

## RESEARCH

## Antimicrobial resistance in Pakistan and global context

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One of the most important global health issues of the twenty-first century is antimicrobial resistance (AMR), and because of its distinct epidemiological and socioeconomic setting, Pakistan is particularly vulnerable. This thorough analysis summarizes the most recent data on AMR trends from 2020 to 2025, looking at both worldwide trends and issues unique to Pakistan. According to global surveillance data, the number of resistant infections has increased by 65% since 2000, and AMR is responsible for 4.95 million fatalities each year. With more than 50% of important bacteria, including *Escherichia coli* and *Klebsiella pneumoniae*, resistant to third-generation cephalosporins and fluoroquinolones, Pakistan exhibits startlingly high resistance rates. Overall, carbapenem resistance in *K. pneumoniae* has increased to 25.6%, with rates as high as 44.2% in bloodstream isolates. Due to the shortcomings of its healthcare system, Pakistan is expected to bear a disproportionate amount of the global economic burden, which is estimated to be between \$100 and \$150 billion. Enzymatic inactivation, target alteration, decreased permeability, active efflux, and biofilm formation are important resistance mechanisms. Significant obstacles to Pakistan's National Action Plan execution include insufficient stewardship initiatives, regulatory deficiencies, and shoddy surveillance systems. With pediatric point-prevalence surveys revealing an 82.1% antibiotic use prevalence and only 2% culture-guided prescribing, antibiotic consumption has increased by an estimated 65% nationwide. One Health principles must be part of future plans, as they will lead to the strengthening of the lab networks; strict policies must be enforced more and should strengthen stewardship initiatives. This offers evidence-based recommendations for the prevention of AMR through coordinated national and international initiatives and highlights the critical necessity for extensive interventions across healthcare, agriculture, environmental, and policy domains.

**Keywords:** antimicrobial resistance, Pakistan, global surveillance, One Health, GLASS, WHO

### Introduction

Antimicrobial resistance (AMR) concern is threatening worldwide and raising concerns for health security about how to cure the infections and diseases in a safe manner through contemporary medical therapies (1). According to the World Health Organization (WHO), AMR is considered one of the biggest risks that global public health is facing nowadays if no heed is paid to the current trends, it can lead to disastrous outcomes (2). Pakistan has a population of over 240 million; it is also a lower middle-income nation that faces

unique hurdles against AMR due to socioeconomic issues, healthcare system constraints, and regulatory deficiencies (3). The increased use of antibiotics, poor diagnostic facilities, and wide socioeconomic gaps will impact the health care sector and lead to AMR spread (4). The AMR is causing a burden globally, as the trend of fatality rate is around 700,000 AMR-attributable fatalities per year, in reference to the recent comprehensive assessments (5). Household expenses are increased by AMR. Poorer people suffer more because of the suffering and early deaths it causes. It hinders economic progress and lowers community productivity. Early death

and disability are caused by a decrease in labor supply and an increase in healthcare demand (6).

## Literature review

Antimicrobial resistance (AMR) is one of the increasing threats to global health. The risk in surgeries and medical procedures, which includes organ transplant, heart surgeries, cancer therapies, and other surgical operations, has major health risks due to hospital-acquired AMR. Patients experience vast issues due to longer hospital stays, and very less options for treatments are available, as with time antibiotics lose their effectiveness; all these concerns raise the burden on the healthcare system. AMR has vital societal and economic implications in addition to its influence on clinical outcomes. AMR is directly related to longer hospital stays; as the patients' stay becomes longer, the medical cost also increases, and the healthcare resources are used more in both developed and developing countries. AMR decreases the productivity of workers, and it also puts pressure on national economies at the societal level. As estimated, it impacts the economic growth, which is a major worldwide health issue. To properly handle this crisis, global efforts are required to overcome these major problems. We require strong surveillance systems to detect, monitor, and respond quickly to resistance trends and robust antimicrobial stewardship programs, which are essential for ensuring the proper and sensible use of antibiotics. The effective approach of One Health shows the link between human, animal, and environmental health. This acknowledges that the use of antibiotics in the environment and in agriculture directly contributes to the development of resistance in human populations. In short, AMR is a complicated, diverse issue. As the resistance is rising, it will continue to hinder medical advancement, deteriorate health systems, and place increasing stress on future generations until further actions are taken (7).

## Aims and objectives

The following goals guided the creation of this study:

- To compile worldwide patterns in AMR from 2020 to 2025.
- To assess and outline the state of AMR.
- To illustrate the parallels and discrepancies between Pakistan's AMR trends and worldwide trends.
- To evaluate the financial and medical costs associated with AMR in Pakistan.
- To point out areas for improvement in stewardship, policy, and surveillance and offer recommendations for the future.

## Methodology

### Study design

This study was conducted as a systematic review and meta-analysis to summarize the latest data on AMR in Pakistan and compare it to global trends between 2020 and 2025.

### Study population and sampling frame

The "population" of studies, surveillance reports, and datasets that examined the mechanisms of antibiotic resistance and the prevalence of AMR in human clinical samples. Studies were carried out at the national level in Pakistan as well as international reports. No direct patient recruitment was carried out. Instead, a systematic sampling of published literature was carried out via reference screening and database searches.

### Search strategy

The databases PubMed, Scopus, Web of Science, and Google Scholar were used in a methodical search. Articles published between January 2020 and June 2025 were included in the search. "Antimicrobial resistance" OR "AMR" AND "Pakistan" OR "global trends" AND "GLASS" OR "One Health" OR "ESBL" OR "carbapenem resistance" were among the keywords and Boolean operators utilized. To find more pertinent articles, the reference lists of the included research and official reports from the Global Antimicrobial Resistance and Use Surveillance System (GLASS) and the WHO were also searched.

### Eligibility criteria

#### Inclusion criteria

- Research on the prevalence of AMR, resistance mechanisms, or patterns of antibiotic use.
- Articles that offer information particular to Pakistan or on a worldwide scale.
- Systematic reviews, surveillance reports, or peer-reviewed observational research.
- Printed in English from 2020 to 2025.

#### Exclusion criteria

- Editorials, conference papers, or case reports that don't include primary data.
- Research that has no obvious connection to human health and only looks at environmental or veterinary materials.
- Incomplete or duplicate reports that lack adequate methodological information.

## Sample size consideration

The number of eligible studies included in this meta-analysis determined the sample size, despite the fact that no patients were personally recruited. To enable pooled estimates across research, the patient/sample population size from each study was retrieved and presented.

## Data extraction and management

Reviewers used a standardized data collection sheet to independently extract this data. Publication year, study design, geographic location, study population, bacterial species, sample size, antibiotic susceptibility patterns, and resistance rates were among the data that were extracted.

## Statistical analysis

Instead of doing a primary data study, this research was carried out as a systematic research analysis. There were no new mathematical models or statistical tests used. A descriptive comparison of data taken from official surveillance reports and published studies was used instead.

- The findings were categorized thematically, covering bacterial species, antibiotic consumption patterns, resistance mechanisms, and worldwide versus Pakistan-specific trends.
- Reported prevalence rates and resistance percentages were documented precisely as they were in the original sources.
- The results of several research studies that looked at the same parameter were compared side by side to find trends, variances, and consistent findings.
- After that, the data were narratively synthesized to show the main parallels and divergences between Pakistan and the global AMR trends of 2020–2025.

## Duration of study

The search, screening, data extraction, and analysis steps of the procedure were carried out from July 2024 to August 2025.

## Ethical considerations

This study was carried out as a meta-analysis and systematic review. There were no new human or animal participants in this study. Every piece of information was taken from publicly accessible surveillance reports and previously published peer-reviewed research. Therefore, ethical clearance was not necessary.

## Global AMR trends and burden

### Worldwide resistance patterns

Global surveillance data shows that AMR has grown at a never-before-seen rate in all major disease groups and geographical locations. The most recent comprehensive analysis, which spans 2020–2025, reveals concerning trends in illnesses associated with both the general public and healthcare. Sub-Saharan Africa bears the largest burden of AMR-associated mortality in 2023, with approximately 1.4 million deaths, followed by South Asia with 980,000 deaths. This highlights the disproportionate impact on regions with few resources. AMR mortality is still highest in low- and middle-income areas, as **Table 1** illustrates, highlighting the critical need for improved stewardship and surveillance (8).

### Key pathogen-antibiotic combinations

The worldwide burden of AMR has increased dramatically, affecting all regions, but low- and middle-income countries are disproportionately impacted due to their insufficient healthcare, weak laboratory capacity, and surveillance systems. A number of pathogen-antibiotic combinations have become specific issues (9):

**Critical priority pathogens:** – Carbapenem-resistant *Acinetobacter baumannii* – Carbapenem-resistant *Pseudomonas aeruginosa* – Carbapenem-resistant *Enterobacteriaceae*

**High priority pathogens:** – Vancomycin-resistant *Enterococcus faecium* – Methicillin-resistant *Staphylococcus aureus* (MRSA) – Fluoroquinolone-resistant *Campylobacter* spp.

### Economic impact and healthcare burden

Beyond just direct medical costs, AMR has significant economic repercussions, such as decreased productivity, extended hospital stays, and the need for more expensive

**TABLE 1** | Global AMR burden by region (2020–2023) (8).

Region	Deaths 2020	Deaths 2023	Increase (%)
Sub-Saharan Africa	1,200,000	1,400,000	16.7
South Asia	850,000	980,000	15.3
East Asia & Pacific	650,000	750,000	15.4
Europe & Central Asia	400,000	420,000	5.0
Latin America & Caribbean	320,000	365,000	14.1
Middle East & North Africa	280,000	315,000	12.5
North America	180,000	195,000	8.3

alternative therapies. Global estimates currently place the yearly expenses between \$100 and \$150 billion, and without effective intervention, projections show exponential increases. Higher rates of treatment failure, longer hospital admissions, and the requirement for more intensive care treatments are all signs of the healthcare burden. Between 2020 and 2025, the AMR research timetable identifies important worldwide initiatives and research goals, including financing pledges, behavior change research, and pandemic preparedness (Figure 1).

## AMR situation in Pakistan: current status and challenges

### National surveillance data and resistance patterns

Participation by Pakistan in international monitoring networks, especially GLASS, has yielded important information about patterns of domestic opposition. Nonetheless, there are still large gaps in data from primary healthcare settings and rural areas, and surveillance coverage is still restricted. Data that is currently available shows alarming patterns in a number of disease groupings (10):

**Gram-negative bacteria:** *E. coli* and *Klebsiella* spp. are becoming more resistant to carbapenem and polymyxins throughout Africa. *E. coli* is more than 50% resistant to cephalosporins and fluoroquinolones, while *Klebsiella* is more than 25% resistant to carbapenem. (11).

**Gram-positive microorganisms:** The frequency of MRSA varies greatly from hospital to hospital (15–60%). Enterococci resistant to vancomycin are appearing in tertiary care facilities. Concerning penicillin and macrolide resistance in *Streptococcus pneumoniae* (12).

### Antibiotic consumption patterns

Over the past 10 years, Pakistan's national consumption of antibiotics has increased by an estimated 65% due to a number of variables, including patient demand, improper prescribing practices, and over-the-counter availability. With an antibiotic use prevalence of 82.1% and a hospital culture-guided prescribing rate of only 2%, pediatric point-prevalence surveys show especially alarming trends (13).

Essential Consumption Factors: Antibiotics available over-the-counter; limited diagnostic capabilities resulting in empirical medication; and incomplete treatment regimens because of financial limitations. The use of antibiotics in agriculture and veterinary medicine; the absence of systems to enforce prescriptions.

## Healthcare system challenges

The following structural issues with Pakistan's healthcare system contribute to the emergence and spread of AMR:

**Infrastructure limitations:** Limitations of the Infrastructure: Insufficient lab space for sensitivity and culture testing, restricted availability of quick diagnostic instruments, inadequate methods to prevent and control infections, and overcrowding in medical institutions makes transmission easier.

**Human resource constraints:** Limited training on antimicrobial stewardship – Shortage of clinical microbiologists and infectious disease specialists – Inadequate continuing education programs – Poor awareness among healthcare workers.

## Mechanisms of antimicrobial resistance

### Enzymatic inactivation

One of the most important resistance mechanisms in clinical practice is the generation of enzymes that render antimicrobial drugs inactive. With high prevalence rates among *Enterobacteriaceae*, carbapenemases and extended-spectrum beta-lactamases (ESBLs) have become especially problematic in Pakistan (13).

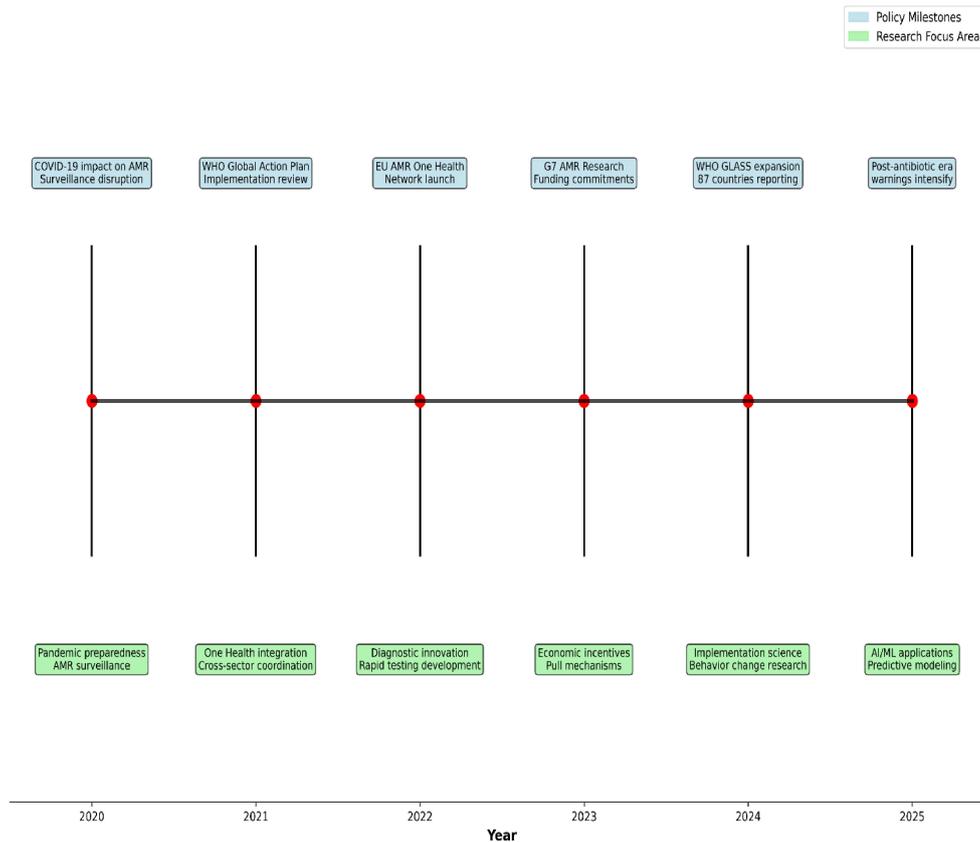
**Key enzyme families:** ESBLs: Cefotaximase-Munich (CTX-M), sulfhydryl variable (SHV), and temoniera (TEM) Carbapenemases: *Klebsiella pneumoniae* carbapenemase (KPC), New Delhi metallo- $\beta$ -lactamase (NDM), imipenemase metallo- $\beta$ -lactamase (IMP), oxacillinase (OXA)-48-like, and verona integron-encoded metallo- $\beta$ -lactamase (VIM) Change-causing enzymes for aminoglycosides chloramphenicol acetyltransferases.

### Modification of the target

Antimicrobial target site alterations that reduce drug binding affinity lead to resistance. This procedure is particularly important for: fluoroquinolone-resistant DNA gyrase and topoisomerase IV mutations.

- Penicillin-binding protein alterations in *S. aureus* (MRSA).
- Methylation of 16S rRNA in resistance to aminoglycosides.
- Resistance to vancomycin due to alteration of peptidoglycan precursors

AMR Research Timeline and Key Milestones (2020-2025)



**FIGURE 1** | AMR research timeline and key milestones (2020–2025). This figure illustrates the progression of major AMR research developments, policy implementations, and surveillance milestones from 2020 to 2025, including the expansion of GLASS networks, development of national action plans (NAPs), and key breakthrough research findings.

## Reduced permeability and active efflux

The multidrug resistance patterns seen in Pakistan are largely caused by modifications in the permeability of the bacterial cell membrane and increased efflux pump activity:

**Permeability changes:** Porin loss or alteration in *Enterobacteriaceae* Bacteria that are Gram-negative Composition of lipopolysaccharides (14).

**Efflux pump systems:** resistance-nodulation-division (efflux pump family) (RND) family pumps in gram-negative bacteria (15) *S. aureus* ABC transporters major facilitator superfamily (efflux pump family) (MFS) pumps in a variety of species.

## Biofilm formation

Biofilm-associated disorders provide special challenges in Pakistani healthcare settings since they result in chronic infections and treatment failures. Biofilms provide protection against antibiotics in a number of ways (16).

Decreased immune system evasion, altered metabolic states of implanted bacteria, facilitated horizontal gene

transfer, and decreased penetration of antimicrobial agents (16).

## Surveillance systems and data quality

### Global surveillance networks

Pakistan's participation in international surveillance networks, particularly WHO GLASS, has enhanced understanding of national resistance patterns. However, data quality and coverage remain significant challenges (10):

**GLASS participation:** few participating laboratories – Attention on tertiary care centers – Inadequate illustration of rural areas – Standardization challenges across laboratories.

### National surveillance infrastructure

Pakistan's national surveillance system faces multiple challenges that limit its effectiveness in monitoring AMR trends:

**System limitations:** Fragmented data collection mechanisms – few capacities laboratory for quality surveillance – Insufficient data management systems – Poor unification between public and private sectors.

**Quality assurance issues:** Inconsistent laboratory methods – Limited external quality assessment participation – Inadequate staff training – Resource constraints affecting testing quality.

## Data gaps and limitations

Significant gaps exist in Pakistan's AMR surveillance data, potentially introducing bias toward urban, tertiary care settings. Standardization of laboratory methods and resistance definitions may vary between studies, affecting comparability. The economic impact analysis is limited by the scarcity of comprehensive cost-effectiveness studies specific to the Pakistani context (17).

## Policy framework and national action plan

### Pakistan's national action plan on AMR

In line with WHO's Global Action Plan, Pakistan created its National Action Plan (NAP) on AMR in 2017. However, there are several obstacles to implementation:

**NAP goals:** The NAP on AMR aims to reduce infection risks through better biosecurity, hygiene, and vaccination programs, ensure responsible and prudent use of antimicrobials in human medicine and livestock production, promote long-term investment in sustainable alternatives like vaccines, probiotics, and phytochemicals, and increase awareness and knowledge of AMR across human, animal, and environmental health sectors. In line with Sustainable Development Goals 3 (Good Health and Well-Being), 12 (Responsible Consumption and Production), and 15 (Life on Land), these goals are incorporated into the One Health framework (18).

**Implementation difficulties:** Poor inter-sectoral coordination, a lack of finance, and inadequate monitoring and evaluation systems—Inadequate provincial political commitment (19).

### Regulatory framework

The antimicrobial regulatory framework in Pakistan has to be significantly strengthened:

**Current rules:** The 1976 Drug Act and the 1978 Drug Regulations, National Drug Policy 2018, antimicrobial

import and manufacturing licenses, and inadequate enforcement measures.

**Regulatory omissions:** Prescription medicines that are available over-the-counter, inadequate quality control of imported antimicrobials, little regulation of the use of antibiotics in veterinary medicine, and lax penalties for regulatory infractions.

## Antimicrobial stewardship programs

Pakistan's adoption of antimicrobial stewardship is still lacking, with notable gaps in the public and private healthcare systems:

**Present situation:** A small number of hospitals have official stewardship initiatives. Poor monitoring of antibiotic use, inadequate prescriber education, and a lack of clinical chemist engagement (20).

**Implementation obstacles:** Lack of qualified staff, inadequate institutional support, restricted ability to diagnose, and financial problems in environments with limited resources.

## Economic burden and healthcare costs

### Direct healthcare costs

Although thorough cost estimates are still scarce, there are several ways that AMR's economic burden appears in Pakistan:

**Rising medical expenses:** Longer hospital stays and more costly second-line therapies, extra diagnostic tests a rise in the need for critical care (21).

**Costs of treatment failure:** Recurrent hospital stays, needs for long-term care, needs for palliative care (22).

### Indirect economic impact

Antimicrobial resistance (AMR) has substantial indirect economic consequences in addition to direct healthcare costs:

**Losses in productivity:** Prolonged period of illness, the premature death rate (23), the strain of caregiving (24), and decreased involvement in the labor force (25).

**Impact on the healthcare system:** A diminished ability to do elective treatments (26), enhanced standards for infection control (27), and the strain on infrastructure (28).

## Projected economic burden

Pakistan risks increasing economic implications from AMR in the absence of effective intervention. According to conservative estimates, if current trends continue, GDP losses might reach 2–3% by 2030, with vulnerable communities bearing a disproportionate amount of the burden.

## One health approach and environmental factors

### Human-animal-environment interface

Environmental factors and agricultural practices in Pakistan have a major impact on the emergence and spread of AMR:

**Agricultural antibiotic use:** Livestock growth promotion, aquaculture disease prevention, inadequate veterinarian supervision, and food product contamination.

**Environmental contamination:** Waste from pharmaceutical manufacture, discharge of hospital effluent, and runoff from agriculture and urban wastewater systems.

### Food safety and AMR (29)

In Pakistan, one important route for the spread of AMR is the food chain:

**Contamination sources:** Production of poultry and livestock, aquaculture methods, food processing facilities, and retail and distribution networks.

**Risk factors:** Inadequate cold chain infrastructure, inadequate personal hygiene, and inadequate laws pertaining to food safety.

### Environmental surveillance

Pakistan still lacks adequate environmental surveillance for AMR, which is a crucial knowledge gap in resistance ecology (9):

**Priority areas:** Wastewater from hospitals, manufacturing facilities for pharmaceuticals, urban water systems, and agricultural settings.

In order to prevent AMR, the One Health paradigm stresses the integration of environmental, animal, and human health through integrated actions such as waste management, surveillance, and responsible antibiotic use (Figure 2).

## Antimicrobial stewardship and infection prevention

### Hospital-based stewardship programs

Despite several obstacles, the implementation of antimicrobial stewardship programs in Pakistani hospitals is an essential intervention (30):

**Core components:** Guidelines for prescribing antibiotics (31), pre-authorization specifications, prospective evaluation and comments, and interventions in education (32).

**Implementation Barriers:** Clinical pharmaceutical services are limited (33), poor diagnostic assistance, prescriber resistance (34), and limitations on resources.

### Community-level interventions

Interventions for community-based stewardship are crucial in combating improper use of antibiotics:

**Key strategies:** Campaigns for public awareness (35), interventions based on pharmaceuticals (36), and programs for community health workers and training for primary healthcare providers.

**Challenges:** Low levels of health literacy, cultural perspectives on antibiotics, financial obstacles to receiving the right care, and inadequate enforcement of regulations.

### Infection prevention and control

Improving infection prevention and control (IPC) strategies is essential to lowering the spread of AMR:

**Priority interventions:** Programs for hand hygiene (37), procedures for cleaning the environment (38), precautions for isolation, and monitoring of infections linked to healthcare.

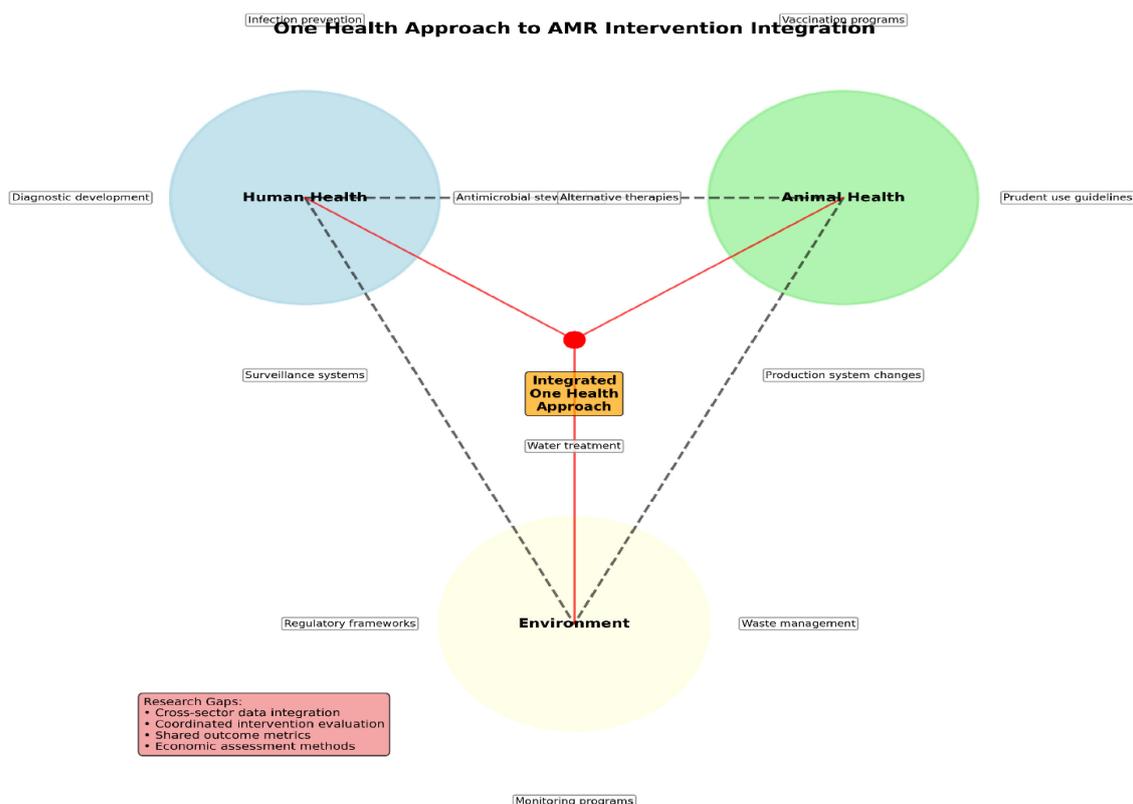
**System requirements:** Programs for IPC training (39), sufficient numbers of employees, enhancements to the infrastructure, and mechanisms for ensuring quality.

## Laboratory capacity and diagnostic challenges

### Current laboratory infrastructure

Pakistan's laboratory capability for clinical management and AMR surveillance is still insufficient:

**Limitations on capacity:** A small number of authorized labs, inadequate supplies and equipment, a lack of



**FIGURE 2 |** One Health approach to AMR intervention integration. The link of the human, animal, and environmental health sectors in AMR prevention and control is shown in this picture, which also spotlights the importance of coordinated efforts across all three domains and how interventions in one can affect the others.

technological know-how, and inadequate programs for quality assurance (40).

**Geographical differences:** Concentration in cities, restricted access to laboratories in remote places, difficulties with transportation, and barriers to communication.

## Gaps in diagnostic technology

Modern diagnostic technology access is still restricted, which has an impact on clinical care and surveillance:

**Needs for technology:** Systems for automated susceptibility testing, quick diagnostic tools, capabilities for molecular diagnostics, and options for point-of-care testing.

**Execution challenges:** Expensive equipment and requirements for maintenance and requires training the supply chains for reagents.

## Quality assurance and standardization

There must be methodical changes made to Pakistan's laboratory network to guarantee quality and uniformity:

**Measures of quality:** Programs for external quality

assessment, standardized protocols for operations, participation in proficiency testing, and procedures for accreditation.

**Capacity developing requirements:** Programs for technical training, support for equipment maintenance, systems for managing quality, and capabilities for data management.

## Future strategies and recommendations

### Strengthening surveillance systems

Effective AMR response requires a comprehensive strengthening of the surveillance system:

**Priority tasks:** Increase participation in GLASS, create national guidelines for surveillance, and combine data from the public and private sectors and create regional networks for surveillance.

**Integration of technology:** Electronic medical records, information systems for laboratories and platforms for sharing data in real time, and mechanisms for automated reporting.

## Policy and regulatory reforms

To effectively combat AMR, significant legislative and regulatory changes are required:

**Priorities for legislation:** Antimicrobials are only available with a prescription, veterinary antibiotic laws, requirements for quality control, and enhancement of penalties for infractions.

**Mechanisms of implementation:** Platforms for interagency coordination, systems for monitoring and evaluating performance, procedures for engaging stakeholders, and tactics for mobilizing resources.

## Capacity building and education

For a sustainable AMR response, comprehensive capacity building in all sectors is essential:

**Healthcare workforce:** Training in antimicrobial stewardship, education on infection prevention, and capacity building for laboratories' ongoing professional growth.

**Education of the Public:** Campaigns for community awareness, programs for education in schools, strategies for engaging the media, and interventions for behavior change.

## Priorities for research and innovation

Research and innovation are essential for developing context-appropriate solutions:

**Priority research areas:** – Economic impact assessments – Implementation research on stewardship interventions (41).

**Innovation needs:** – Rapid diagnostic development – Novel therapeutic approaches – Digital health solutions – Implementation tools and resources.

## International collaboration and support

### Global partnerships

International cooperation and assistance are beneficial to Pakistan's AMR response:

**Important collaborations:** WHO technical support, financed by the World Bank Agreements for bilateral cooperation, and collaborations in academic research.

**Areas of support:** Building technical competence and providing financial support, sharing of knowledge, and transfer of technology.

## Collaboration in the region

In South Asia, regional collaboration is crucial to tackling cross-border AMR issues:

**Cooperation prospects:** Coordinated regulatory standards and shared surveillance systems and coordinated policy responses and collaborative research projects.

**Regional difficulties:** Tensions in politics, inequalities in income, disparities in regulations, and inadequate institutional capability.

## Results

Antimicrobial resistance (AMR) rates have significantly increased globally, and in Pakistan specifically, according to the analysis's findings for the years 2020–2025. Majorly two resistances are increased, which are fluoroquinolone and third-generation cephalosporin resistance. In Pakistan, a major variety of bacterial infections, such as *K. pneumoniae* and *E. coli*, show resistance to these antibiotics.

## Discussion

The AMR is particularly increasing in Pakistan; it shows concerns for the urgent need for comprehensive strategies that incorporate the One Health paradigm, surveillance, and responsible antibiotic use. The One Health shows the interconnected health problems that impact humans, animals, and the environment, which is a synergistic approach to AMR control. The socioeconomic and healthcare problems in Pakistan, such as the more use of antibiotics and inadequate diagnostic facilities lead to a higher mortality rate. The lab networks and resources should be strengthened, and the protocol of hygiene and sanitization should be maintained to overcome the AMR initially.

## Conclusions

The prevalence rate of AMR in Pakistan is higher than the global average for several pathogen-antibiotic combinations, which presents an important and growing public health risk. Several important conclusions are drawn from the analysis:

- **Escalating burden:** Pakistan is facing an increasing AMR burden that is in line with global trends, but regional challenges are exacerbated by limitations in the healthcare and socioeconomic systems.
- **Surveillance gaps:** The significant gaps in surveillance coverage and data quality make it challenging to effectively track trends and guide responses.

- **Implementation challenges:** Despite having a NAP, there are several challenges to its implementation, including inadequate funding, a lack of coordination, and a lack of enforcement of regulations.
- **Economic impact:** AMR has a significant and increasing financial burden, and without effective action, forecasts show dire repercussions for Pakistan's healthcare system and economy.
- **Multisectoral nature:** The One Health approach tackles the environmental, animal, and human elements that affect the spread of resistance and is required to combat AMR in Pakistan.

To counter the rising tide of resistance, antimicrobial stewardship programs, improved surveillance systems, and legislative reforms must be implemented immediately. For Pakistan's public health security, prompt, coordinated intervention is essential because the window for effective action is closing.

## Future research directions

Several areas warrant priority attention for future research in Pakistan:

- **Economic modelling:** The creation of thorough economic models that account for direct medical expenses, lost productivity, and wider economic effects in order to fully assess the burden of AMR.
- **Implementation research:** Studies on practical, affordable stewardship initiatives tailored to environments with limited resources.
- **One health surveillance:** Extensive surveillance studies that look at the intersection of environmental reservoirs and food chain contamination with human, animal, and environmental resistance.
- **Social and behavioral research:** To guide focused treatments, it is important to comprehend patient expectations, prescribing practices, and cultural elements affecting antibiotic use.
- **Diagnostic innovation:** Creation and assessment of quick, reasonably priced diagnostic instruments appropriate for Pakistani medical environments.
- **Policy research:** Assessing the application of policies and regulatory actions to determine the best governance strategies.

## Author contributions

AA: Conceptualization, Data collection, Meta-analysis, Writing – original draft. SR: Literature review, Methodology refinement, Writing – review and editing. Both authors: Review and approval of the final version, Accountability for all aspects of the work.

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## Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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