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Colistin-resistance among *Acinetobacter baumannii* and *Pseudomonas aeruginosa* from clinical specimens in Africa: a systematic review and meta-analysis

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Background: *Acinetobacter baumannii* and *Pseudomonas aeruginosa* are multidrug-resistant Gram-negative pathogens increasingly resistant to colistin, a last-resort antibiotic. This study estimated the pooled prevalence of colistin resistance among clinical isolates of these bacteria in Africa.

Methods: Relevant studies were retrieved from PubMed, Scopus, ScienceDirect and Google Scholar. Eligible studies reported colistin resistance in *A. baumannii* and *P. aeruginosa* from clinical specimens in Africa using EUCAST or CLSI standards. Data were analysed in STATA 17 using a random-effects model. Heterogeneity was assessed with the I^2 statistic, and publication bias with Egger's test. Subgroup and sensitivity analyses explored heterogeneity sources.

Results: Twenty-five studies on *A. baumannii* and seventeen on *P. aeruginosa* were included. The pooled prevalence of colistin resistance was 13.75% (95% CI: 5.99%–21.51%), for *A. baumannii* and 14.42% (95% CI: 3.35%–25.48%) for *P. aeruginosa*, both showing high heterogeneity $I^2 > 99\%$. Resistance varied significantly across countries $P \leq 0.001$. In *A. baumannii*, prevalence was 18.26% in Egypt and 10.89% in South Africa, with regional rates of 10.9%, 13.53% and 20.05% in Southern, North and East Africa, respectively. For *P. aeruginosa*, regional rates were 20.73% in East, 10.85% in North and 7.19% in Southern Africa. Resistance rose over time; from 5.64% to 16.45% in *A. baumannii* and from 2.26% to 30.54% in *P. aeruginosa* between 2010–2017 and 2018–2023.

Conclusions: Colistin resistance in *A. baumannii* and *P. aeruginosa* is rising across Africa, emphasizing the urgent need for robust antimicrobial stewardship, infection control and molecular surveillance.

Introduction

Antibiotic resistance among Gram-negative bacteria is a critical global health issue, particularly affecting developing nations.[1] This resistance significantly compromises the treatment of various diseases, leading to increased morbidity and mortality.[2] *Acinetobacter baumannii* (*A. baumannii*) is a significant MDR nosocomial bacterium that poses a major challenge in healthcare settings due to its resistance to multiple antibiotics.[3] Similarly, *Pseudomonas aeruginosa (P. aeruginosa)* is a major opportunistic pathogen responsible for healthcare-associated infections, including pneumonia, urinary tract infections and sepsis, particularly in immunocompromised patients.[4]

Both *A. baumannii* and *P. aeruginosa* are Gram-negative pathogens commonly implicated in nosocomial infections. They share key characteristics, including a high capacity for biofilm formation and extensive antimicrobial resistance, making them particularly challenging in clinical settings.[5] According to the 2024 WHO Bacterial Priority Pathogens List, carbapenem-resistant *A. baumannii* is classified as a critical priority pathogen, while carbapenem-resistant *P. aeruginosa* is now listed as a high priority pathogen.[6]

Colistin, also known as polymyxin E, is a last-resort antibiotic used to treat infections caused by MDR bacteria, particularly *A. baumannii* and *P. aeruginosa*.[7] MDR bacteria are non-susceptible to at least one agent in three or more antimicrobial categories.[8]

Colistin exerts its bactericidal effect by targeting and disrupting the bacterial membrane, making it particularly effective against resistant strains of *A. baumannii* and *P. aeruginosa*.[9] Colistin was initially restricted to veterinary medicine due to its potential toxicity, particularly to the kidneys and nervous system in humans, which is why it is reserved as a last-resort option.[7]

However, the rise of MDR and carbapenem-resistant Gram-negative bacteria has led to its renewed use in humans.[10] In the 21st century, colistin has been increasingly used in Africa to manage infections caused by carbapenem-resistant Enterobacterales, extensively drug-resistant *A. baumannii,* and MDR *P. aeruginosa* in clinical settings.[11] Its use also extends to veterinary, agricultural and environmental contexts, raising major concerns for antimicrobial resistance. In food–animal production, colistin has historically been used for prophylaxis and growth promotion in several African countries, although available data are limited and fragmented. Regulatory control varies widely across the region; despite the adoption of WHO-aligned restrictions in some countries, enforcement remains uneven, especially beyond hospital settings.[12]

A. baumannii and *P. aeruginosa* are two critical Gram-negative pathogens that have developed resistance to colistin.[13] *A. baumannii* often becomes resistant by changing or losing its LPS target. And *P. aeruginosa* also has a resistance mechanism of LPS modification, overexpression of the arnBCADTEF operon, efflux pumps and outer membrane remodelling.[14]

The dissemination of plasmid-mediated colistin resistance genes *mcr* genes among *A. baumannii* and *P. aeruginosa* in Africa is an emerging public health concern. Notably, several *mcr* gene variants, including *mcr*-1, *mcr*-2, *mcr*-3, *mcr*-5, *mcr*-8 and *mcr*-9, have been detected in clinical and environmental isolates across the continent.[15]

The emergence of colistin resistance is being reported with increasing frequency, posing a significant and escalating threat to global public health. The rise of resistance further complicates the treatment of MDR infections in clinical settings.[16] The rising colistin resistance in *A. baumannii* and *P. aeruginosa* across Africa poses a growing public health challenge and has serious implications for antimicrobial therapy strategies.[17]

However, a comprehensive study that analyses and synthesizes the available evidence on the prevalence of colistin resistance in *A. baumannii* and *P. aeruginosa* isolates in Africa is still lacking. This underscores the urgent need for an extensive review to provide a clearer and more accurate understanding of the current situation. This study aimed to systematically assess and synthesize existing data on the prevalence of colistin resistance in *A. baumannii* and *P. aeruginosa* across Africa and pinpoint regions at higher risk. These insights are essential for developing targeted interventions and provide valuable guidance for health policymakers in implementing evidence-based strategies to reduce colistin resistance throughout the continent.

Methods

Study protocol and registration

In conducting this systematic review and meta-analysis, we followed the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA 2020 guidelines.[18]

Literature search

A systematic literature search was conducted to identify studies reporting colistin resistance published between 1 January 2010, and 2023. Publicly available electronic databases, including PubMed, Scopus, ScienceDirect and Google Scholar search engines, were used to access potential papers. Two reviewers, Y.G. and M.A.R., independently conducted the literature search using predefined search terms and phrases across selected electronic databases. Medical Subject Headings MeSH and other relevant keywords or phrases were combined using Boolean operators 'AND' and 'OR' to construct the search strategy. For *Acinetobacter baumannii*, the following terms were used: 'prevalence' OR 'epidemiology' AND 'colistin' OR 'polymyxin' OR 'antimicrobial resistance' OR 'drug resistance' OR 'multidrug resistance' AND '*Acinetobacter baumannii*' OR '*Acinetobacter* spp.' AND 'clinical isolates' OR 'clinical samples' AND 'Africa'. For *Pseudomonas aeruginosa*, a similar strategy was applied: 'prevalence' OR 'epidemiology' AND 'colistin' OR 'polymyxin' OR 'antimicrobial resistance' OR 'drug resistance' AND '*Pseudomonas aeruginosa*' OR '*Pseudomonas* spp.' AND 'clinical isolates' OR 'clinical samples' AND 'Africa'. Each African country was individually searched, using relevant keywords to enhance the retrieval of country-specific studies. Details of the search strategies applied to the electronic databases are available in the Table S1 (available as Supplementary data at *JAC-AMR* Online).

Eligibility

Inclusion and exclusion criteria

The collected articles were imported into EndNote version 20, reference management software developed by Thomson Reuters New York, NY. Three reviewers, Y.G., M.T. and A.S., independently assessed the titles and abstracts of the papers to select the full-text articles. Any disagreements among the three authors were resolved with the assistance of another reviewer M.A.R.

To identify and select eligible articles, we established clear, predetermined inclusion and exclusion criteria. Articles meeting the inclusion criteria were reviewed and included, while those that did not meet the criteria were excluded: the inclusion criteria were as follows: (i) All original articles published in English between 01 January 2010 and 2023 that reported colistin resistance in *P. aeruginosa* and *A. baumannii* isolates recovered from clinical samples; (ii) studies that used antibiotic susceptibility testing based on criteria established by CLSI and EUCAST for colistin resistance testing;[19] (iii) studies conducted exclusively in the African countries were included. The exclusion criteria included: (i) studies presenting results from systematic reviews or meta-analyses, and (ii) studies that reported general antibiotic resistance without specifically focusing on colistin resistance, or those that employed colistin susceptibility testing methods other than microdilution. Additionally, (iii) studies with inaccessible full-text articles, case reports, conference papers, letters of communication and studies with only abstracts or grey literature were also excluded. A manual search and the bibliographies of each study

were reviewed to identify additional potential papers. Colistin susceptibility was assessed using the microdilution method, which is the sole recommended approach for determining colistin antibiotic susceptibility.[19] Duplicate articles were removed using EndNote version 20 reference management software, with additional manual screening performed to ensure complete removal of duplicates. A pilot test was conducted before initiating full screening to ensure consistency between reviewers. Three reviewers, Y.G., M.T. and A.S., independently screened a random sample of 35 articles for titles and abstracts using the predefined inclusion and exclusion criteria. Discrepancies were discussed and resolved by consensus, leading to minor refinements in the screening criteria to improve clarity.

Quality assessments

The quality of the included studies was evaluated using the Joanna Briggs Institute JBI critical appraisal tool for prevalence data.[20] Two reviewers, Y.G. and M.A.R., independently conducted a critical appraisal of each study. All studies included in the analysis had a quality assessment score of 55.6% and above, indicating moderate to high quality and eligibility for inclusion in the study (Table S2).

Data extraction

A pilot data extraction was conducted on five full-text articles to evaluate the data extraction form. Following this initial test, minor revisions were made to the definitions of variables and the formatting. Three reviewers, Y.G., M.T. and A.S., independently extracted relevant data from the included studies using a standardized data extraction form developed in Microsoft Excel 2013. The extracted information included the country of study, first author's surname, publication year, methodology, diagnostic techniques, sample size, types of clinical specimens e.g. urine, blood, sputum, endotracheal aspirate and swabs, bacterial species identified, presence of MDR isolates and colistin susceptibility profiles for *P. aeruginosa* and *A. baumannii*. Any discrepancies among the reviewers were resolved through discussion and consensus. If consensus could not be achieved, the fourth reviewer M.A.R. was consulted for a final decision.

Data management and statistical analysis

The data extracted from the included studies using Microsoft Excel 2013 were exported to STATA 17.0 software StataCorp, Texas, USA for the final analysis. A random-effects model was used to calculate the pooled prevalence in the included studies. The inverse variance I^2 test was conducted to assess statistical heterogeneity such as study design, sample size and data reporting quality across studies, with I^2 values interpreted as follows: 0% no heterogeneity, 0–25% low heterogeneity, 25–50% moderate heterogeneity, 50–75% substantial heterogeneity and >75% high heterogeneity.[21] In some studies, a continuity correction was applied to those reporting 0 or 100% colistin resistance values to calculate the pooled prevalence, preventing a zero-standard error during the meta-analysis.[22] Subgroup and sensitivity analyses were conducted to assess clinical heterogeneity. Subgroup analysis was performed based on publication time interval, country and regional categories to explore sources of high heterogeneity among the studies. Egger's test was used to detect potential publication bias, with a significance level set at $P<0.05$ with 95% CI.

Results

Searching results

The retrieved articles were imported into EndNote version 20, reference management software developed by Thomson Reuters New York, NY. In this systematic review and meta-analysis, a total of 13 940 studies were identified through searches of electronic databases and the Google Scholar searching engine. After removing duplicates, 9277 unique articles were screened for eligibility. Following title and abstract screening, as well as exclusions due to duplicates, review articles, studies not addressing colistin resistance and non-English publications, 8955 articles were excluded. Consequently, 322 studies underwent full-text review. The final meta-analysis estimating the prevalence of colistin resistance among clinical isolates across Africa included 35 eligible studies (Figure 1). Of these, 25 studies investigated *A. baumannii* (with 20 exclusively examining *A. baumannii*), 17 studies assessed *P. aeruginosa* (10 of which focused solely on *P. aeruginosa*) and 5 studies evaluated both organisms (Tables 1 and 3).

A descriptive summary of the studies included in A. baumannii

This systematic review and meta-analysis included 25 studies from nine countries, documenting the colistin resistance profile in *A. baumannii* clinical isolates. The majority of the data originated from North and South Africa (Tables 1 and 2). The distribution of studies by country was as follows: Egypt $n=9$, South Africa $n=8$ and Algeria, which contributed two studies $n=2$. The remaining studies were from Mali, Kenya, Morocco, Rwanda, Somalia and Tunisia, with one study from each country (Table 1). All studies included in the meta-analysis employed the minimum inhibitory concentration MIC dilution method to evaluate colistin susceptibility and followed a cross-sectional study design. Collectively, the 25 studies examined 4249 clinical isolates of *A. baumannii*, of which 2443 were identified as MDR, and 297 were found to be resistant to colistin. These isolates were obtained from a range of clinical specimens (Table 1).

Meta-analysis

The pooled prevalence of colistin resistance in A. baumannii *isolates.* This meta-analysis evaluates the pooled prevalence of colistin resistance in *A. baumannii* clinical isolates. The initial pooled prevalence was estimated at 13.75% (95% CI: 5.99%–21.51%), indicating significant heterogeneity across studies $I^2=99.64\%$, $P<0.001$ (Figure 2). The geographical distribution of colistin resistance among *A. baumannii* varied, ranging from 2.63% in Morocco to 60% in Kenya.

2.63% (95% CI: 0.16%–30.91%) in Morocco to 4.17% (95% CI: 2.2%–7.7%) in Somalia, 5.67% (95% CI: 1.23%–10.11%) in Algeria, 9.90% (95% CI: 4.08%–15.73%) in Tunisia, 10.9% (95% CI: 6.1%–18.7%) in South Africa, 20.22% (95% CI: 5.94%, 34.5%) in Egypt, 18.53% (95% CI: 14.23–22.83%) in Rwanda and 60% 17.06%–102.94% in Kenya. Apparent differences in colistin resistance across countries were observed, but due to the limited number of studies per country, these findings should be interpreted with caution (Figure 3).

Publication bias was detected through an asymmetric funnel plot (Figure 4) and confirmed by Egger's test, which indicated significant bias $P=0.008$. To account for this bias, a trim-and-fill analysis was performed, imputing four missing studies on the right side. After adjusting for publication bias, the final recalculated pooled prevalence of colistin resistance increased to 15.55% (95% CI: 9.41%–23.7%) (Table S3).

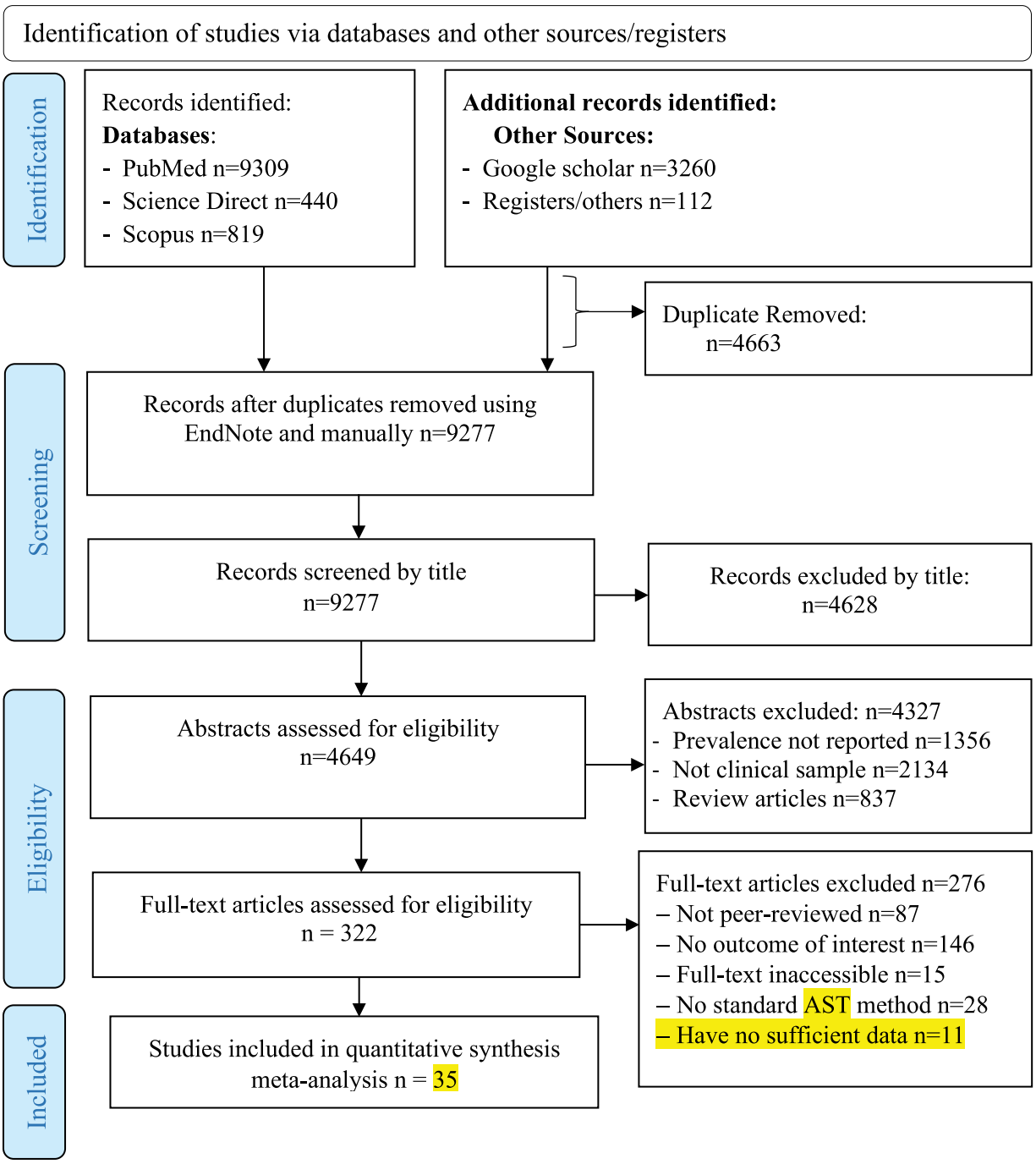

Figure 1. PRISMA flow diagram showed the results of the search and reasons for exclusion.

Subgroup-analysis

***Subgroup analysis of colistin resistance in* a. baumannii.** Due to the considerable heterogeneity among studies, a subgroup analysis was performed to evaluate the pooled prevalence of colistin resistance in *A. baumannii* by country, geographic region and publication period.

Publication time intervals. The analysis of resistance trends over time revealed that the prevalence of colistin resistance in *A. baumannii* was 5.64% between 2010 and 2017 $P=0.113$, showing no significant change. However, from 2018 to 2023, the prevalence rose significantly to 16.45% $P=0.001$. Despite this notable increase, no statistically significant difference was observed between the two periods $P=0.121$. Additionally, both periods exhibited high heterogeneity, with I^2 values exceeding 98.5% (Table 2).

Country-based analysis. A significant variation in colistin resistance was observed across different countries $P<0.001$. The highest

Table 1. Description of the studies included to assess colistin resistance in *A. baumannii* isolates obtained from clinical samples across Africa

First author	Publication year	Country	No. of isolates	No. of MDR isolates	No. of CST-S isolates	No. of CST-R isolates
Adil *et al.*[23]	2022	Morocco	19	19	19	0
Ahmed *et al.*,[24]	2012	S. Africa	232	0	232	0
Azzab *et al.*,[25]	2016	Egypt	8	0	7	1
Benamrouch *et al.*,[26]	2021	Algeria	92	89	87	5
Carrol *et al.*,[27]	2016	Rwanda	313	0	255	58
Chekih *et al.*,[28]	2018	Tunisia	101	101	91	10
Elbrolosy *et al.*,[29]	2019	Egypt	64	64	58	6
Fam *et al.*,[30]	2020	Egypt	17	0	11	6
Hasanin *et al.*,[31]	2014	Egypt	126	0	126	0
Jalal *et al.*,[32]	2021	Egypt	37	37	33	4
Maina *et al.*,[33]	2023	Kenya	5	5	2	3
Mohammed *et al.*,[34]	2020	Egypt	151	68	143	8
Mohammed *et al.*,[35]	2022	Somalia	24	0	23	1
Snyman *et al.*,[36]	2020	S. Africa	26	0	6	20
Abdulzahra *et al.*,[37]	2018	Egypt	40	0	38	2
Lowe *et al.*,[38]	2022	S. Africa	96	78	87	9
Seifert *et al.*,[39]	2022	M.E. Africa	266	0	260	6
Romadan *et al.*,[40]	2023	Egypt	50	50	20	30
Seleim et al.,[41]	2022	Egypt	100	0	51	49
Nogbou *et al.*,[42]	2021	S. Africa	100	70	99	1
Lowings *et al.*,[43]	2015	S. Africa	94	94	94	0
Lowe *et al.*,[44]	2018	S. Africa	143	143	141	2
Bakou *et al.*,[45]	2015	Algeria	12	0	11	1
Perovic *et al.*,[46]	2022	S. Africa	2033	1525	1958	75
Anane *et al.*,[47]	2020	S. Africa	100	100	100	0
Total isolates			**4249**	**2443**	**3952**	**297**

CST-S, colistin sensitive; CST-R, colistin resistance; M.E. Africa, Middle East Africa.

Table 2. Subgroup analysis for the pooled prevalence of colistin resistance in *A. baumannii* clinical isolates from clinical samples across Africa

Subgroup	Characteristics	No. of included studies	Pooled prevalence at 95% CI	I^2	*P*-value
Years	2010–2017	6	5.64% 3.1%–10.0%	98.60%	0.113
	2018–2023	19	16.45% 6.32%–26.57%	99.51%	0.001
	Test of group difference:				0.08
Country	Egypt	9	18.26% 5.0–31.58%	98.0%	0.007
	South Africa	8	10.9% 6.1%–18.7%	99.91%	0.208
	Test of group difference:				0.001
Sub-regional	Southern Africa	8	10.9% 6.1%–18.7%	99.91%	0.208
	North Africa	15	13.53 4.42–22.64%	98.62%	0.004
	East Africa	3	20.05% 15.8%–25.2%	94.3%	0.096
	Test of group difference				0.083
	Overall	25	13.75% 5.99%–21.51%		0.001

Table 3. Characteristics of the included studies to estimate colistin resistance in *P. aeruginosa* isolates recovered from clinical samples in Africa

First author	Publication year	Country	No. of isolates	MDR isolates	No. of CST-S isolate	No. of CST- R isolates
Andualem *et al.*,[48]	2012	Ethiopia	92	0	92	0
Annear *et al.*,[49]	2017	S. Africa	81	0	80	1
Azzab *et al.*,[25]	2016	Egypt	13	0	13	0
Carrol *et al.*,[27]	2016	Rwanda	375	0	364	11
Elbaradei *et al.*,[50]	2022	Egypt	55	25	55	0
Hammami *et al.*,[51]	2011	Tunisia	24	24	24	0
Hasanin *et al.*,[31]	2014	Egypt	234	0	205	29
Hashe *et al.*,[52]	2016	Egypt	147	16	145	2
Maina *et al.*,[33]	2023	Kenya	13	13	1	12
Nichols *et al.*,[53]	2016	M.E. Africa	689	0	686	3
Romadan *et al.*,[40]	2023	Egypt	43	43	21	22
Kassa *et al.*,[54]	2016	Ethiopia	7	2	6	1
Abdi El-baky *et al.*,[55]	2020	Egypt	75	72	59	16
Mohammed *et al.*,[35]	2022	Somalia	19	9	16	3
Ateba *et al.*,[56]	2013	Cameroon	49	49	48	1
Zubair *et al.*,[57]	2018	Nigeria	200	0	168	32
Mudau *et al.*[58]	2013	S. Africa	9	9	7	2
Total isolates			**2125**	**262**	**1990**	**135**

CST-S, colistin sensitive; CST-R, colistin resistance; M.E. Africa, Middle East Africa.

prevalence was reported in Egypt at 18.26% (95% CI: 5.0%–31.58%) and followed by South Africa at 10.9% (95% CI: 6.1%–18.7%). Despite these differences, substantial heterogeneity remained, particularly in South Africa $I^2 = 99.91\%$ and Egypt $I^2 = 98.0\%$ (Table 2).

Regional analysis. Sub-regional subgroup analysis revealed no statistically significant differences across regions $P = 0.05$. However, the highest pooled prevalence was recorded in East Africa, at 20.05% (95% CI: 15.8%–25.2%) with an I^2 value of 94.3%, followed by North Africa at 13.53% (95% CI: 4.42%–22.64%) and Southern Africa at 10.9% (95% CI: 6.1%–18.7%) (Table 2).

Sensitivity test. The result of the sensitivity analysis showed that there was no outlier study, which had an impact on the overall estimation. Based on the random effects model, no single study had a disproportionate impact on the overall pooled estimates of *A. baumannii* resistance. The findings revealed that the estimates from all included studies were within the pooled estimate's confidence interval, indicating the reliability of the aggregated results (Figure S1).

A descriptive summary of studies included in P. aeruginosa

This systematic review and meta-analysis incorporated 17 studies from 9 different countries, focusing on the colistin resistance patterns in *P. aeruginosa* clinical isolates. The majority of data originated from North and East African regions (Table 4). By country, the included studies were distributed as follows: Egypt $n = 6$, Ethiopia $n = 2$ and South Africa $n = 2$. Additionally, one study each was included from Kenya, Rwanda, Somalia, Nigeria, Cameroon and Tunisia (Table 3).

All studies utilized the MIC dilution method to assess colistin susceptibility and employed a cross-sectional study design. In total, the studies analysed 2,125 clinical isolates of *P. aeruginosa*, of which 262 were identified as MDR, and 135 were found to be resistant to colistin (Table 3). These isolates were obtained from a variety of clinical specimens.

The pooled prevalence of colistin resistance in P. aeruginosa *isolates*

This meta-analysis examines the pooled prevalence of colistin resistance in *P. aeruginosa* clinical isolates. The initial pooled prevalence was estimated at 14.42% (95% CI: 3.35%–25.48%), with high heterogeneity across studies $I^2 = 99.74\%$, $P < 0.001$ (Figure 5). The geographical distribution of colistin resistance among *P. aeruginosa* varied, ranging from 0.5% (95% CI: 0.07–3.50%) in Tunisia to 1.07% (95% CI: 0.15%- 7.4%) in Ethiopia, 2.04 (95% CI: 0.29%–13.1%) in Cameroon, 2.93% (95% CI: 1.23%–4.64%) in Rwanda, 7.19% (95% CI: 3.4%–14.4%) in South Africa, 13.55% (95% CI: 9.4%–19.5%) in Egypt, 15.79% (95% CI: 6.1%–35.4%) in Somalia, 19.05% (95% CI: 13.7%–25.7%) in Nigeria and 92.31% (95% CI: 83.0%–96.7%) in Kenya (Figure 6).

Publication bias was detected through an asymmetric funnel plot (Figure 7) and confirmed by Egger's test, which indicated significant bias $P < 0.001$. To account for this bias, a trim-and-fill analysis was performed, leading to the imputation of five missing studies on the right side of the funnel plot. After adjusting for publication bias, the final recalculated pooled prevalence of colistin resistance increased to 20.76% (95% CI: 10.96%–30.57%) (Table S4).

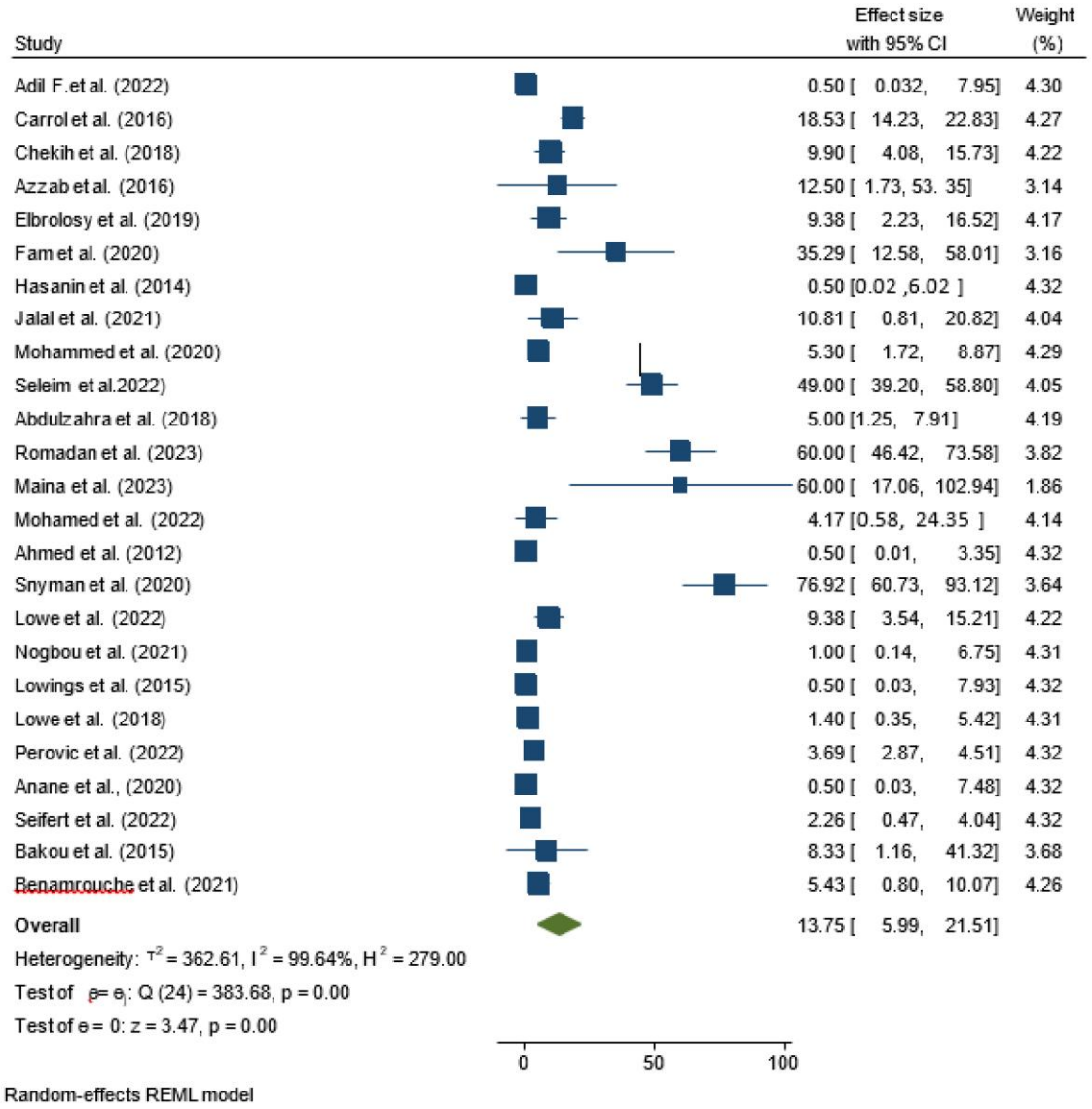

Figure 2. Forest plot illustrating the pooled prevalence of colistin-resistance in *A. baumannii* isolated from clinical samples across Africa. Logit transformation was used to ensure confidence intervals remained within the plausible 0%–100% range.

Subgroup analysis of colistin resistance in P. aeruginosa

Due to the high heterogeneity across studies, a subgroup analysis was conducted to assess the pooled prevalence of colistin resistance in *P. aeruginosa* based on country, region and publication period. The prevalence of colistin resistance in *P. aeruginosa* isolates showed a notable increase over time. Between 2010 and 2017, the prevalence was 2.26% (95% CI: 0.21%–4.31%), with a *P*-value of 0.031, indicating a statistically significant result. However, this prevalence rose substantially to 30.54% (95% CI: 7.33%–53.74%) between 2018 and 2023, with a *P*-value of 0.02. A significant difference was observed between the two time periods $P < 0.001$. Despite this upward trend, both periods exhibited high heterogeneity, with an I^2 value exceeding 98.5% (Table 4).

The country-based analysis showed significant variation in colistin resistance across different nations $P < 0.001$. The pooled prevalence rates differed notably by country. For instance, Egypt reported a relatively high prevalence of colistin was 13.55% (95% CI: 9.4%–19.5%) with high heterogeneity $I^2 = 98.99\%$ and a *P*-value of 0.045. In contrast, Ethiopia had a much lower prevalence of 1.07% (95% CI:0.15%–7.4%) with low heterogeneity $I^2 = 7.67\%$ (Table 4). Similarly, sub-regional analysis also revealed significant differences in colistin resistance across regions $P < 0.001$. East Africa had the highest pooled prevalence at 20.73% (95% CI: 13.4%–30.8%), accompanied by substantial heterogeneity $I^2 = 99.82\%$ and a *P*-value of 0.001. Conversely, the lowest prevalence was observed in Southern Africa at 7.19% (95% CI:3.4%–14.4%) (Table 4).

Sensitivity test

The sensitivity test was computed and the result of the analysis showed that there was no outlier study, which had an impact on the overall estimation (Figure S2).

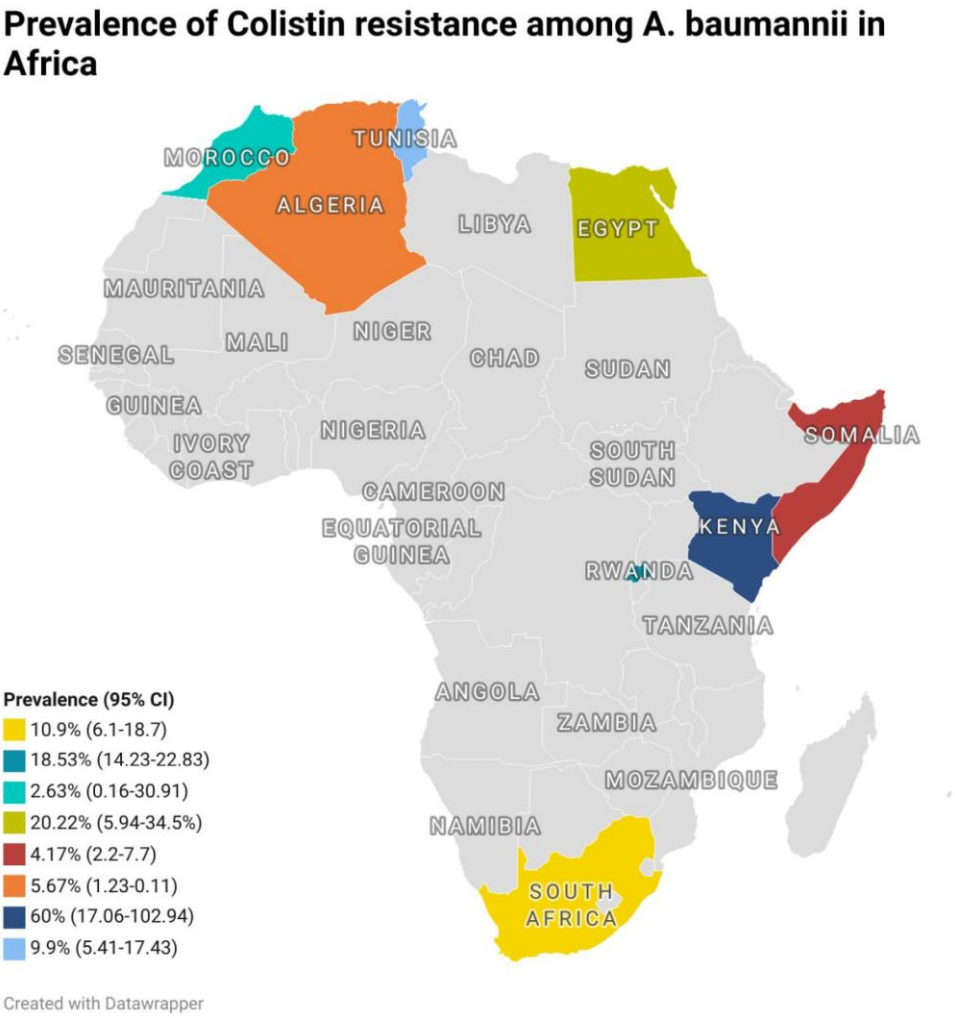

Figure 3. Geographical distribution of pooled colistin resistance in *A. baumannii* isolates recovered from clinical samples across Africa.

Discussion

The increasing prevalence of colistin resistance in Africa has major clinical consequences, as it compromises the treatment of infections caused by multidrug- and extensively drug-resistant Gram-negative pathogens, particularly *A. baumannii* and *P. aeruginosa*.[59] This threatens the role of colistin as a last-resort therapy and is associated with higher morbidity, mortality and healthcare costs. Urgent action is therefore needed to strengthen antimicrobial stewardship, implement standardized resistance surveillance and reinforce infection prevention and control measures across the region.[60]

Various antimicrobial susceptibility testing AST methods, such as BMD, the VITEK 2 automated system and disc diffusion, are used to detect colistin-resistant strains, though BMD is considered the gold standard because disk diffusion is unreliable and VITEK 2 may miss resistant subpopulations.[61] This study included only articles that used the BMD method, which detects colistin resistance in *A. baumannii* and *P. aeruginosa*. BMD offers high accuracy, sensitivity and the ability to detect low-level resistance that other methods may miss. Although its results are considered reliable and representative, limited accessibility remains a challenge in Africa.[62]

The overall colistin resistance rate among *A. baumannii* isolates in our analysis was 13.75% (95% CI: 5.99%–21.51%), which is higher than the previously reported rates in Africa, 2.8%, and globally, 4%.[63] Our finding is comparable to rates reported in Lebanon, 17.5%,[64] China, 12%,[64] Europe, 13%,[65] India, 12.2%,[66] Asia, 10%,[65] and Turkey, 18.2%.[67] In contrast, our result is lower than those reported in a global meta-analysis 26%,[68] in America 29%,[65] and in a more recent study showing a pooled prevalence of approximately 33% across *Acinetobacter* species.[69]

Subgroup analyses based on year, country and sub-regional classifications were performed; however, substantial heterogeneity remained. Sensitivity analysis showed that there was no outlier study, which had an impact on the overall estimation. The persistence of heterogeneity likely reflects true variations in clinical practice, resistance patterns and diagnostic standards across different settings. While this limits the generalizability of specific estimates, the overall trends and direction of findings remain informative and relevant.

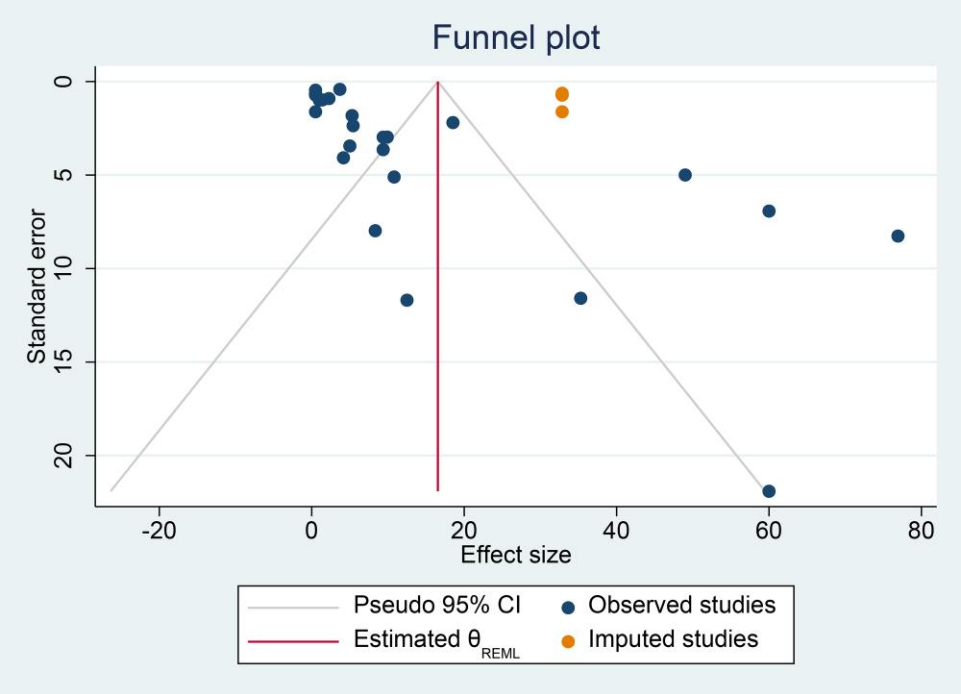

Figure 4. Funnel plot depicting publication bias in the pooled prevalence of colistin resistance in *A. baumannii* isolates recovered from clinical samples across Africa.

Table 4. Subgroup analysis for the pooled prevalence of colistin resistance in *P. aeruginosa* clinical isolates from clinical samples across Africa

Subgroup	Characteristics	No. of included studies	Pooled prevalence 95%CI	I^2	*P*-value
Years	2010–2017	10	2.26% 0.21%–4.31%	90.25%	0.031
	2018–2023	7	30.54% 7.33%–53.74%	98.52%	0.010
	Test of group difference: Q_b 1 = 6.00, P = 0.02				0.02
Country	Egypt	6	13.55% 9.4%–19.5%	98.99%	0.045
	South Africa	2	7.19% 3.4%–14.4%	56.06%	0.447
	Ethiopia	2	1.07% 0.15%–7.4%	7.67	0.70
	Test of group difference: Q_b 1 = 205.31				0.001
Sub-regional	Southern Africa	2	7.19% 3.4%–14.4%	56.06%	0.447
	North Africa	6	13.55% 9.4%–19.5%	98.76%	0.001
	East Africa	6	20.73% 13.4%–30.8%	99.82%	0.001
	Test of group difference: Q_b 4 = 43.5				0.001
	Overall		14.42 3.35%–25.48%	99.70	0.001

Between 2010 and 2017, colistin resistance in *A. baumannii* remained relatively low at 5.64%, with a *P*-value of 0.113. This indicates that the trend over this period was not statistically significant, suggesting that colistin largely retained its effectiveness. This stability may be attributed to the limited use of colistin or an effective antimicrobial stewardship programme that helped prevent resistance development. However, during the period from 2018 to 2023, resistance rates rose sharply to 16.45%,

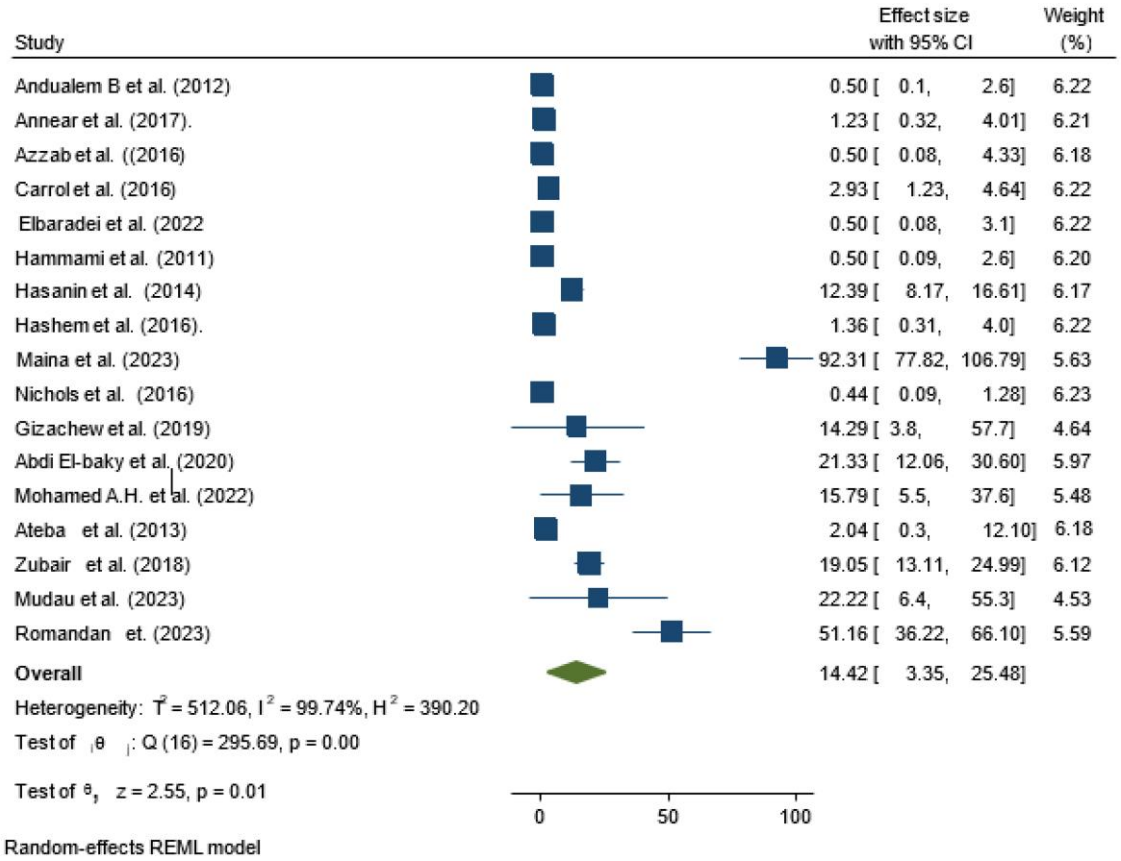

Figure 5. Forest plot illustrating the pooled prevalence of colistin-resistance in *P. aeruginosa* isolated from clinical samples across Africa. Logit transformation was used to ensure confidence intervals remained within the plausible 0%–100% range.

with a *P*-value of 0.002. This statistically significant increase reflects a real upward trend in colistin resistance, likely driven by increased reliance on colistin as a last-resort treatment, especially in response to widespread carbapenem resistance. This heightened use may have contributed to the emergence and selection of colistin-resistant strains.

Interestingly, when comparing the two time periods directly, the overall difference in resistance rates does not reach statistical significance $P=0.121$. This seeming contradiction can be explained by several factors, including variability among studies, differences in sample size, uneven study distribution across time and overlapping confidence intervals. These factors may obscure the true difference in resistance rates when aggregated across broad timeframes.

Colistin resistance varied significantly between countries $P<0.001$, suggesting the differences are unlikely due to chance. Among the countries analysed, the highest prevalence was reported in Egypt 18.26% followed by South Africa, 10.9%. These disparities suggest that local factors, such as antimicrobial usage patterns, infection control practices, healthcare infrastructure and surveillance capacity, may significantly influence the emergence and spread of colistin resistance. The sub-regional subgroup analysis did not reveal any statistically significant differences across regions, with a $P=0.083$, suggesting that the resistance rates observed across different sub-regions were similar and that regional variation in colistin resistance was not significant at the statistical level. This finding implies that other factors, such as country-specific practices, may play a more significant role than broad regional trends.

The pooled prevalence of colistin resistance among *P. aeruginosa* in this study was 14.42% (95% CI: 3.35%–25.48%), notably higher than previous reports. For instance, a study conducted in Africa reported a prevalence of 3%, a global meta-analysis of 619 studies found a prevalence of just 1%,[70] and a separate ICU-focused meta-analysis reported 3.3%.[71] However, our finding aligns with a global meta-analysis reporting 11%[68] and a study from India showing a resistance rate of 13.3%.[66]

The prevalence of colistin resistance in *P. aeruginosa* isolates has increased markedly over time. From 2010 to 2017, the prevalence was 2.26% $P=0.031$, indicating a statistically significant finding. This rate rose sharply to 30.54% $P=0.010$ between 2018 and 2023. The difference between the two time periods was also statistically significant $P<0.001$. The significant increase in colistin resistance in *P. aeruginosa* isolates between the two time periods from 2.26% in 2010%–2017% to 30.54% in 2018–2023 suggests a growing concern regarding the emergence of resistance to colistin. The substantial rise in resistance could indicate several factors, such as increased selective pressure, evolution of resistance mechanisms and environmental and healthcare factors. The significant difference between the two

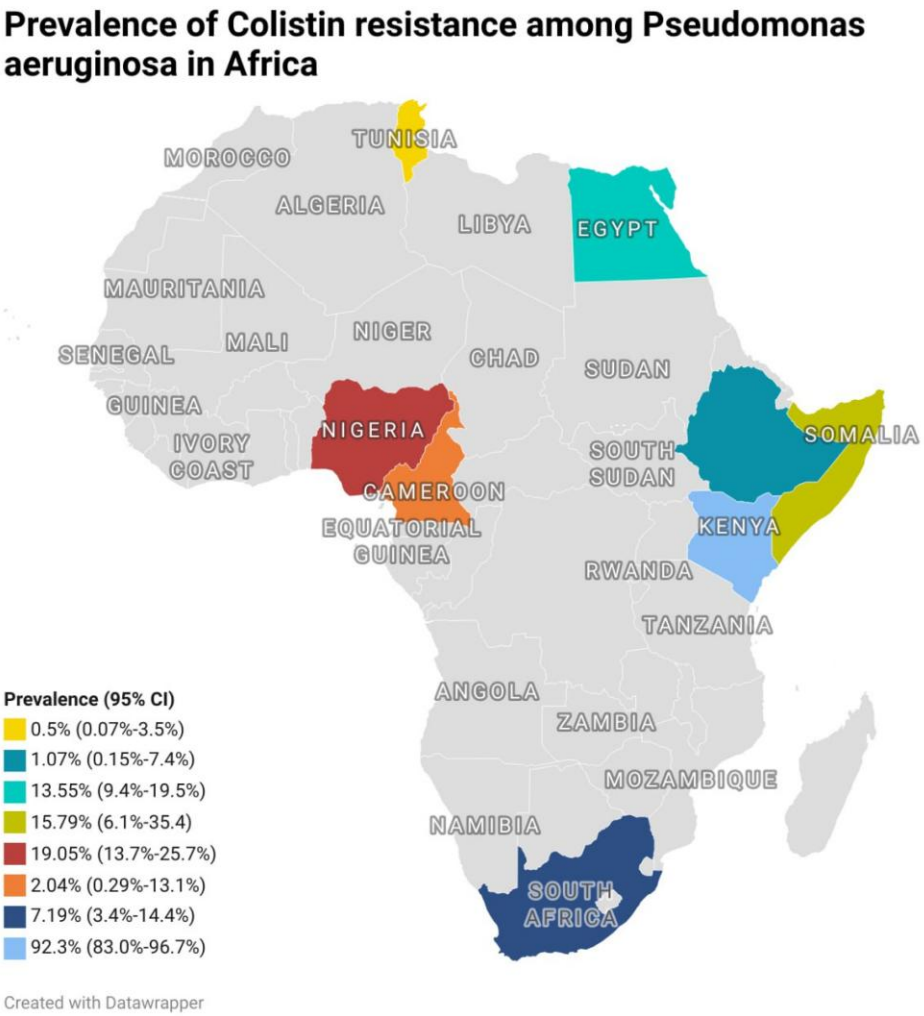

Figure 6. Geographical distribution of pooled prevalence of colistin-resistance in *P. aeruginosa* isolated from clinical samples across Africa.

periods $P < 0.001$ reinforces the idea that this rise is not due to random variation but rather reflects a true shift in the resistance patterns of *P. aeruginosa*. Despite this, the high heterogeneity $I^2 > 98.5\%$ indicates that there is still a considerable degree of variability across studies or geographic regions, meaning that the trend may not be uniform everywhere and local factors could influence the observed resistance rates.

The country-based analysis showed significant variation in colistin resistance across different nations $P < 0.001$. Apparent differences in colistin resistance across countries/regions were observed, but due to the limited number of studies per country and region, these findings should be interpreted with caution. The pooled prevalence rates differed notably by country. For instance, Egypt reported a relatively high prevalence of colistin resistance of 13.55% with high heterogeneity $I^2 = 98.99\%$ and a *P*-value of 0.045. In contrast, South Africa had a lower prevalence of 7.19% with substantial heterogeneity $I^2 = 56.06\%$. The differences between the countries might be local factors such as healthcare practices, antibiotic usage and surveillance quality.[72] Similarly, sub-regional analysis also revealed significant differences in colistin resistance across regions $P < 0.001$. East Africa had the highest pooled prevalence at 20.73%, accompanied by substantial heterogeneity $I^2 = 99.82\%$ and a *P*-value of 0.001. Conversely, the lowest prevalence was observed in Southern Africa at 7.19%.

The consistently high I^2 values >99% indicate substantial heterogeneity that remains largely unexplained despite subgroup analyses. This variability likely arises from multiple factors, including differences in patient populations such as ICU versus non-ICU patients, severity of illness, prior colistin exposure, hospital settings like tertiary referral centres versus district hospitals and study designs and sample sizes. Additional contributors may include variations in antimicrobial prescribing practices, infection prevention and control measures, laboratory methodologies and regional epidemiology of multidrug-resistant organisms. Together, these factors can markedly influence resistance estimates and limit the interpretability of pooled prevalence results.

Limitations of the study

This study provides useful information regarding resistance to colistin in *A. baumannii* and *P. aeruginosa* in Africa, highlighting

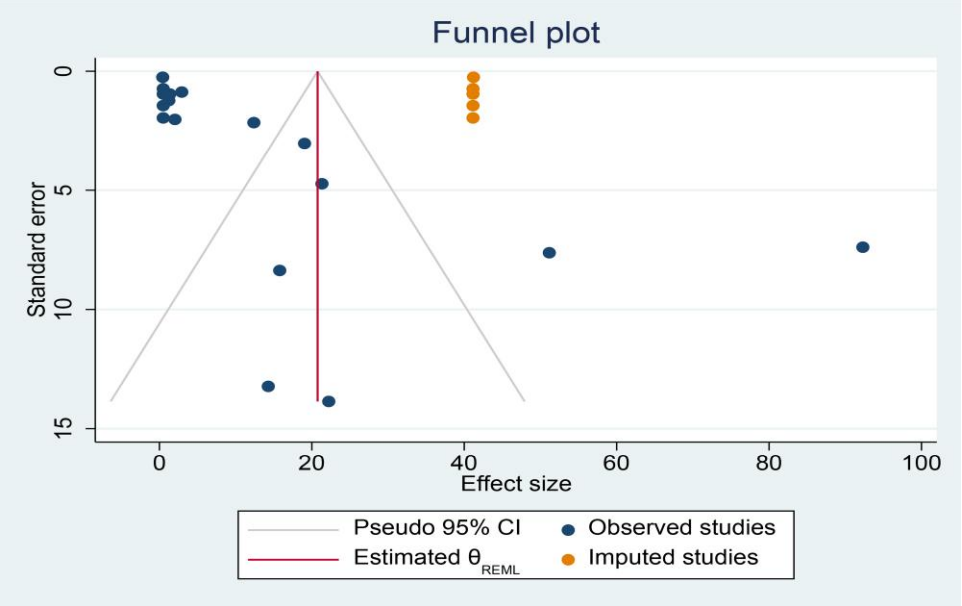

Figure 7. Funnel plot depicting publication bias in the pooled prevalence of colistin resistance in *P. aeruginosa* isolates recovered from clinical samples across Africa.

long-term trends and the growing issue of resistance. We also included studies that used BMD, the reference method for antimicrobial susceptibility testing of colistin resistance in *A. baumannii* and *P. aeruginosa*. However, this meta-analysis had a few limitations, including high heterogeneity, which might arise from differences in geographic distribution, population, antimicrobial use practices and significant publication bias. Excluding non-English studies and restricting inclusion to BMD-based testing may have introduced selection bias. These criteria likely reduced geographic representation and sample size, particularly in regions where resistance data is reported in local languages and non-BMD methods are commonly used, thereby limiting the generalisability of the findings.

In this study, only subgroup and sensitivity analyses were performed; more advanced approaches, such as meta-regression and narrative exploration, which could offer deeper insights into sources of heterogeneity, were not conducted. Additionally, there might be sampling bias, as the majority of the included studies were hospital-based and data from many countries were absent due to the inclusion criteria requiring the use of the BMD method. These limitations may have affected the representativeness of the estimated pooled prevalence of colistin resistance.

Conclusion

Colistin resistance in both *A. baumannii* and *P. aeruginosa* was found to be high in Africa. While resistance in *A. baumannii* showed a non-significant increase over time, *P. aeruginosa* exhibited a significant upward trend. Notable variations in colistin resistance were observed across countries and regions; however, these findings should be interpreted with caution due to the limited number of studies available per location. This study underscores the urgent need for strict colistin regulation, strengthened antimicrobial stewardship programmes, the implementation of rapid diagnostic tools for resistance detection and further molecular epidemiological research.

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Transparency declarations

The authors declare that they have no conflicts of interest.

Authors' contributions

Y.G. led the systematic review and meta-analysis, overseeing the study's conceptualization, article selection, data extraction, statistical analysis, and manuscript preparation. Y.G., M.A.R., Z.A., E.G., A.G., E.T., and A.S. were involved in searching for relevant articles, conducting data extraction, performing statistical analysis, and contributing to manuscript drafting. M.T., E.T., W.A., A.B., M.W., G.B., and M.A.R. were involved in reviewing the manuscript. All authors actively participated in reviewing the study, analysing the data, and writing the manuscript. They also approved the final version for submission, confirming their endorsement of its content and findings.

Ethical approval and consent to participate

In this study, ethics approval and consent to participate were not required, as it exclusively utilized publicly available aggregated data.

Consent for publication

All authors of this manuscript have given their approval for its publication.

Availability of data and materials

All data generated and materials used in this systematic review and meta-analysis are provided within the paper and supplementary materials.

Supplementary data

Figures S1 and S2 and Tables S1–S4 are available as Supplementary data at *JAC-AMR* Online.

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