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Antimicrobial resistance pattern of *Acinetobacter baumannii* clinical isolate in Ethiopia. A systematic review and meta-analysis

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Abstract

Background Antimicrobial resistance (AMR) is a growing global health threat. *Acinetobacter baumannii* (*A. baumannii*) emerged as one of the most concerning critical priority pathogens due to its ability to develop resistance to multiple antimicrobial agents. In Ethiopia, the public health impact of AMR is increasingly significant, with *A. baumannii* responsible for a variety of infections. Although *A. baumannii* causes a range of infections in Ethiopian patients, the drug resistance status of the clinical isolates has not been thoroughly assessed. Therefore, this systematic review and meta-analysis aimed to determine the country-wide AMR of *A. baumannii*.

Methods This systematic review and meta-analysis followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We conducted a search of articles on PubMed, Web of Science, Science Direct, Scopes electronic databases, Google Scholar search engine, and institutional repositories/libraries for studies published between 2015 and 2024. Eligible studies on *A. baumannii*-related infections and AMR in Ethiopia were assessed for quality using the Joanna Briggs Institute (JBI) criteria. Data on study characteristics were extracted, and statistical analyses, including heterogeneity (Invers of variance), publication bias (Eggers test), and subgroup analyses, were performed using STATA 17.0. A random effect model was used to compute the pooled prevalence of AMR.

Results This systematic review and meta-analysis of 26 Ethiopian studies (26,539 participants) found an *A. baumannii* prevalence of 3.99% (95% CI: 3.01–4.98%) and 9.13% of all bacterial infections (95% CI: 6.73–11.54%). The most common infections were surgical site infections, urinary tract infections, pneumonia, and sepsis. Pooled resistance to antibiotics varied, with amikacin showing the lowest resistance (20.27%) (95% CI: 11.51–29.03) and cefotaxime the highest (83.18) (95% CI: 71.87–94.48). A pooled multi-drug resistant (MDR) *A. baumannii* was found in 88.22% (95% CI: 82.28–94.15) of isolates, with regional and infection-type variations, particularly in higher prevalence in Oromia and Amhara regions and sepsis cases.

Conclusion This systematic review underscores the alarming rise of antimicrobial resistance in *A. baumannii*, particularly against carbapenems. The findings highlight a high prevalence of MDR *A. baumannii* and widespread extended-spectrum beta-lactamase production, with notable regional variations in resistance patterns. These high resistance

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rates reinforce *A. baumannii* as a critical global health threat, necessitating urgent interventions such as enhanced antimicrobial stewardship programs, improved infection control measures, and the development of alternative treatment strategies. Healthcare professionals, policymakers, and researchers must collaborate to mitigate the clinical and public health impact of this pathogen.

Protocol registration This systematic review and meta-analysis was registered on PROSPERO (Registration ID: CRD42024623927).

Keywords Multi-drug resistance, Acinetobacter, Carbapenem resistance, Ethiopia

Introduction

Antimicrobial resistance (AMR) has become a significant worldwide health concern, resulting in longer illness duration, more complex treatment, higher deaths, and increased healthcare expenses [1]. Antimicrobial drugs are essential to contemporary medical treatment, but as infections become more resistant, their efficacy is declining. *Acinetobacter baumannii* (*A. baumannii*) is a very dangerous bacterium in medical settings, especially for patients who are immunocompromised or had invasive operations done [2]. Nowadays, most of the infections are difficult to manage due to the rapid development of antibiotic resistance, which raises the burden on healthcare systems and the rate of complications [3]. The bacterium thrives in hospital environments, including intensive care units (ICUs) and long-term care facilities, where it can persist on surfaces and medical equipment, aiding in its spread [3].

Globally, AMR was responsible for an estimated 1.27 million deaths in 2019, with an additional 4.95 million deaths related to its effects [4]. In the World Health Organization (WHO) regions of Europe, the Eastern Mediterranean, and Africa, hospital-acquired *A. baumannii* infections account for approximately 2.5% of all infections [5]. The economic burden of these infections includes extended hospital stays, increased treatment costs, and additional expenditures related to complications and resistance management [6]. According to the World Bank, AMR could lead to an extra US$1 trillion in healthcare costs by 2050, with potential global gross domestic product losses of US$1 trillion to US$3.4 trillion annually by 2030 [7].

Although AMR is a challenge worldwide, its impact is particularly severe in low-resource settings where healthcare systems struggle with issues such as inadequate diagnostic infrastructure, inconsistent surveillance, and excessive use of antibiotics [8]. These factors accelerate the emergence and spread of drug-resistant pathogens. The world health organization (WHO) has categorized carbapenem-resistant *A. baumannii* as a critical priority pathogen, stressing the need for improved research into treatments and diagnostics [9].

In Ethiopia, managing *A. baumannii* infections is especially difficult due to limited diagnostic capabilities and inconsistent antibiotic stewardship practices. Data on the resistance profiles of *A. baumannii* in Ethiopia remain incomplete and inconsistent. For example, a 2017 WHO report highlights carbapenem resistance rates exceeding 50% in some African countries, including Ethiopia, but a more recent review suggests a lower prevalence [9, 10]. The wide variation in resistance patterns from full susceptibility to total resistance complicates treatment protocols [11–13]. These disparities emphasize the need for a systematic and comprehensive analysis of *A. baumannii* resistance in Ethiopia to better inform clinical management.

This study seeks to address these gaps by conducting a systematic review and meta-analysis of the AMR patterns of *A. baumannii* in clinical specimens from Ethiopian patients. The results will fill critical gaps in the current literature, offer valuable insights for clinical practice, and guide policy and resource allocation for managing drug-resistant infections. By providing robust data, this research will contribute to global efforts to combat AMR, in line with the WHO's call to prioritize pathogens such as carbapenem-resistant *A. baumannii*. While this study has direct implications for policy and clinical practice, its relevance extends to the broader field of AMR, infectious disease management, and global health.

Methods

Protocol registration

This systematic review and meta-analysis have been registered on PROSPERO (International Prospective Register of Systematic Reviews) (registration ID: CRD42024623927).

Search strategy

Comprehensive and systematic searches were conducted across various databases, including PubMed, Web of Science, and ScienceDirect electronic databases, to retrieve relevant published articles. Additionally, articles accessible through Google Scholar and online repositories of various institutions were included. The search targeted studies published in English between January 1, 2015, and January 31, 2024, using Medical Subject Headings (MeSH) terms and keywords such as ((Antimicrobial resistance [MeSH Terms]) OR (Antibiotic resistance [MeSH Terms]) OR (Microbial drug resistance [MeSH Terms])) AND *Acinetobacter baumannii* [MeSH Terms] AND ((infection) OR (infections)) AND Ethiopia.

Study selection process and eligibility criteria

Articles were imported into EndNote X7 (Thomson Reuters, Toronto, Canada), and duplicates were removed. Two reviewers (Z.A. and M.A.R.) independently assessed the eligibility of articles based on predefined criteria, with disagreements resolved by other reviewers (A.S. and Y.G). Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline [14] (Fig. 1), studies underwent title screening, followed by abstract and full-text reviews. Inclusion criteria were; studies conducted in Ethiopia, published in English, and reported AMR in *A. baumannii* using validated phenotypic or molecular Antimicrobial susceptibility testing (AST) methods. Exclusion criteria included: (a) broad AMR categories, (b) combined data without specifying isolates and AMR patterns, or (c) missing outcomes of interest.

Quality assessments

The quality of each study was evaluated using the updated Joanna Briggs Institute (JBI) tool for prevalence studies [15]. Two independent reviewers(Z.A. and M.A.R.,) critically appraised each study. In cases of disagreement, additional reviewers (A.S. and Y.G.), were consulted to resolve. Studies with a final quality score of 50% or higher were deemed eligible for inclusion in the systematic review and meta-analysis.

Data extraction

We used a standardized data extraction form prepared in Microsoft Excel 2016 to systematically collect relevant

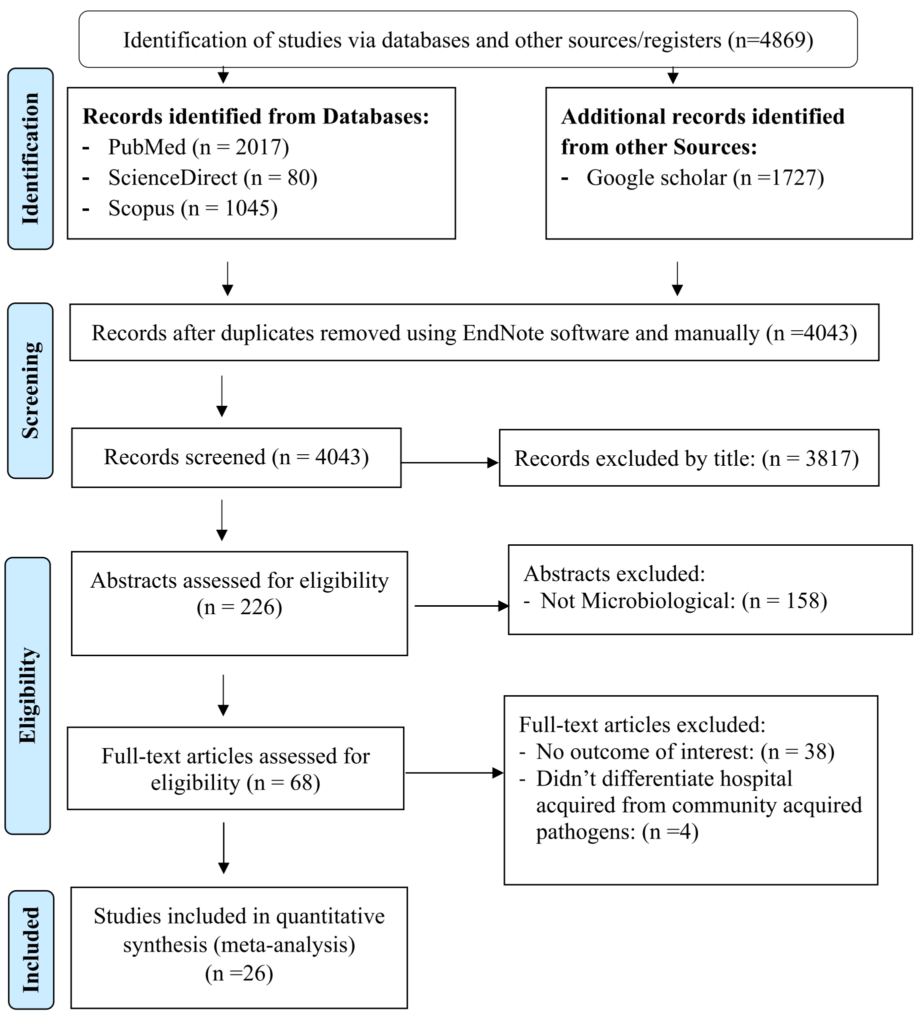

Fig. 1 PRISMA flow diagram showed the results of the search and reasons for exclusion [14]

information from each included study. The extraction process covered several domains, including study attributes such as; the author(s), year of publication, study design, and study location. It also included information on the types and number of study participants, clinical data such as infection types (healthcare-associated urinary tract infections, surgical site infections (SSIs), and puerperal sepsis), specimen types (urine, pus/swab, blood, and mixed specimens), the total number of isolated bacteria, and the count of *A. baumannii*. Additionally, it provided details on the AST methods, and AMR profile of *A. baumannii* to various antibiotics, including the number of tested isolates, the count of AMR isolates, and the number of MDR isolates.

Statistical analysis

The data was first entered into Microsoft Excel before being transferred to STATA 17.0 software (StataCorp, Texas, USA) for analysis. The inverse variance test (I^2) was used to assess the heterogeneity among studies. Interpretations were given according to the I^2 values, which were 0%, 0–25%, 25–50%, and >75%, which denoted no, low, medium, and high heterogeneity, respectively [16]. Sub-group analyses were conducted when there was significant heterogeneity among the studies. Egger's test was utilized to assess the existence of publication bias, employing a significance threshold of $p < 0.05$. Additionally, a trim-and-fill analysis was carried out to address and mitigate potential bias. A random-effects model for meta-analysis was employed to determine the pooled prevalence of infections associated with *A. baumannii*, as well as the pooled prevalence of AMR and MDR *A. baumannii*. The aggregate prevalence of infections associated with *A. baumannii* was determined by assessing the proportion of *A. baumannii* cases among the total number of specimens. To calculate the pooled prevalence of AMR and MDR continuity correction was made for zero and hundred percent AMR values which resulted in zero standard error [17]. Finally, the pooled prevalence of AMR was calculated separately for each antibiotic tested.

Results

Searching results and description of included articles

A total of 26 potential studies investigating AMR, MDR, ESBL production, and carbapenemase enzyme production in *A. baumannii* isolated from clinical specimens in Ethiopian patients were included in this systematic review and meta-analysis [11–13, 18–40] (Table 1). Collectively, these studies assessed 26,539 participants for *A. baumannii* infections, identifying 1,630 isolates that were tested for resistance to 15 different antibiotics using disc diffusion AST. The findings revealed a wide variation in resistance rates, ranging from 0.0% to 100% for the antibiotics evaluated [11–13, 18–40].

The pooled prevalence of *A. baumannii* clinical isolates

The pooled prevalence of *A. baumannii* infections among study participants was 3.99% (95% CI: 3.01–4.98). Additionally, the proportion of *A. baumannii* among all bacterial infections was 9.13% (95% CI: 6.73–11.54). The most common infections associated with *A. baumannii* were SSIs, catheter-associated urinary tract infections (CAUTIs), sepsis, and pneumonia.

Antimicrobial resistance of *A. baumannii* clinical isolates

In this systematic review and meta-analysis, a minimum of eight studies for imipenem and tobramycin, and a maximum of twenty-three studies for gentamicin, ciprofloxacin, and ceftazidime were included. *A. baumannii* clinical isolates showed variable pooled resistance rates, ranging from 20.27% for amikacin (95% CI: 11.51–29.03) to 83.18% for cefotaxime (95% CI: 71.87–94.48). Four of the thirteen antibiotics had pooled resistance rates below 50%, including amikacin (20.27%) (95% CI: 11.51–29.03), imipenem (33.5%) (95% CI: 16.84–50.16), meropenem (43.58%) (95% CI: 32.29–54.88), and tobramycin (47.02%) (95% CI: 40.04–54.00). The remaining nine antibiotics had resistance rates exceeding 50% (Table 2).

Egger's test was computed to detect the presence of publication bias, with a significance level of $p < 0.05$. Studies exhibiting publication bias were then subjected to trim-and-fill analysis to correct for bias. For all antibiotics, the results of the trim-and-fill analysis were higher than the pooled resistance estimates before the adjustment. Specifically, for gentamicin, resistance increased from 57.12% to 65.48% (7 imputed studies), ceftazidime from 81.83% to 94.88% (10 studies), trimethoprim-sulfamethoxazole from 79.94% to 88.41% (6 studies), meropenem from 43.58% to 53.48% (6 studies) and ceftriaxone from 81.93% to 84.13% (1 study). Tetracycline and cefepime showed no effect from trim-and-fill analysis despite significant publication bias (Table 2).

Subgroup analysis and leave-one-out sensitivity analyses

Subgroup analyses were carried out based on study year, geographical region, and infection type to explore potential sources of heterogeneity. Furthermore, leave-one-out sensitivity analyses were conducted for each antibiotic to evaluate the stability of the pooled estimates and identify any studies with an outsized impact on the results.

The subgroup analysis revealed variations in antibiotic resistance across study years, infection types, and regions. Resistance to several antibiotics, such as ciprofloxacin, ceftazidime, cefotaxime, and meropenem, has shown a significant upward trend over time, indicating a

Table 1 Characteristics and quality appraisal of included studies in the meta-analysis

S. N	Author	Study year	Region	Study design	Infection type	Sample size	No of *A. baumannii* isolated	Reports	Quality score (Out of 9)
1	Abosse et al	2021	AM	CS	SSI	165	9	AMR, MDR	8
2	Admas et al	2020	AM	CS	Sepsis	166	6	AMR, MDR	8
3	Alelign et al	2022	SNNPR	CS	SSI	245	6	AMR, MDR	7
4	Asres et al	2017	AA	CS	SSI	197	17	AMR, MDR	7
5	Asmare et al	2024	AM	CS	CAUTI	363	6	AMR, MDR	8
6	Bizuayehu et al	2022	AA	CS	CAUTI	220	15	AMR, MDR	9
7	Dessie et al	2016	AA	CS	SSI	107	23	AMR, MDR	8
8	Mekonen et al	2021	AM	CS	Mixed	254	16	AMR, MDR	8
9	Motbinor et al	2020	AM	CS	Mixed	238	9	AMR, MDR	9
10	Tilahun et al	2022	AM	CS	Mixed	423	29	AMR, MDR, ESBL, CP	8
11	Worku et al	2023	Mixed	CS	SSI	752	38	AMR, MDR	9
12	Abdeta et al	2021	AA	CS	Mixed	1337	74	AMR, MDR, CP	9
13	Abdeta et al	2023	AA	CS	Mixed	7110	161	AMR	9
14	Adane et al	2020	AM	CS	Mixed	5328	52	AMR	9
15	Alebel et al	2021	AM	CS	Mixed	270	13	AMR, MDR, ESBL, CP	8
16	Araya et al	2023	AA	CS	Mixed	-	893	MDR	9
17	Seneshat et al	2018	AA	CS	Mixed	422	7	AMR, MDR	8
18	Bitew et al	2019	AA	CS	Mixed	996	28	AMR, MDR. ESBL	9
19	Bitew et al	2023	AA	CS	Sepsis	844	7	AMR, MDR, ESBL	8
20	Gashaw et al	2019	OR	CS	Sepsis	313	16	AMR, MDR	8
21	Gashaw et al	2024	OR	CS	Mixed	1794	122	ESBL	9
22	Hailemariamet al	2021	SNNPR	CS	Mixed	1085	17	AMR, MDR	8
23	Legesse et al	2022	Mixed	CS	Sepsis	1416	34	AMR, MDR	9
24	Mussema et al	2023	OR	CS	Pneumonia	150	7	AMR, MDR	7
25	Tadesse et al	2023	AM	CS	Mixed	384	20	AMR, MDR, ESBL CP	8
26	Tekele et al	2020	AA	CS	Mixed	-	9	AMR, MDR	8

AM Amhara, *SNNPR* Southern Nation Nationality People Region, *AA* Addis Ababa, *OR* Oromia, *CS* Cross-sectional, *SSI* Surgical Site Infection, *CAUTI* Catheter-associated Urinary Tract Infection, *AMR* Antimicrobial Resistance, *MDR* Multi-drug Resistance, *ESBL* Extended-Spectrum Beta-Lactamase, *CP* Carbapenemase Production

Table 2 The pooled resistance of *A. baumannii* clinical isolates for different antibiotics in Ethiopia

Antibiotics	No of studies included	Pooled resistance (95% CI)	Heterogeneity (I^2) (*p*-value)	Pooled resistance after trim-and-fill analysis	(Egger's test) *p*-value
Gentamicin	23	57.12 (49.20–65.04)	74.76%	65.48%, 7[a]	< 0.01
Ciprofloxacin	23	53.13 (42.96–63.29)	88.54%		0.683
Ceftazidime	23	81.83 (73.97–89.69)	94.74%	94.88%, 10[a]	< 0.01
Trimethoprim-sulfamethoxazole	20	79.94 (71.71–88.17)	94.34%	88.41%, 6[a]	< 0.01
Meropenem	19	43.58 (32.29–54.88)	88.14%	53.48%, 6[a]	0.039
Ceftriaxone	17	81.93 (71.81–92.04)	97.25%	84.13%, 1[a]	< 0.01
Cefotaxime	15	83.18 (71.87–94.48)	96.78%		0.086
Tetracycline	13	73.69 (59.74–87.64)	97.18%	No effect	< 0.01
Amikacin	11	20.27 (11.51–29.03)	87.5%		0.219
Cefepime	11	74.47 (64.11–84.83)	81.96%	No effect	< 0.01
Piperacillin-tazobactam	9	66.51 (47.41–85.61)	96.09%		0.393
Imipenem	8	33.50 (16.84–50.16)	91.37%		0.934
Tobramycin	8	47.02 (40.04–54.00)	27.64%		0.063

[a] The number of imputed studies. The Egger's test output, trim-and-fill analysis, and funnel plots for each antibiotic are provided in Supplementary file S2

growing challenge of AMR in recent years. Ciprofloxacin resistance rose markedly from 42.20% in 2015–2020 to 60.24% in 2021–2024. Similarly, ceftazidime and cefotaxime resistance increased sharply from 71.17% to 88.89% and 71.81% to 89.57% during the same periods, while meropenem resistance more than doubled, rising from 20.53% to 48.21% (Table 3).

The analysis of infection types revealed significant variations in antibiotic resistance. The highest resistance rates were observed in different infection types, with CAUTI showing alarming resistance levels for ceftazidime (99.5%), cefotaxime (95.13%), trimethoprim-sulfamethoxazole (91.85%), and meropenem (67.33%). In SSI, the highest resistance was found for ceftazidime (88.18%), Meropenem (53.51%), and cefotaxime (92.69%). For sepsis, resistance was highest for trimethoprim-sulfamethoxazole (93.55%) and lowest for meropenem (34.04%) (Table 3).

The geographical analysis revealed significant variations in antibiotic resistance across regions. In Amhara, high resistance rates were observed for trimethoprim-sulfamethoxazole (82.88%) and meropenem (44.96%). In Addis Ababa, resistance was notably higher for ciprofloxacin (64.78%) and cefotaxime (93.49%). In Oromia, higher resistance rates were observed for ceftazidime and trimethoprim-sulfamethoxazole, with 99.50% for each. Lastly, SNNPR exhibited lower resistance levels for trimethoprim-sulfamethoxazole at 34.07% and meropenem at 20.54% (Table 3).

Leave-one-out sensitivity analyses demonstrated that the pooled estimates were robust, with minimal variations in results across the range of values after omitting individual studies. No single study significantly influenced the overall pooled result, as evidenced by consistent 95% confidence intervals and *p*-values (S1 - 8 Figures in File S1).

Multi-drug resistance *A. baumannii* clinical isolates

A total of 22 studies were analyzed to estimate the pooled prevalence of MDR in *A. baumannii* clinical isolates, found to be 88.22% (95% CI: 82.28–94.15). The studies exhibited significant heterogeneity, with an I^2 value of 94.43% (Fig. 2). Egger's test indicated the presence of publication bias ($p < 0.01$). To account for this, a trim-and-fill analysis was conducted, adjusting the MDR prevalence to 93.57% after incorporating six additional studies.

Subgroup analysis by region and infection type revealed significant variations. Geographically, the highest MDR prevalence was observed in the Oromia region at 99.5% (95% CI: 96.62–102.38) and Amhara at 98.90% (95% CI: 96.96–100.84), while the lowest was in SNNPR at 69.63% (95% CI: 50.85–88.41). Similarly, infection types showed significant differences, with sepsis exhibiting the highest MDR prevalence at 98.62% (95%CI: 95.82–101.42) and SSI having a lower prevalence of 74.92% (95% CI: 50.62–99.22) (Fig. 3).

ESBL and carbapenemase production among *A. baumannii* clinical isolates

The pooled prevalence of ESBL production among *A. baumannii* clinical isolates was 42% (95% CI: 23.08–60.92), with substantial heterogeneity ($I^2 = 86.43\%$). Egger's test indicated no significant publication bias, with a p-value of 0.41 (Fig. 4). The pooled prevalence of carbapenemase production was 8.82% (95% CI: 3.47–14.18), with moderate heterogeneity ($I^2 = 65.60\%$). However, Egger's test revealed significant publication bias ($p = 0.01$) (Fig. 5). After adjusting for publication bias using trim-and-fill analysis, the prevalence of carbapenemase production was reduced to 3.37%.

Discussion

Acinetobacter baumannii shows significant resistance to carbapenem antibiotics, with pooled resistance rates of 33.5% for imipenem and 43.58% for meropenem, highlighting its classification by WHO as a critical AMR pathogen [41]. The findings of this systematic review and meta-analysis highlight the alarming AMR patterns of *A. baumannii* clinical isolates in Ethiopia, posing a significant threat to both patient outcomes and public health. The high resistance rates to commonly used antibiotics, including carbapenems and aminoglycosides, underscore the urgent need for enhanced antimicrobial stewardship programs, improved infection prevention and control measures, and the implementation of routine surveillance systems. Given the limited treatment options, the emergence of MDR strains raises concerns about therapeutic failure and increased morbidity and mortality. These results call for immediate action to optimize antibiotic use, strengthen laboratory diagnostic capacities, and explore alternative treatment strategies such as bacteriophage therapy and combination therapy to combat *A. baumannii* infections effectively.

Acinetobacter baumannii resistance trends are increasing globally [42], aligning with studies from Taiwan [43], Iran (30.43% for imipenem) [44], and China (51.9% for meropenem) [45]. However, higher resistance rates are reported in Asia (51.9–79.8%) [43, 45–50], Brazil (76.7%) [51], Greece (88.9%) [52], and Turkey (99.4%) [53]. The elevated carbapenem resistance in *A. baumannii* may be attributed to overuse of antibiotics, inadequate infection control practices, the organism's adaptive mechanisms, prolonged hospitalization, and limited surveillance, geographical locations, necessitating coordinated global efforts to mitigate this growing threat [54, 55].

Table 3 Subgroup analysis of the pooled resistance of *A. baumannii* clinical isolates in Ethiopia

Antibiotics	Category		Number of studies	Resistance (95% CI)	*P*-value
Gentamicin	Year	2015–2020	9	55.99% (43.15–68.82)	0.85
		2021–2024	14	57.58% (47.16–68.00)	
	Infection type	SSI	5	59.55% (37.33–81.76)	0.08
		Sepsis	4	49.12% (31.63–66.61)	
		Mixed infections	12	61.85% (52.98–7073)	
	Region	Amhara	9	54.69% (42.52–66.85)	0.24
		Addis Ababa	8	56.50% (41.56–71.44)	
		Oromia	2	42.47% (22.43–62.50)	
		SNNPR	2	61.12% (41.36–80.87)	
Ciprofloxacin	Year	2015–2020	9	42.20% (25.16–59.24)	0.08
		2021–2024	14	60.24% (48.83–71.65)	
	Infection type	CAUTI	2	52.91% (29.19–76.64)	0.08
		SSI	4	62.25% (52.52–77.98)	
		Sepsis	4	41.41% (29.62–53.20)	
		Mixed infections	12	51.67% (35.59–67.75)	
	Region	Amhara	9	39.04% (21.31–56.78)	0.06
		Addis Ababa	9	64.78% (53.53–76.02)	
		Oromia	2	49.24% (9.84–88.65)	
Ceftazidime	Year	2015–2020	9	71.17% (55.28–87.05)	0.05
		2021–2024	14	88.89% (81.93–95.85)	
	Infection type	CAUTI	2	99.5% (96.15–102.85)	< 0.01
		SSI	5	88.18% (81.78–94.58)	
		Sepsis	4	83.69% (65.69–101.7)	
		Mixed infections	11	74.47% (60.94–88.0)	
	Region	Amhara	9	77.24% (63.09–91.38)	< 0.01
		Addis Ababa	8	78.14% (61.81–94.47)	
		Oromia	2	99.50% (96.62–102.4)	
		SNNPR	2	84.58% (69.26–99.91)	
Trimethoprim-sulfameth-oxazole	Year	2015–2020	6	80.70% (64.58–96.81)	0.90
		2021–2024	14	79.47% (69.56–89.38)	
	Infection types	CAUTI	2	91.85% (73.19–110.5)	< 0.01
		SSI	3	82.35% (72.99–91.67)	
		Sepsis	4	93.55% (83.67–103.4)	
		Mixed infections	10	71.06% (58.53–83.59)	
	Region	Amhara	8	82.88% (69.65–96.11)	< 0.01
		Addis Ababa	6	77.65% (68.8–86.51)	
		Oromia	2	99.50% (96.62–102.4)	
		SNNPR	2	34.07% (15.02–53.11)	
Meropenem	Year	2015–2020	4	20.53% (11.97–29.10)	< 0.01
		2021–2024	15	48.21% (35.41–61.01)	
	Infection types	CAUTI	2	67.33% (2.48–132.18)	0.82
		SSI	3	53.51% (17.49–89.54)	
		Sepsis	3	34.04% (17.49–89.54)	
		Mixed infections	10	38.27% (27.17–49.38)	
	Region	Amhara	8	44.96% (25.33–64.59)	0.01
		Addis Ababa	5	40.61% (23.88–57.34)	
		Oromia	2	29.42% (11.06–47.78)	
		SNNPR	2	20.54% (4.22–36.86)	

Table 3 (continued)

Antibiotics	Category		Number of studies	Resistance (95% CI)	*P*-value
Ceftriaxone	Year	2015–2020	7	80.20% (62.87–97.53)	0.79
		2021–2024	10	83.11% (70.27–95.94)	
	Infection types	SSI	4	88.29% (74.10–102.6)	0.02
		Sepsis	4	84.90% (67.38–102.4)	
		Mixed infections	7	73.21% (53.98–92.45)	
	Region	Amhara	4	60.44% (37.21–83.66)	< 0.01
		Addis Ababa	7	95.57% (92.09–99.06)	
		Oromia	2	99.50% (96.62–102.4)	
		SNNPR	2	38.88% (19.13–58.64)	
Cefotaxime	Year	2015–2020	4	71.81% (36.93–106.7)	0.33
		2021–2024	11	89.57% (82.46–96.69)	
	Infection type	CAUTI	2	95.13% (83.24–107.0)	0.43
		SSI	4	92.69% (82.45–102.6)	
		Mixed infections		76.13% (56.44–95.83)	
	Region	Amhara	8	80.05% (61.30–98.81)	< 0.01
		Addis Ababa	4	93.49% (85.73–101.3)	
Imipenem	Region	Amhara	3	9.02% (2.25–15.78)	< 0.01
		Addis Ababa	4	36.11% (17.03–55.20)	

SNNPR Southern Nation Nationality People Region, *SSI* Surgical Site Infection, *CAUTI* Catheter-associated Urinary Tract Infection

Further compounding the challenge is *A. baumannii*'s resistance to beta-lactam/beta-lactamase inhibitor combination, which exhibited pooled resistance rates of 66.51% for piperacillin/tazobactam in this study. This resistance suggests mechanisms beyond beta-lactamase production, potentially including bacterial resistance to beta-lactamase inhibitors, warranting further investigation into the underlying resistance mechanisms. The resistance to piperacillin/tazobactam observed in this study aligns with rates reported in Taiwan (68.4%) [43] and Brazil (69.6%) [51], as well as studies from China (75.3% and 74.8%) [47, 56]. However, it is lower than resistance rates reported in Greece (91.6%) [52], highlighting regional variability. This discrepancy may be attributed to differences in antibiotic usage patterns, infection control measures, and surveillance systems across regions [57].

Cefepime, a fourth-generation cephalosporin with extended activity against gram-negative pathogens and stability against beta-lactamases, exhibited a high resistance rate of 74.47% in *A. baumannii*. Resistance to third-generation cephalosporins ranged from 81.83% to 83.18%. This resistance aligns with reports from China, Taiwan, and Iran, where cefepime resistance ranged from 71.3% to 77.9% [43, 46–49]. However, some studies from Iran showed complete resistance to cefepime [44], while resistance rates were higher in Brazil (96.4%) [51] and Greece (91.6%) [52]. In contrast, a study in China reported lower resistance to ceftazidime (60.6%) and cefotaxime (56.7%) [45], while resistance across Asia generally ranged from 70.2% to 85.7% [43, 46–49]. Notably, Iran reported up to 100% resistance to cefotaxime, and Brazil, Turkey, and Greece showed higher resistance to ceftazidime (92.8%, 99.4%, and 91.6%, respectively) [44, 51–53].

Amikacin demonstrated the highest activity against *A. baumannii*, with a resistance rate of 20.27%, making it the least resisted antibiotic in this analysis. However, it is not commonly prescribed in Ethiopia, potentially contributing to its lower resistance rate. Other aminoglycosides, including gentamicin (57.12%) and tobramycin (47.02%), also showed relatively lower resistance compared to extended-spectrum cephalosporins.

The low resistance to amikacin aligns with findings from Brazil (21.4%) [51] but contrasts with the higher resistance reported in Turkey (91.8%) [53] and China (66–69.5%) [46–48]. Aminoglycosides remain among the least resisted antibiotics by *A. baumannii* after carbapenems, despite some regional variability. The reduced use of amikacin in Ethiopia may contribute to its sustained efficacy, highlighting the importance of targeted prescription practices to preserve antibiotic effectiveness.

Ciprofloxacin and trimethoprim-sulfamethoxazole are among the most commonly prescribed antibiotics in

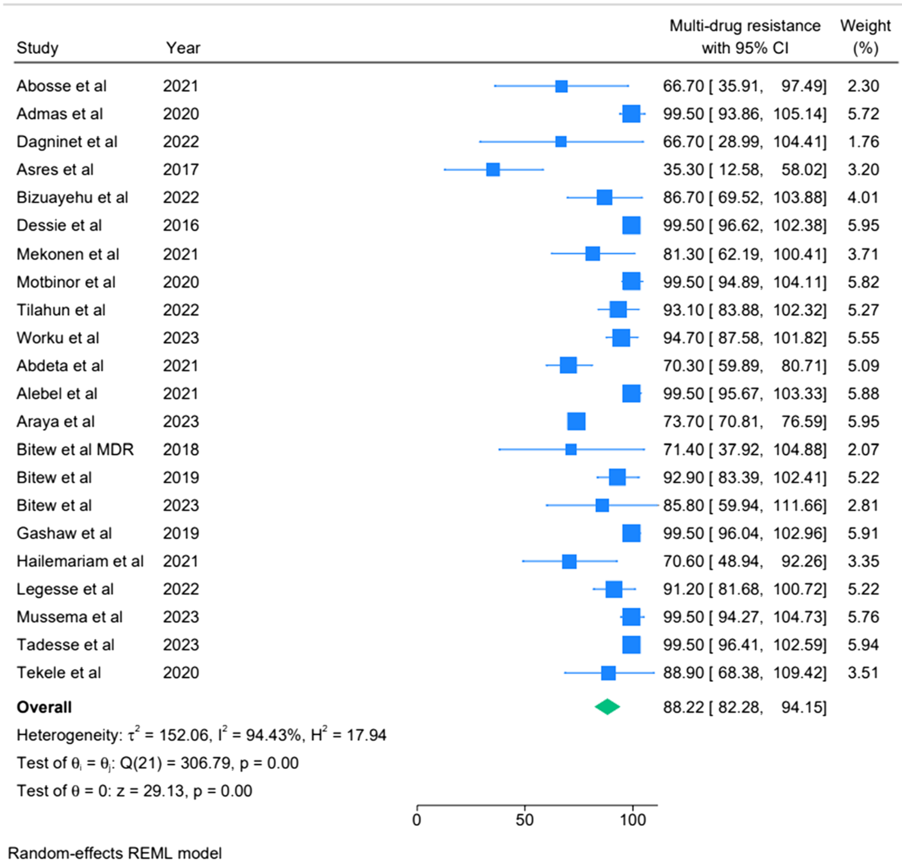

Fig. 2 The prevalence of multi-drug resistant *A. baumannii* clinical isolates

Ethiopia, with ciprofloxacin ranked as the fourth most frequently prescribed [58]. Despite their widespread use, these antibiotics demonstrated resistance in more than half of *A. baumannii* isolates, with resistance rates of 53.13% for ciprofloxacin and 79.94% for trimethoprim-sulfamethoxazole. The resistance of *A. baumannii* to ciprofloxacin in this study aligns with findings from China, where resistance was reported at 51.9% [45]. However, significantly higher resistance rates have been reported from Iran and Turkey (100%), and from Greece and Brazil (91%) [44, 51–53]. Although the resistance status of colistin and tigecycline was not reported in this study, these antibiotics have been shown to be effective against *A. baumannii* in regions such as Asia, Europe, and Brazil, with resistance rates ranging from 1.2% to 10.6% [49,51,52,53,56].

Subgroup analysis revealed significant variations in antibiotic resistance over time, by infection type, and across regions. Resistance rates for ciprofloxacin, ceftazidime, cefotaxime, and meropenem increased notably from 2015–2020 to 2021–2024, with meropenem resistance more than doubling (20.53% to 48.21%). CAUTI exhibited the highest resistance levels for several antibiotics, while SSI and sepsis also showed concerning patterns. Geographically, Oromia and Addis Ababa had the highest resistance rates, while SNNPR had lower levels for some antibiotics. These subgroup variations underscore the complex dynamics of AMR, emphasizing the need for tailored interventions, enhanced infection control, and optimized antibiotic stewardship to address localized resistance drivers. Additionally, the significant resistance in certain sample types highlights the importance of robust surveillance systems and customized clinical strategies to mitigate these trends effectively. This multifaceted approach can enhance the precision and impact of resistance management efforts.

This study also revealed that 88.22% of *A. baumannii* isolates were MDR, which is higher than rates reported from China (39.88%) [59] and Iran (74%) [50]. These differences in MDR prevalence can be linked to factors such as antibiotic prescribing practices, local AMR patterns, healthcare infrastructure, infection control, antibiotic stewardship, and population characteristics. The studies showed considerable heterogeneity (I^2 = 94.43%), reflecting variability due to geographic and demographic factors. Publication bias was identified (p < 0.01), and a

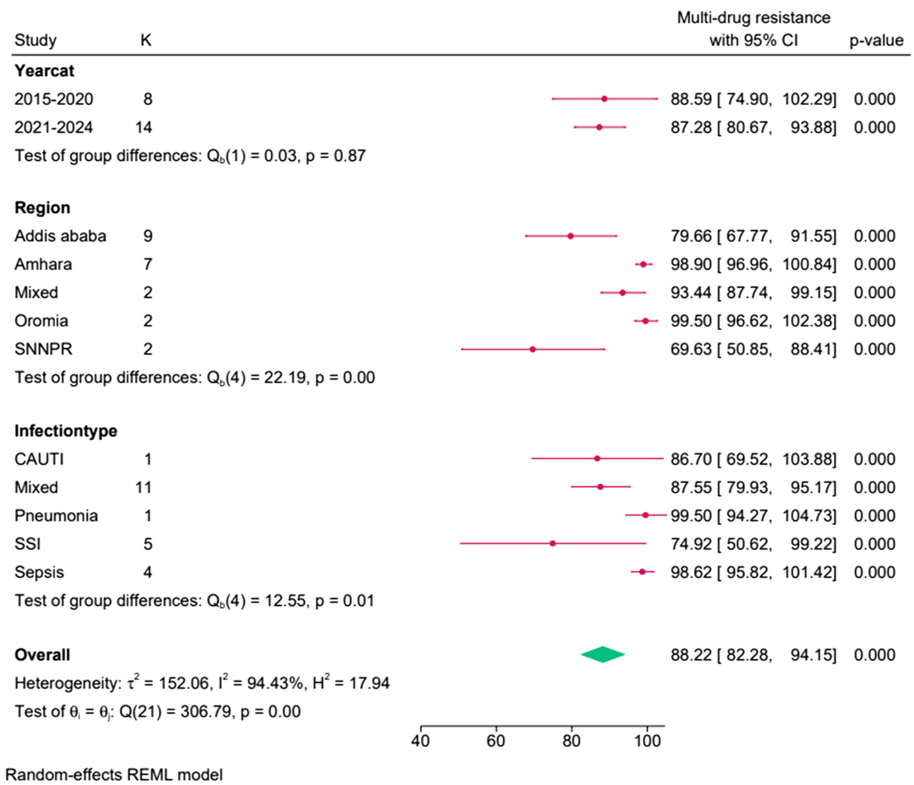

Fig. 3 Sub-group analysis of Multi-drug resistant *A. baumannii* clinical isolates. Yearcat: Categorized year, SNNPR: Southern Nation Nationality and People Region, CAUTI: Catheter-Associated Urinary Tract Infection

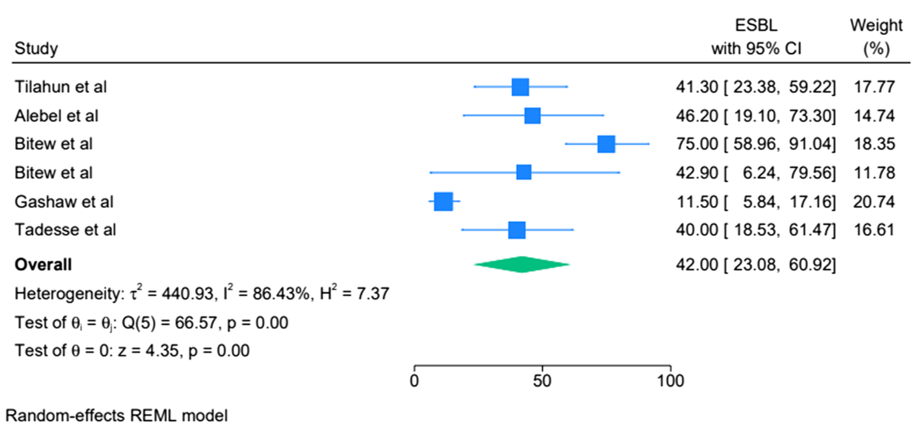

Fig. 4 The pooled prevalence of ESBL producing *A. baumannii* clinical isolates

trim-and-fill analysis adjusted the MDR prevalence to 93.57%, offering a more precise estimate.

The pooled prevalence of ESBL production in *A. baumannii* isolates was 42% (95% CI: 23.08–60.92), with substantial heterogeneity ($I^2 = 86.43\%$), likely due to regional or methodological differences. Carbapenemase production had a lower pooled prevalence of 8.82% (95% CI: 3.47–14.18) but moderate heterogeneity ($I^2 = 65.60\%$). Publication bias was detected for carbapenemase production ($p = 0.01$), and a trim-and-fill analysis adjusted the prevalence to 3.37%. This difference between ESBL and carbapenemase prevalence highlights distinct resistance mechanisms, suggesting that while beta-lactam resistance is widespread, carbapenem resistance may involve alternative mechanisms, such as efflux pumps or porin mutations [60–63].

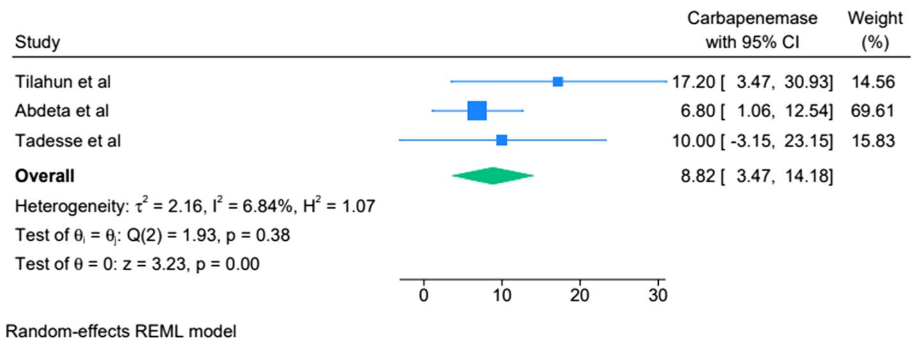

Fig. 5 The pooled prevalence of carbapenemase producing *A. baumannii* clinical isolates

This systematic review and meta-analysis revealed a troubling rise in AMR in *A. baumannii* across various antibiotics, highlighting deficiencies in antimicrobial stewardship, AMR surveillance, and infection control in Ethiopia. Due to the high resistance rates, clinicians should reconsider empirical antibiotic choices and adjust treatment protocols to improve patient outcomes. The study calls for the immediate implementation of antimicrobial stewardship programs and strengthened infection control measures. These findings provide essential data for policy development, resource allocation, and future research into novel therapies and the mechanisms behind resistance.

Strength and limitations

This systematic review and meta-analysis benefit from a robust methodology, including a predefined search strategy, a data extraction process, and internationally recognized quality appraisal tools. However, several limitations must be acknowledged. The exclusion of non-English studies and potential selection bias may have influenced the results. Variability in study quality, research methodologies, and reported outcomes contributed to heterogeneity, even after statistical adjustments. Publication bias, favoring positive findings, remains a concern. Additionally, inconsistencies in data extraction and reporting across studies hindered some subgroup analyses, affecting the overall precision of certain findings.

Conclusion and recommendations

This systematic review and meta-analysis highlight the alarming prevalence of MDR *A. baumannii* in Ethiopia, posing significant challenges to infection management in healthcare settings. The high resistance rates underscore the urgent need for comprehensive infection control measures, stringent antimicrobial stewardship programs, and robust surveillance systems to track resistance trends. Addressing these challenges requires a coordinated, multi-sectoral approach involving local, national, and international stakeholders.

To mitigate the impact of AMR, we recommend policy interventions aimed at regulating antibiotic use, enhancing laboratory diagnostic capacity, and strengthening antimicrobial stewardship initiatives. Infection prevention strategies, including improved hand hygiene compliance, hospital disinfection protocols, and stringent surveillance of healthcare-associated infections, should be prioritized. Additionally, future research should focus on the molecular characterization of resistance genes in *A. baumannii* isolates to better understand the genetic mechanisms driving resistance. Collaborative efforts between healthcare institutions, policymakers, and public health agencies are essential to implement sustainable, evidence-based strategies that curb the spread of *A. baumannii* and reduce the burden of AMR.

Abbreviations

AMR	Antimicrobial Resistance
AST	Antimicrobial Susceptibility Testing
CAUTI	Catheter-associated Urinary Tract Infection
ESBL	Extended Spectrum Beta-Lactamase
MDR	Multi-Drug Resistance
SNNPR	Southern Nation, Nationality and People Region
SSI	Surgical Site Infection
WHO	World Health Organization

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Clinical trial number

Not applicable.

Authors' contributions

ZA led the systematic review and meta-analysis, overseeing the study's conceptualization, article selection, data extraction, statistical analysis, and manuscript writing. ZA, MAR, ET, ME, YG, AS, KE, DA and MG. played a pivotal role in searching for relevant articles, conducting data extraction, performing statistical analysis, and involved in manuscript writing, and ensuring the accuracy and completeness of the data. MAR further involved in consultation of the overall process of this systematic review, and meta-analysis. Additionally, all authors actively engaged in critically reviewing the study's progress, data analysis, and manuscript writing, involved in the approval of the final manuscript for submission, thereby affirming their endorsement of its content and findings.

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Data availability
All data generated and analyzed during this study are included in this manuscript and supplementary material.

Declarations

Ethical approval and consent to participate
Not applicable for this systematic review and meta-analysis.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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