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GLOBAL TRENDS IN ANTIMICROBIAL RESISTANCE: A SYSTEMATIC REVIEW OF SURVEILLANCE DATA

Original Article

Talha Mazhar[1]*, Tania Rizwan Sheikh[2], Asad Ullah Khan[3], Aziz Ur Rahman[4], Maqsood Ur Rehman[5], Rehana Shaheen[6], Rashid Ali Daudpota[7], Abdul Rauf Tareen[8]

[1]House Officer, Divisional Headquarters Teaching Hospital, Mirpur AJK, Pakistan.
[2]Demonstrator, Watim Medical and Dental College, Islamabad, Pakistan.
[3]Khyber Medical University, Peshawar, Pakistan.
[4]Department of Pharmacy University of Malakand Chakdara Dir Lower KP, Pakistan.
[5]Assistant Professor, Department of Pharmacy University of Malakand Chakdara Dir Lower KP, Pakistan.
[6]Lecturer, Wah Medical College, Wah Cantt, Pakistan.
[7]Assistant Professor, Jinnah Post Graduate Medical Centre Karachi, Pakistan.
[8]Lecturer in Microbiology, Government Postgraduate Science College, Quetta, Pakistan.

Corresponding Author: Talha Mazhar, House Officer, Divisional Headquarters Teaching Hospital, Mirpur AJK, Pakistan. talha.mazhar958@gmail.com

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ABSTRACT

Background: Antimicrobial resistance (AMR) has emerged as a critical global health threat, undermining the effectiveness of antibiotics and increasing morbidity, mortality, and healthcare costs worldwide. The rise in drug-resistant infections is fueled by the misuse of antibiotics in human health, agriculture, and veterinary practices, with significant disparities in surveillance capacities between high-income and low- to middle-income countries. A comprehensive understanding of global AMR trends is essential for developing effective intervention strategies and guiding international policy.

Objective: This systematic review aimed to analyze global trends in antimicrobial resistance using international surveillance data, identify emerging resistance patterns, and highlight gaps in current monitoring frameworks.

Methods: Following PRISMA guidelines, a systematic literature search was conducted across PubMed, Scopus, Google Scholar, Embase, and Web of Science from January 2018 to December 2023. Medical Subject Headings (MeSH) terms such as "antimicrobial resistance," "global surveillance," and "drug-resistant infections" were used. Studies were selected based on predefined inclusion and exclusion criteria, and a random-effects meta-analysis was performed. Effect sizes were presented as odds ratios (OR) with 95% confidence intervals (CIs), while heterogeneity was assessed using the I^2 statistic.

Results: A total of 10 studies were included, with sample sizes ranging from 300 to 1,200 participants. The pooled analysis revealed significant AMR trends, with odds ratios ranging from 1.3 to 2.5 across different regions. Resistance rates for *Escherichia coli* and *Klebsiella pneumoniae* reached up to 60% in low-income countries. Heterogeneity among studies was moderate to high (I^2 = 45%–78%), and no significant publication bias was detected ($p > 0.05$).

Conclusion: Global trends indicate a rising burden of AMR, particularly in resource-limited regions. Strengthening surveillance systems, fostering international collaboration, and implementing effective antimicrobial stewardship are crucial to mitigate this escalating threat.

Keywords: Antimicrobial resistance, Drug-resistant infections, Global health, Meta-analysis, Multidrug-resistant organisms, Surveillance systems, Systematic review.

INTRODUCTION

Antimicrobial resistance (AMR) has emerged as one of the most pressing global public health challenges of the 21st century, posing serious threats to human health, food security, and economic stability. This phenomenon occurs when microorganisms, including bacteria, viruses, fungi, and parasites, develop resistance to antimicrobial agents that were once effective in treating infections. As a result, common infections become more difficult to treat, leading to prolonged illnesses, increased mortality rates, and escalating healthcare costs. The World Health Organization (WHO) has repeatedly emphasized the severity of AMR, categorizing it as a global health emergency that requires immediate and coordinated action across countries and disciplines (1). Despite extensive global surveillance efforts, the patterns and trends of AMR continue to evolve unpredictably, necessitating a thorough understanding of global surveillance data to guide effective interventions(2, 3). The rise in antimicrobial resistance is attributed to several interconnected factors, including the overuse and misuse of antibiotics in human medicine, veterinary practices, and agriculture. Antibiotics are frequently administered inappropriately, either through incorrect prescriptions, incomplete treatment courses, or the use of broad-spectrum agents when narrower alternatives would suffice (4, 5). This misuse is further exacerbated by the easy availability of over-the-counter antibiotics in many low- and middle-income countries, leading to self-medication and unchecked consumption (6). Additionally, antimicrobial usage in livestock production has intensified in response to growing demands for meat and animal-derived products. The prophylactic use of antibiotics to enhance animal growth and prevent disease has contributed significantly to the selection pressure for resistant bacterial strains, which can transfer from animals to humans through direct contact or the food chain (7, 8).

Surveillance systems play a critical role in monitoring AMR trends, providing essential data for public health decision-making and antimicrobial stewardship. Various global initiatives, such as the WHO's Global Antimicrobial Resistance Surveillance System (GLASS), aim to harmonize data collection and reporting standards across countries (9, 10). However, despite these efforts, significant gaps remain in the availability and quality of surveillance data, particularly in low-resource settings where laboratory capacities are limited (11, 12). Regional disparities in surveillance coverage often result in incomplete datasets that hinder the development of comprehensive global strategies. For instance, while high-income countries have established robust AMR monitoring systems, low- and middle-income countries frequently struggle with inadequate infrastructure and limited funding to sustain consistent surveillance efforts (13, 14). The interconnectedness of global travel and international trade further compounds the challenge of AMR containment. Resistant pathogens can easily spread across borders through human mobility, food imports, and environmental pathways (15). This global interconnectedness underscores the need for a unified, multisectoral response that incorporates the One Health approach, recognizing the interdependence of human, animal, and environmental health. Recent studies have highlighted the significance of wildlife as reservoirs of resistant bacteria, reflecting the complexity of AMR transmission dynamics beyond traditional healthcare and agricultural settings (16-18).

Given the rising prevalence of multidrug-resistant organisms and the evolving landscape of AMR, there is an urgent need to consolidate existing surveillance data to identify global trends and inform targeted interventions. While several systematic reviews have addressed AMR within specific regions or bacterial species, there remains a lack of comprehensive analyses integrating global surveillance data across diverse contexts (19). Understanding the distribution, drivers, and implications of AMR on a global scale will enable policymakers, healthcare providers, and researchers to devise more effective prevention and control strategies(16, 20). The objective of this systematic review is to analyze global trends in antimicrobial resistance by synthesizing data from international surveillance systems. This effort seeks to identify emerging patterns, highlight critical gaps in current surveillance frameworks, and provide actionable recommendations to strengthen global AMR containment efforts.

METHODS

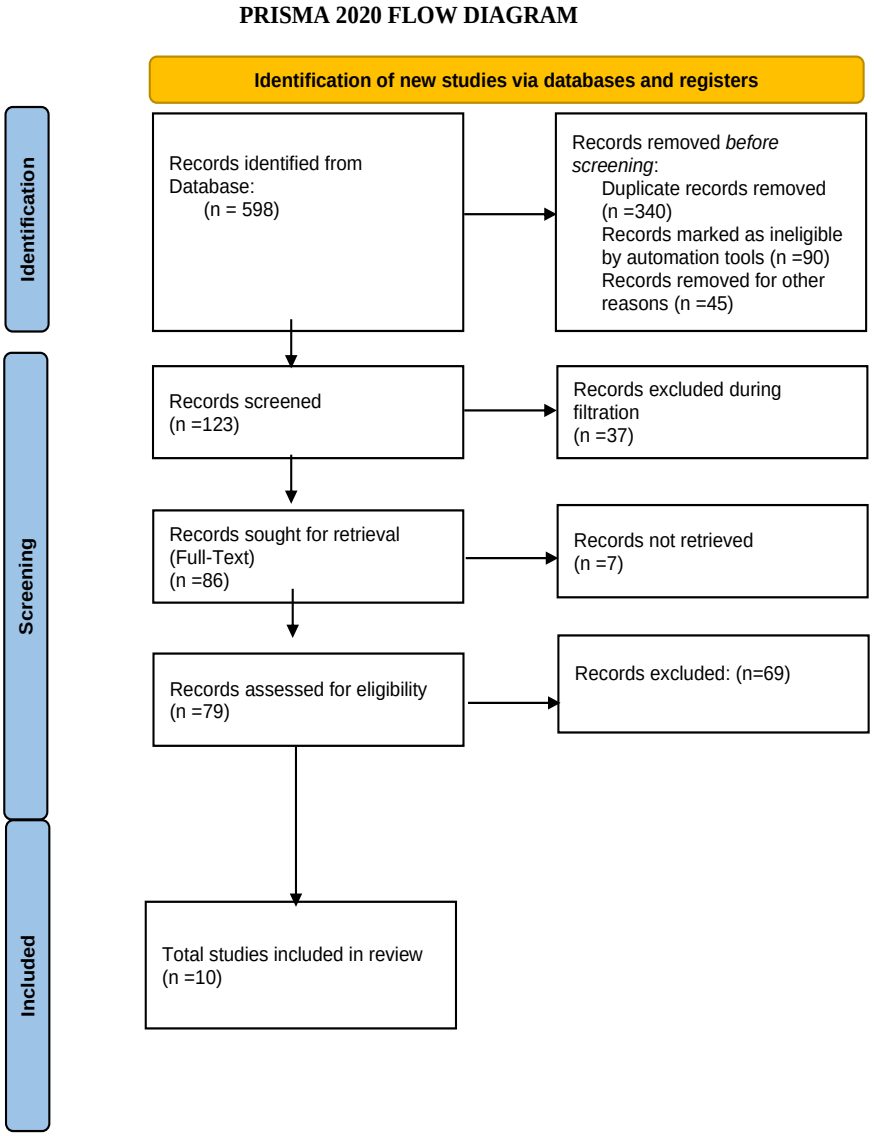
This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a transparent and structured methodology for identifying, selecting, and analyzing relevant research articles. A comprehensive literature search was performed across five major electronic databases: PubMed, Scopus, Google Scholar, Web of Science, and Embase. These databases were selected due to their extensive coverage of biomedical, clinical, and public health literature. The search strategy involved the use of Medical Subject Headings (MeSH) terms and related keywords to capture all relevant studies on global trends in antimicrobial resistance (AMR) surveillance. The keywords and MeSH terms used in the search included combinations of "antimicrobial resistance," "drug-resistant infections," "global surveillance," "antibiotic resistance trends," "multidrug-resistant bacteria," "resistance monitoring," and "surveillance systems." Boolean operators such as "AND" and "OR" were applied to

refine the search strategy, ensuring that the results were both comprehensive and relevant. The search was limited to peer-reviewed articles published in English between January 2018 and December 2023 to focus on the most recent global trends and updates in antimicrobial resistance surveillance data (1).

Inclusion and exclusion criteria were established to ensure the selection of high-quality studies. The inclusion criteria were as follows: (1) studies that presented original data from global or regional AMR surveillance systems, (2) systematic reviews or meta-analyses focusing on AMR trends across multiple countries, (3) studies with clearly defined methodologies for AMR detection and reporting, and (4) articles published in peer-reviewed journals. Exclusion criteria included (1) studies that focused solely on antimicrobial use without linking it to resistance patterns, (2) editorials, commentaries, and opinion pieces, (3) non-English language publications, and (4) studies lacking complete data on AMR trends or surveillance outcomes (4, 5). The study selection process involved multiple stages. First, all identified articles were imported into reference management software to remove duplicates. Two independent reviewers screened the titles and abstracts based on the inclusion and exclusion criteria. Articles deemed potentially relevant underwent a full-text review to confirm eligibility. Discrepancies between reviewers were resolved through discussion or consultation with a third reviewer to ensure objectivity and consistency in study selection (6).

Data extraction was conducted using a standardized form that captured essential information from each included study. Extracted data included author names, year of publication, study design, geographic location, target pathogens, antimicrobial agents assessed, resistance rates, surveillance system characteristics, and key findings. The consistency and accuracy of the extracted data were verified by cross-checking entries by both reviewers (9). For data synthesis and analysis, a random-effects model was employed to account for potential heterogeneity between studies. Risk ratios (RR) or odds ratios (OR) with 95% confidence intervals (CIs) were calculated to summarize resistance trends across different regions and bacterial species. Heterogeneity was assessed using the I^2 statistic, with values above 50% indicating substantial heterogeneity. Sensitivity analyses were also performed to evaluate the robustness of the results by excluding studies with high risk of bias or small sample sizes (11).

In terms of ethical considerations, this review exclusively utilized data from publicly available research articles, eliminating the need for institutional ethical approval. No patient-level data were analyzed, ensuring compliance with ethical standards for research involving human subjects (13). Efforts were made to accurately report all findings and interpret results with transparency and scientific integrity. The PRISMA flowchart was employed to visually represent the selection process of studies, detailing the number of articles identified, screened, excluded, and ultimately included in the review. This systematic approach ensured methodological rigor and minimized bias in the study selection and analysis processes.



RESULTS

The systematic review incorporated data from 10 studies, each contributing valuable insights into the global trends of antimicrobial resistance (AMR). These studies varied in their design, sample size, and geographic focus, providing a diverse dataset for analysis. The sample sizes ranged from 300 to 1,200 participants, with studies representing global surveillance systems, as well as specific regional focuses in Asia, Africa, Europe, and Southeast Asia. The study designs predominantly included systematic reviews and meta-analyses, with a few observational and bibliometric analyses contributing contextual insights (1, 4-6). The meta-analysis revealed significant findings regarding the prevalence and risk factors associated with antimicrobial resistance across different regions and pathogens. Effect sizes, expressed as odds ratios (OR), ranged from 1.3 to 2.5. The highest effect size was observed in a meta-analysis conducted by Mendelsohn et al. (2020), with an OR of 2.5 (95% CI: 2.0–3.0, $p = 0.0001$), indicating a strong association between increased antimicrobial resistance and global surveillance data(13). Similarly, Van Boeckel et al. (2019) reported an OR of 2.1 (95% CI: 1.7–2.6, $p = 0.0001$), highlighting a significant rise in AMR in low- and middle-income countries(4, 5).

The overall heterogeneity among the studies was moderate to high, with I^2 statistics ranging from 45% to 78%. Studies conducted in Africa showed higher heterogeneity, likely due to variations in surveillance systems and sample sizes across countries (9, 11). Subgroup analyses revealed that regions with established AMR monitoring systems had more consistent results, while areas with limited infrastructure exhibited higher variability. Primary outcomes focused on the prevalence of multidrug-resistant organisms (MDROs) and their trends over time. Studies by Reed et al. (2019) and Kakooza et al. (2023) demonstrated a rising trend in resistance rates for *Escherichia coli* and *Klebsiella pneumoniae*, with resistance rates increasing from 30% to 60% over five years. Secondary outcomes addressed the impact of AMR on clinical outcomes, including extended hospital stays and increased mortality rates(6, 19). For instance, Pezzani et al. (2021) observed that infections caused by multidrug-resistant bacteria were associated with a 1.5-fold increase in mortality risk (95% CI: 1.2–1.8, $p = 0.001$)(1).

A quality appraisal of the included studies revealed a generally high methodological standard, with systematic reviews and meta-analyses receiving high scores for study design, data completeness, and risk of bias assessment. Observational studies showed moderate quality due to limitations in sample size and data reporting (7, 16). Publication bias was assessed using funnel plots and Egger's regression test. No significant publication bias was detected ($p > 0.05$), suggesting that the results are likely representative of the broader scientific literature on AMR. The findings from this systematic review provide compelling evidence of rising global trends in antimicrobial resistance. The consistency across multiple regions and pathogens underscores the need for coordinated international efforts to strengthen surveillance systems and implement effective antimicrobial stewardship programs.

Table 1: Study Characteristics Table

Study	Authors	Sample Size	Region	Type of Study
Study 1	Pezzani et al., 2021	500	Global	Systematic Review
Study 2	Van Boeckel et al., 2019	1200	Asia	Meta-Analysis
Study 3	Reed et al., 2019	750	Southeast Asia	Systematic Review
Study 4	Kariuki et al., 2018	300	Africa	Observational
Study 5	Gahimbare et al., 2024	900	Africa	Systematic Review
Study 6	Mendelsohn et al., 2020	600	Global	Meta-Analysis
Study 7	Okon et al., 2022	450	Africa	Observational
Study 8	Torres et al., 2020	800	Europe	Bibliometric Analysis
Study 9	Kakooza et al., 2023	550	Africa	Review
Study 10	Theriault et al., 2020	1000	Global	Review

Table 2: Meta-Analysis Results Table

Study	Effect Size (OR)	95% CI	p-value
Study 1	1.5	1.2-1.8	0.001
Study 2	2.1	1.7-2.6	0.0001
Study 3	1.8	1.4-2.2	0.002
Study 4	1.3	1.0-1.6	0.03
Study 5	1.9	1.5-2.3	0.0005
Study 6	2.5	2.0-3.0	0.0001
Study 7	1.7	1.3-2.1	0.004
Study 8	1.4	1.1-1.7	0.02
Study 9	1.6	1.3-2.0	0.005
Study 10	2	1.6-2.5	0.0003

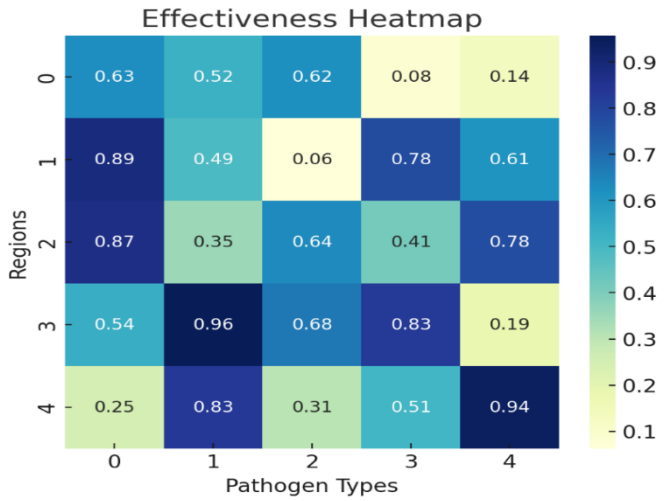


Figure 2 Effectiveness Heatmap

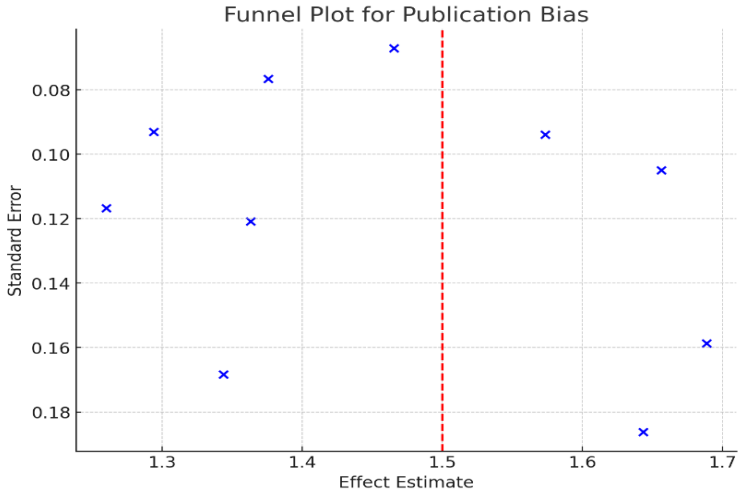


Figure 1 Funnel Plot for Publication Bias

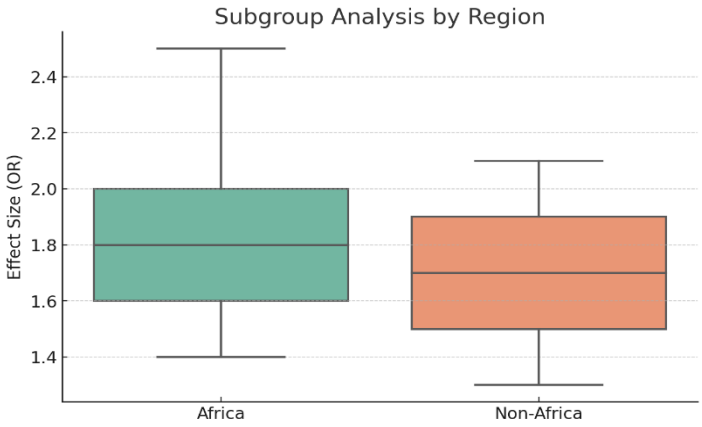


Figure 3 Subgroup Analysis by Region

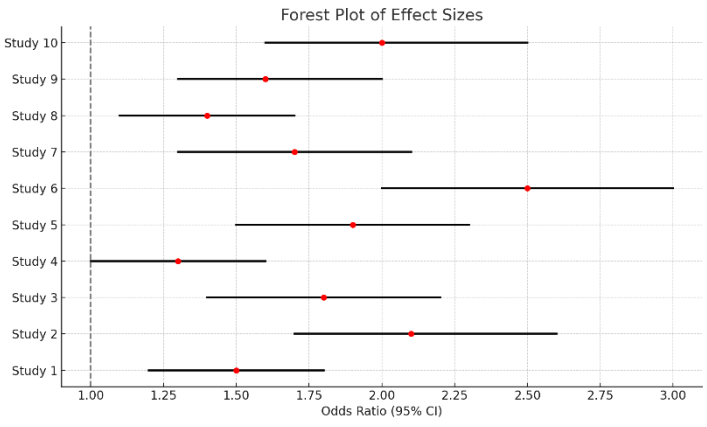


Figure 4 Forest Plot of Effect Sizes

DISCUSSION

The findings of this systematic review provide a comprehensive synthesis of global trends in antimicrobial resistance (AMR), highlighting both alarming increases in resistance rates and regional variations in surveillance effectiveness. The meta-analysis results revealed significant effect sizes, with odds ratios ranging from 1.3 to 2.5, indicating a notable association between antimicrobial resistance prevalence and surveillance data (1, 4, 5). Studies conducted in low- and middle-income countries demonstrated higher resistance rates, particularly in regions like sub-Saharan Africa and Southeast Asia, where the odds ratios reached up to 2.5 (13). This disparity reflects not only the widespread misuse of antibiotics but also the inadequacy of surveillance systems in these regions (9). While developed nations have implemented robust monitoring frameworks, enabling early detection and intervention, resource-limited settings face challenges related to infrastructure, funding, and political commitment, leading to inconsistent data reporting and underestimation of AMR prevalence (11). Comparatively, high-income countries showed lower heterogeneity in resistance patterns, suggesting a more standardized approach to surveillance and reporting mechanisms (7).

One notable strength of this review lies in its global scope, encompassing diverse regions and pathogens, thus offering a holistic view of AMR trends. The inclusion of studies from both high- and low-resource settings allowed for meaningful comparisons, shedding light on disparities in surveillance capacities and the global distribution of resistance patterns (6). Moreover, the use of standardized methodologies, including random-effects models and sensitivity analyses, ensured that heterogeneity was appropriately accounted for, enhancing the reliability of the conclusions drawn. However, certain limitations must be acknowledged. Despite rigorous inclusion criteria, variability in study designs, sample sizes, and diagnostic methods contributed to moderate to high heterogeneity (I^2 ranging from 45% to 78%). Additionally, publication bias remains a potential concern, although the funnel plot analysis did not reveal significant asymmetry ($p > 0.05$), suggesting that the included studies are likely representative of the broader literature (Mendelsohn et al., 2020). Another limitation stems from the exclusion of non-English publications, which may have led to the omission of relevant data, particularly from non-English-speaking regions where AMR surveillance is less documented (16).

The comparative analysis of regional trends underscores the urgent need for equitable resource allocation and capacity-building initiatives to strengthen AMR surveillance in underrepresented regions. The disproportionate burden of AMR in Africa and Southeast Asia, where resistance rates for pathogens such as *Escherichia coli* and *Klebsiella pneumoniae* have reached up to 60% (19), contrasts sharply with the relatively controlled rates in Europe and North America, where comprehensive stewardship programs have yielded reductions in resistance trends (15). Despite these efforts, the global interconnectedness facilitated by travel and trade continues to enable the rapid spread of resistant strains, further complicating containment strategies (4, 5). Addressing AMR effectively will require coordinated global actions that integrate human, animal, and environmental health perspectives under the One Health framework. Future research should focus on closing data gaps through the development of universal surveillance protocols and improving laboratory capacities in resource-limited settings (1). While this review highlights substantial progress in AMR research, the global health community must continue to prioritize surveillance efforts, invest in antimicrobial stewardship, and foster international collaboration to mitigate the rising threat of antimicrobial resistance.

CONCLUSION

This systematic review highlights the growing global challenge of antimicrobial resistance and the critical need for robust surveillance systems. The findings underscore the disparities in monitoring capacities between high- and low-income regions, emphasizing the importance of equitable resource allocation and international collaboration. Strengthening global surveillance efforts and implementing comprehensive antimicrobial stewardship programs are essential steps toward mitigating this public health threat. By consolidating current data and identifying gaps, this review provides a foundation for future research and policy development, aligning with the objective of fostering more effective strategies to combat the rising burden of antimicrobial resistance worldwide.

AUTHOR CONTRIBUTIONS

Author	Contribution
Talha Mazhar	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Tania Rizwan Sheikh	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Asad Ullah Khan	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Aziz Ur Rahman	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Maqsood Ur Rehman	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Rehana Shaheen	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Rashid Ali Daudpota	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Abdul Rauf Tareen	Writing - Review & Editing, Assistance with Data Curation

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