite rigorous subgroup analyses, reflecting the profound disparity in clinical settings and diagnostic protocols across the continent. Furthermore, geographic representativeness remains fragmented; available data originated from only five of the 54 African nations, with a disproportionate concentration in East Africa. This limited spatial coverage, coupled with a modest sample size (n = 15), inevitably curtails the statistical power required for a robust assessment of publication bias. From a technical standpoint, the infrequent utilization of advanced molecular biology techniques in primary studies may have obscured emerging resistance mechanisms that conventional phenotypic methods fail to detect. Finally, the lack of standardized criteria for defining multidrug resistance (MDR) across the included studies hinders a rigorous head-to-head comparison of resistance magnitudes between different regions.

5. Conclusion

This meta-analysis of 15 studies comprising 5004 samples reveals a heavy burden of ocular infections in Africa, with a prevalence exceeding 1 in 2 patients. *Staph-*

ylococcus aureus predominates (39.6%), followed by coagulase-negative staphylococci (CoNS; 18.6%), with an alarming emergence of CoNS and *Klebsiella pneumoniae*. Multidrug resistance rates are concerning, at 63.5% for CoNS and 76% for *K. pneumoniae*, far exceeding global averages. The high heterogeneity ($I^2 = 97\%$) and limited geographic coverage call for: 1) standardized continental surveillance programs, 2) strengthening microbiological diagnostics, 3) promoting antibiotic stewardship in ophthalmology, and 4) further research in under-represented regions. These actions are essential to curb antimicrobial resistance and prevent avoidable blindness in Africa.

Authors' Contributions

All named authors have approved the final version of the manuscript and consented to its submission.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Watson, S., Cabrera-Aguas, M. and Khoo, P. (2018) Common Eye Infections. *Australian Prescriber*, **41**, 67-72. https://doi.org/10.18773/austprescr.2018.016

[2] Zhang, Z., Cao, K., Liu, J., Wei, Z., Xu, X. and Liang, Q. (2022) Pathogens and Antibiotic Susceptibilities of Global Bacterial Keratitis: A Meta-Analysis. *Antibiotics*, **11**, Article No. 238. https://doi.org/10.3390/antibiotics11020238

[3] Teweldemedhin, M., Gebreyesus, H., Atsbaha, A.H., Asgedom, S.W. and Saravanan, M. (2017) Bacterial Profile of Ocular Infections: A Systematic Review. *BMC Ophthalmology*, **17**, Article No. 212. https://doi.org/10.1186/s12886-017-0612-2

[4] Asbell, P.A., Sanfilippo, C.M., Sahm, D.F. and DeCory, H.H. (2020) Trends in Antibiotic Resistance among Ocular Microorganisms in the United States from 2009 to 2018. *JAMA Ophthalmology*, **138**, 439-450. https://doi.org/10.1001/jamaophthalmol.2020.0155

[5] Bertret, C., Knoeri, J., Leveziel, L., Bourcier, T., Brignole-Baudouin, F., Merabet, L., *et al.* (2024) Predisposing Factors, Clinical and Microbiological Insights of Bacterial Keratitis: Analysis of 354 Cases from a Leading French Academic Centre. *British Journal of Ophthalmology*, **109**, 15-20. https://doi.org/10.1136/bjo-2024-325261

[6] Bashir, G., Shah, A., Rashid, S., *et al.* (2005) Bacterial and Fungal Profile of Corneal Ulcers—A Prospective Study. *Indian Journal of Pathology and Microbiology*, **48**, 273-277.

[7] Orlans, H.O., Hornby, S.J. and Bowler, I.C.J.W. (2011) *In Vitro* Antibiotic Susceptibility Patterns of Bacterial Keratitis Isolates in Oxford, UK: A 10-Year Review. *Eye*, **25**, 489-493. https://doi.org/10.1038/eye.2010.231

[8] Solomon, Z., Anberbir, S., Churiso, G., Mitiku, A., Bogale, A., Gebrie, H., *et al.* (2025)

Bacterial Spectrum and Antimicrobial Resistance Patterns of External Ocular Infections among Patients Attending Dilla University General Hospital Ophthalmic Clinic, Southern Ethiopia. *Canadian Journal of Infectious Diseases and Medical Microbiology*, **2025**, Article ID: 5593194. https://doi.org/10.1155/cjid/5593194

[9] Bale, B.I., Elebesunu, E.E., Manikavasagar, P., Agwuna, F.O., Ogunkola, I.O., Sow, A.U., *et al.* (2023) Antibiotic Resistance in Ocular Bacterial Infections: An Integrative Review of Ophthalmic Chloramphenicol. *Tropical Medicine and Health*, **51**, Article No. 15. https://doi.org/10.1186/s41182-023-00496-x

[10] Sohrabi, C., Franchi, T., Mathew, G., Kerwan, A., Nicola, M., Griffin, M., *et al.* (2021) PRISMA 2020 Statement: What's New and the Importance of Reporting Guidelines. *International Journal of Surgery*, **88**, Article ID: 105918. https://doi.org/10.1016/j.ijsu.2021.105918

[11] Moola, S., Munn, Z., Tufanaru, C., Aromataris, E., Sears, K., Sfetic, R., *et al.* (2020) Chapter 7: Systematic Reviews of Etiology and Risk. In: Aromataris, E. and Munn, Z., Eds., *JBI Manual for Evidence Synthesis*, JBI.

[12] Abebe, T., Teklemariam, Z., Shume, T., Mekuria, S., Urgesa, K. and Weldegebreal, F. (2023) Bacterial Profile of External Ocular Infections, Its Associated Factors, and Antimicrobial Susceptibility Pattern among Patients Attending Karamara Hospital, Jigjiga, Eastern Ethiopia. *International Journal of Microbiology*, **2023**, Article ID: 8961755. https://doi.org/10.1155/2023/8961755

[13] Adeyeba, O.A., Anorue, M.C., Adefioye, O.A., *et al.* (2010) Conjunctivitis among Children in a Teaching Hospital in the South-West of Nigeria: Role of *Staphylococcus aureus* as an Aetiologic Agent and Its Antibiogram. *African Journal of Microbiology Research*, **4**, 1945-1948.

[14] Ahmed, K.S., Bhayal, B.K., Eman, D., *et al.* (2022) Identification of Bacterial Profiles, Common Associated Risk Factors, and Antimicrobial Susceptibility Patterns of Bacterial Keratitis in Community Hospitals of Asmara, Eritrea. *Ethiopian Medical Journal*, **60**, 245-256.

[15] Ayehubizu, Z., Mulu, W. and Biadglegne, F. (2021) Common Bacterial Causes of External Ocular Infections, Associated Risk Factors and Antibiotic Resistance among Patients at Ophthalmology Unit of Felege Hiwot Referral Hospital, Northwest Ethiopia: A Cross-Sectional Study. *Journal of Ophthalmic Inflammation and Infection*, **11**, Article No. 7. https://doi.org/10.1186/s12348-021-00238-2

[16] Barakat, G.I.I., Kamal, Y.N. and Sultan, A.M. (2019) Could Aflatoxin B1 Production by *Aspergillus flavus* Affect the Severity of Keratitis: An Experience in Two Tertiary Health Care Centers, Egypt. *European Journal of Clinical Microbiology & Infectious Diseases*, **38**, 2021-2027. https://doi.org/10.1007/s10096-019-03636-6

[17] Belyhun, Y., Moges, F., Endris, M., Asmare, B., Amare, B., Bekele, D., *et al.* (2018) Ocular Bacterial Infections and Antibiotic Resistance Patterns in Patients Attending Gondar Teaching Hospital, Northwest Ethiopia. *BMC Research Notes*, **11**, Article No. 597. https://doi.org/10.1186/s13104-018-3705-y

[18] Getahun, E., Gelaw, B., Assefa, A., Assefa, Y. and Amsalu, A. (2017) Bacterial Pathogens Associated with External Ocular Infections Alongside Eminent Proportion of Multidrug Resistant Isolates at the University of Gondar Hospital, Northwest Ethiopia. *BMC Ophthalmology*, **17**, Article No. 151. https://doi.org/10.1186/s12886-017-0548-6

[19] Teweldemedhin, M., Saravanan, M., Gebreyesus, A. and Gebreegziabiher, D. (2017) Ocular Bacterial Infections at Quiha Ophthalmic Hospital, Northern Ethiopia: An Evaluation According to the Risk Factors and the Antimicrobial Susceptibility of Bacterial

Isolates. *BMC Infectious Diseases*, **17**, Article No. 207. https://doi.org/10.1186/s12879-017-2304-1

[20] Iyamu, E. and Enabulele, O. (2003) A Survey on Ophthalmia Neonatorum in Benin City, Nigeria (Emphasis on Gonococcal Ophthalmia). *The Online Journal of Health and Allied Sciences*, **2**, 1-6.

[21] Neway, S., Desta, K., Dessie, W., *et al.* (2019) Bacterial Profile and Antimicrobial Susceptibility Patterns from External Ocular Infections and Associated Risk Factors at the All Africa Leprosy Rehabilitation and Training Center (ALERT), Addis Ababa, Ethiopia. *Ethiopian Medical Journal*, Supplement 1, 67-77.

[22] Diriba, K., Kassa, T., Alemu, Y. and Bekele, S. (2020) *In Vitro* Biofilm Formation and Antibiotic Susceptibility Patterns of Bacteria from Suspected External Eye Infected Patients Attending Ophthalmology Clinic, Southwest Ethiopia. *International Journal of Microbiology*, **2020**, Article ID: 8472395. https://doi.org/10.1155/2020/8472395

[23] Woreta, A.N., Kebede, H.B., Tilahun, Y., Teklegiorgis, S.G. and Abegaz, W.E. (2022) Antibiotic Susceptibility Pattern and Bacterial Spectrum among Patients with External Eye Infections at Menelik II Referral Hospital in Addis Ababa, Ethiopia. *Infection and Drug Resistance*, **15**, 765-779. https://doi.org/10.2147/idr.s352098

[24] Mohammed, A.A., Ali, M.M. and Zenebe, M.H. (2020) Bacterial Etiology of Ocular and Periocular Infections, Antimicrobial Susceptibility Profile and Associated Factors among Patients Attending Eye Unit of Shashemene Comprehensive Specialized Hospital, Shashemene, Ethiopia. *BMC Ophthalmology*, **20**, Article No. 124. https://doi.org/10.1186/s12886-020-01398-w

[25] Rukyaa, J., Temba, L., Kachira, P., Mwanansao, C. and Seni, J. (2024) Prevalence and Antimicrobial Susceptibility Patterns of Bacteria Colonizing the External Ocular Surfaces of Patients Undergoing Ocular Surgeries at Bugando Medical Center in Mwanza, Tanzania. *BMC Research Notes*, **17**, Article No. 193. https://doi.org/10.1186/s13104-024-06851-3

[26] Okesola, A.O. and Salako, A.O. (2011) Microbiological Profile of Bacterial Conjunctivitis in Ibadan, Nigeria. *Annals of Ibadan Postgraduate Medicine*, **8**, 20-24. https://doi.org/10.4314/aipm.v8i1.63953

[27] Woldemariam, M., Aklilu, A., Manilal, A., Mengistu, M., Tadesse, D., Siraj, M., *et al.* (2024) Microbial Profile and Associated Factors of External Ocular Bacterial and Fungal Infections in Arba Minch General Hospital: A Cross-Sectional Study. *Scientific Reports*, **14**, Article No. 28744. https://doi.org/10.1038/s41598-024-77723-w

[28] Newman, A. and McCluskey, P. (2025) Epidemiological Spectrum of Infectious Uveitis in the Asia-Pacific. *TJO*, **15**, 157-181. https://doi.org/10.4103/tjo.tjo-d-25-00052

[29] Aaby, M., Lalitha, P., Prajna, N.V., *et al.* (2022) Comparing Microbiologic Tests for Pathogen Detection in Infectious Keratitis Using Latent Class Analysis. *Cornea*.

[30] Beutner, K. (2025) Looking Out for Atypical Cornea Infections. EyeWorld. https://www.eyeworld.org/2025/looking-out-for-atypical-cornea-infections/

[31] Tilahun, M., Gedefie, A., Sharew, B., Debash, H. and Shibabaw, A. (2025) Prevalence of Bacterial Eye Infections and Multidrug Resistance Patterns among Eye Infection Suspected Patients in Ethiopia: A Systematic Review and Meta-Analysis. *BMC Infectious Diseases*, **25**, Article No. 705. https://doi.org/10.1186/s12879-025-11095-y

[32] Brown, L., Leck, A.K., Gichangi, M., Burton, M.J. and Denning, D.W. (2021) The Global Incidence and Diagnosis of Fungal Keratitis. *The Lancet Infectious Diseases*, **21**, e49-e57. https://doi.org/10.1016/s1473-3099(20)30448-5

[33] Singh, R.B., Singh Parmar, U.P., Woreta, F., Srikumaran, D., Sharma, N. and Jhanji,

V. (2026) Global Burden, Risk Factors, Causative Organisms and Antibiotic Susceptibility Patterns in Bacterial Keratitis. *The Ocular Surface*, **39**, 49-57. https://doi.org/10.1016/j.jtos.2025.12.003

[34] Stapleton, F. (2023) The Epidemiology of Infectious Keratitis. *The Ocular Surface*, **28**, 351-363. https://doi.org/10.1016/j.jtos.2021.08.007

[35] Maqbool, S., Shan, H., Daud, S., Navied, U. and Mirza, H. (2024) Acute Conjunctivitis through a Public Health Lens: A Review. *BioMedica*, **40**, 153-158. https://doi.org/10.24911/biomedica/5-1165

[36] Somerville, T.F., Mdala, S., Zungu, T., Gandiwa, M., Herbert, R., Everett, D., *et al.* (2024) Microbial Keratitis in Southern Malawi: A Microbiological Pilot Study. *BMJ Open Ophthalmology*, **9**, e001682. https://doi.org/10.1136/bmjophth-2024-001682

[37] André, C., Lebreton, F., Van Tyne, D., Cadorette, J., Boody, R., Gilmore, M.S., *et al.* (2023) Microbiology of Eye Infections at the Massachusetts Eye and Ear: An 8-Year Retrospective Review Combined with Genomic Epidemiology. *American Journal of Ophthalmology*, **255**, 43-56. https://doi.org/10.1016/j.ajo.2023.06.016

[38] Asbell, P.A. and DeCory, H.H. (2018) Antibiotic Resistance among Bacterial Conjunctival Pathogens Collected in the Antibiotic Resistance Monitoring in Ocular Microorganisms (ARMOR) Surveillance Study. *PLOS ONE*, **13**, e0205814. https://doi.org/10.1371/journal.pone.0205814

[39] Obaid, N., Saeed, A., Abbas, S., Perveen, S. and Younas, H. (2025) Resistance Trend in Bacteria Isolated from Corneal Ulcers: A Retrospective Analysis from Pakistan. *PLOS ONE*, **20**, e0325157. https://doi.org/10.1371/journal.pone.0325157

[40] Keay, L.J., Gower, E.W., Iovieno, A., Oechsler, R.A., Alfonso, E.C., Matoba, A., *et al.* (2011) Clinical and Microbiological Characteristics of Fungal Keratitis in the United States, 2001-2007: A Multicenter Study. *Ophthalmology*, **118**, 920-926. https://doi.org/10.1016/j.ophtha.2010.09.011

[41] Tiecco, G., Laurenda, D., Mulè, A., Arsuffi, S., Storti, S., Migliorati, M., *et al.* (2022) Gram-Negative Endogenous Endophthalmitis: A Systematic Review. *Microorganisms*, **11**, Article No. 80. https://doi.org/10.3390/microorganisms11010080

[42] Akinyemi, K.O., Abegunrin, R.O., Iwalokun, B.A., Fakorede, C.O., Makarewicz, O., Neubauer, H., *et al.* (2021) The Emergence of *Klebsiella pneumoniae* with Reduced Susceptibility against Third Generation Cephalosporins and Carbapenems in Lagos Hospitals, Nigeria. *Antibiotics*, **10**, Article No. 142. https://doi.org/10.3390/antibiotics10020142

[43] Azzam, A., Khaled, H., Salem, A., Sayed, M., Mohieldein, A., Elsayed, M.S., *et al.* (2026) Proportion and Antibiogram of Methicillin-Resistant *Staphylococcus aureus* (MRSA) in Africa: A Systematic Review and Meta-Analysis. *Antimicrobial Resistance & Infection Control*, **15**, Article No. 13. https://doi.org/10.1186/s13756-025-01687-3

[44] Fenta, M.D., Bitew, A.B., Demisse, B.W., Abey, S.L., Mengistu, B.A., Kinde, M.Z., *et al.* (2025) Systematic Review and Meta-Analysis of *Staphylococcus aureus* at the Human-Animal-Environment Interface in Eastern Africa: Prevalence, Virulence Genes, and Antimicrobial Resistance Profile. *One Health*, **21**, Article ID: 101229. https://doi.org/10.1016/j.onehlt.2025.101229

[45] Kindiki, S.K., Nyongesa, P.K., Mogoi, N.N. and Kiprono, S. (2025) The Role of *Pseudomonas aeruginosa* in Surgical Site Infections in Sub-Saharan Africa. *Science Mundi*, **5**, 8-22. https://doi.org/10.51867/scimundi.5.1.2

[46] Ather, M. and Conrady, C.D. (2025) Emerging Ocular Pathogen Resistance and Clinically Used Solutions: A Problem That Is More than Meets the Eye. *Pharmaceuticals*, **19**, Article No. 31. https://doi.org/10.3390/ph19010031

[47] Zomorodi, A.R., Mohammadi, M., Farshi, Z.G., Parvizi Mashhadi, M.H., Benam, S.P. and Motamedifar, M. (2025) Prevalence and Antimicrobial Susceptibility Pattern of Coagulase-Negative Staphylococci Isolated from Ocular Infections: A Systematic Review and Meta-Analysis. *The Ocular Surface*, **37**, 227-235. https://doi.org/10.1016/j.jtos.2025.03.006

[48] Serban, D., Popa Cherecheanu, A., Dascalu, A.M., Socea, B., Vancea, G., Stana, D., *et al*. (2021) Hypervirulent *Klebsiella pneumoniae* Endogenous Endophthalmitis—A Global Emerging Disease. *Life*, **11**, Article No. 676. https://doi.org/10.3390/life11070676