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Assessment of Antimicrobial Resistance Patterns in Hospital-Acquired Bacterial Infections: Implications for Clinical Treatment Strategies

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Abstract

Background: Hospital-acquired infections (HAIs) caused by multidrug-resistant bacteria are a leading threat to patient safety, particularly in intensive care units (ICUs). India carries one of the heaviest burdens of antimicrobial resistance (AMR) in the world.

Methods: A structured secondary analysis was performed using national surveillance data from the Indian Council of Medical Research Antimicrobial Resistance Research and Surveillance Network (ICMR-AMRSN) annual reports (2017–2024), the WHO Global Antibiotic Resistance Surveillance Report 2025 (GLASS), and the Global Research on Antimicrobial Resistance (GRAM) burden estimates published in The Lancet (2024). Trends in susceptibility of the major nosocomial pathogens were extracted and compared.

Results: Imipenem susceptibility in Klebsiella pneumoniae fell from 58.5% in 2017 to 31.2% in 2024, and in Escherichia coli from 81.4% to 57.6%. Imipenem resistance in Pseudomonas aeruginosa rose from 26% to 43%, while 88% of Acinetobacter baumannii isolates were carbapenem-resistant in 2023. Globally, one in six laboratory-confirmed infections was resistant in 2023, rising to about one in three in the South-East Asia Region. Deaths attributable to AMR are forecast to increase from 1.14 million in 2021 to 1.91 million in 2050.

Conclusion: Carbapenems can no longer be assumed reliable for empirical therapy of serious HAIs in Indian hospitals. Treatment should be guided by local antibiograms, rapid carbapenemase detection, newer β-lactam/β-lactamase inhibitor combinations, and strong stewardship and infection-control programmes.

Keywords: antimicrobial resistance, hospital-acquired infection, carbapenem resistance, Klebsiella pneumoniae, Acinetobacter baumannii, antimicrobial stewardship

Introduction

Hospital-acquired infections, also called nosocomial or healthcare-associated infections, are infections that develop 48 hours or more after admission and were not incubating at the time of admission. The most common types are ventilator-associated pneumonia (VAP), catheter-associated urinary tract infection (CAUTI), central line-associated bloodstream infection (CLABSI) and surgical site infection (SSI). These infections lengthen hospital stay, raise treatment costs and carry high mortality, especially among critically ill patients.

The problem is made far worse by antimicrobial resistance. Most serious HAIs are caused by a small group of organisms often called the ESKAPE pathogens: Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa and Enterobacter species. These organisms readily acquire resistance genes such as extended-spectrum β-lactamases (ESBLs) and carbapenemases (KPC, NDM, OXA-48-like), and they persist on hospital surfaces and equipment, which allows them to spread between patients.

The global scale of the problem is now well documented. The GRAM study[5] estimated that 4.71 million deaths in 2021 were associated with bacterial AMR, of which 1.14 million were directly attributable to it, and that South Asia will see the highest number of AMR-attributable deaths, about 11.8 million, between 2025 and 2050. India therefore sits at the centre of the crisis. Carbapenems, long treated as the last dependable option for severe Gram-negative infections, are losing activity, which forces clinicians toward costlier, more toxic or less available agents.

The aim of this paper is to (i) assess current resistance patterns among the key pathogens responsible for HAIs, using national and global surveillance data; (ii) describe how these patterns have changed over time; and (iii) outline the implications for empirical and definitive treatment strategies in hospitals.

Materials and Methods

Study design and data sources

This study is a structured secondary analysis of publicly available surveillance data. Three sources were used:

- **ICMR-AMRSN annual reports (2017–2024)**[1–3]**:** laboratory-based surveillance across tertiary-care hospitals in India covering isolates from blood, urine, respiratory and other specimens collected in outpatient departments, wards and ICUs. The 2023 report analysed data from a network of 39 hospitals.
- **WHO GLASS Report 2025**[4]**:** resistance estimates based on more than 23 million bacteriologically confirmed infections from 104 countries, covering 22 antibiotics and eight bacterial pathogens.
- **GRAM study (The Lancet, 2024)**[5]**:** modelled estimates of AMR deaths in 204 countries from 1990 to 2021, with forecasts to 2050, based on 520 million individual records or isolates.

Pathogens and antibiotics assessed

The analysis focused on E. coli, K. pneumoniae, P. aeruginosa, A. baumannii and S. aureus, as these are the most frequent causes of HAIs in Indian surveillance data. Antibiotics of interest were the carbapenems (imipenem, meropenem), piperacillin-tazobactam, third-generation cephalosporins (cefotaxime, ceftazidime) and amikacin, because these form the backbone of empirical therapy for serious hospital infections.

Data extraction and analysis

Percentage susceptibility or resistance values were extracted for the baseline year (2017), 2023 and the most recent available year (2024). Absolute change in percentage points was calculated as the later value minus the 2017 value. Results were tabulated and plotted using Python (matplotlib). Because the data are aggregated and publicly available, ethical approval was not required.

Results

Pathogen distribution

Across ICMR-AMRSN data, E. coli was the most frequently isolated pathogen overall, followed by K. pneumoniae, P. aeruginosa, A. baumannii and S. aureus. In ICU settings, A. baumannii was the most common isolate, and Acinetobacter species were the leading cause of ventilator-associated pneumonia in the 2023 report[2]. A seven-year single-centre AMRSN study from North India (2018–2024)[8] found a similar pattern: Gram-negative bacteria made up 80.3% of isolates, and A. baumannii accounted for 41.9% of ICU isolates.

Resistance in Enterobacterales

Table 1 shows that susceptibility of both E. coli and K. pneumoniae to carbapenems has fallen steeply. In K. pneumoniae, only about one in three isolates remained susceptible to imipenem in 2024, a fall of 27.3 percentage points since 2017. Piperacillin-tazobactam susceptibility in K. pneumoniae dropped to 26.0%. Third-generation cephalosporins are effectively lost for empirical use, with susceptibility of roughly 20% or less in both species. Some agents showed a slight recovery between 2023 and 2024 (for example, E. coli amikacin rose from 68.2% to 72.5%), but carbapenem susceptibility continued to decline (Figure 1).

Table 1: Antibiotic susceptibility (%) of E. coli and K. pneumoniae in India, ICMR-AMRSN

Organism	Antibiotic	2017	2023	2024	Change 2017→2024
E. coli	Imipenem	81.4	62.7	57.6	−23.8
E. coli	Meropenem	73.2	66.0	62.9	−10.3
E. coli	Piperacillin-tazobactam	56.8	42.4	NR	−14.4*
E. coli	Amikacin	79.2	68.2	72.5	−6.7
E. coli	Ceftazidime	NR	19.2	27.5	—
K. pneumoniae	Imipenem	58.5	35.6	31.2	−27.3
K. pneumoniae	Meropenem	48.1	37.6	35.1	−13.0
K. pneumoniae	Piperacillin-tazobactam	42.6	26.5	26.0	−16.6
K. pneumoniae	Cefotaxime	NR	17.3	20.3	—
K. pneumoniae	Amikacin	NR	34.5	39.9	—

*Source: ICMR-AMRSN Annual Reports 2023 and 2024. NR = not reported in the summary data; *change 2017→2023.*

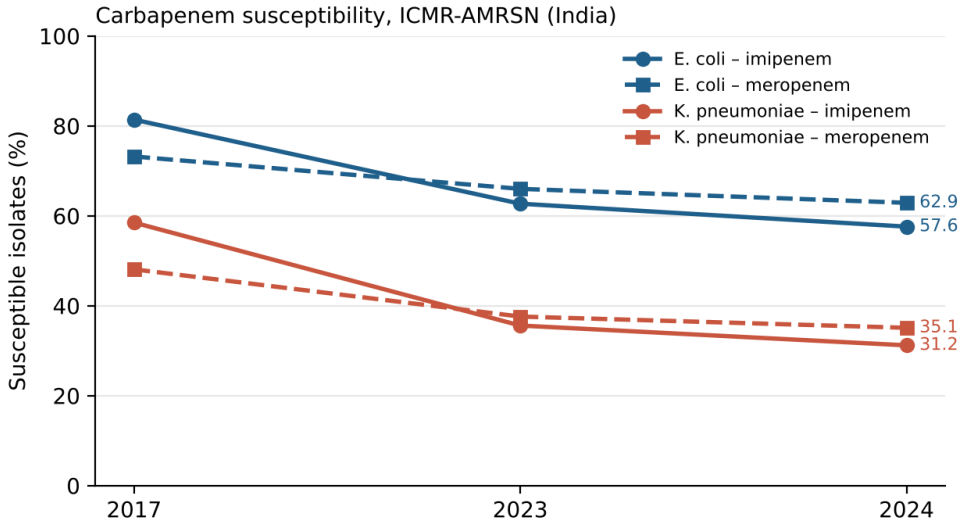


Fig 1: Decline in carbapenem susceptibility of E. coli and K. pneumoniae, 2017–2024 (x-axis shows reported years; intervals are not uniform). Data: ICMR-AMRSN.

Resistance in non-fermenting Gram-negative bacilli

Non-fermenters showed the most alarming patterns (Table 2, Figure 2). Imipenem resistance in P. aeruginosa rose steadily from 26% in 2017 to 43% in 2024, and meropenem resistance from 31.3% to 38%. Ciprofloxacin susceptibility in P. aeruginosa, by contrast, has stayed close to 57%, indicating relatively stable fluoroquinolone activity. A. baumannii was the most resistant organism in the

network, with 88% of isolates resistant to carbapenems in 2023 and the highest resistance seen in ICU patients.

Table 2: Carbapenem resistance (%) in non-fermenting Gram-negative bacteria, ICMR-AMRSN

Organism	Antibiotic	2017	2023	2024
P. aeruginosa	Imipenem (resistant)	26.0	38.5	43.0
P. aeruginosa	Meropenem (resistant)	31.3	34.5	38.0
P. aeruginosa	Ciprofloxacin (susceptible)	57.8	NR	57.0
A. baumannii	Carbapenems (resistant)	NR	88.0	NR

Source: ICMR-AMRSN Annual Reports 2023 and 2024; A. baumannii figure as reported for 2023 by ICMR.

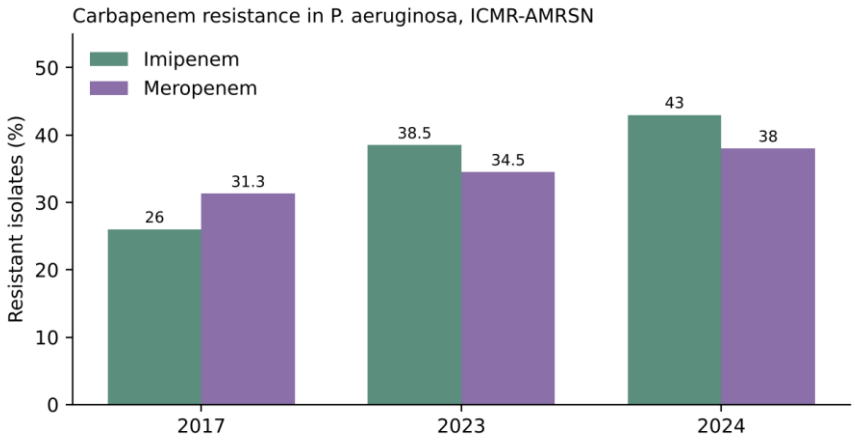


Fig 2: Rising carbapenem resistance in Pseudomonas aeruginosa in Indian hospitals, 2017–2024. Data: ICMR-AMRSN.

Gram-positive pathogens

Among Gram-positive organisms, S. aureus and particularly MRSA showed poor susceptibility to commonly used oral agents. In the 2022 ICMR report[3], erythromycin susceptibility was 38.6% in S. aureus and 23.9% in MRSA, and ciprofloxacin susceptibility was 21.5% and 12.8% respectively. Linezolid and vancomycin remained broadly active, and ICMR recommends reserving linezolid for situations where it is genuinely needed.

Global context

The WHO GLASS 2025 report[4] found that 17.2% (about one in six) of laboratory-confirmed bacterial infections worldwide in 2023 were resistant to antibiotic treatment. Between 2018 and 2023, resistance rose in more than 40% of the pathogen–antibiotic combinations monitored, with an average annual increase of 5–15%. The South-East Asia Region, which includes India, had the highest burden together with the Eastern Mediterranean Region (Table 3, Figure 3).

Table 3: Share of laboratory-confirmed bacterial infections resistant to antibiotics, by WHO region (2023)

WHO region	Approximate proportion resistant	Expressed as %
South-East Asia	About 1 in 3	≈33
Eastern Mediterranean	About 1 in 3	≈33
Africa	About 1 in 5	≈20
Global average	About 1 in 6	17.2
Western Pacific	About 1 in 11	≈9

Source: WHO Global Antibiotic Resistance Surveillance Report 2025 (GLASS).

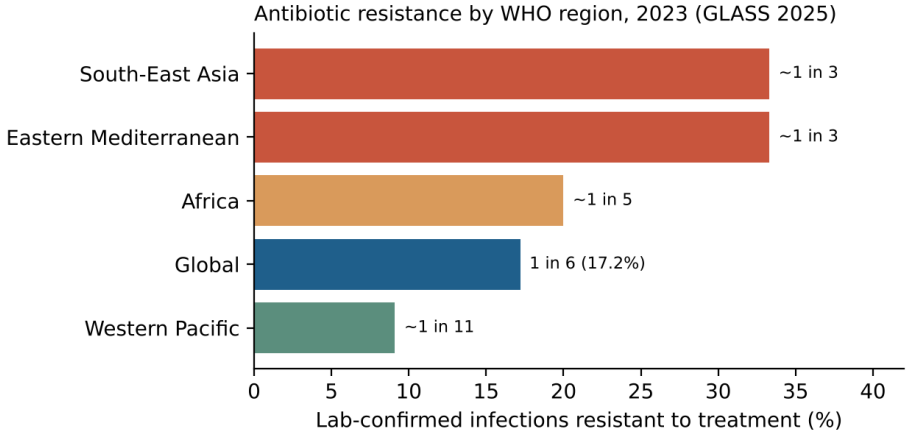


Fig 3: Proportion of laboratory-confirmed infections resistant to antibiotic treatment by WHO region, 2023. Data: WHO GLASS 2025.

The GRAM study[5,6] shows that the mortality burden is also rising (Table 4, Figure 4). AMR directly caused more than one million deaths every year between 1990 and 2021. By 2050, attributable deaths are forecast to reach 1.91 million a year (a 67.5% increase over 2021), and associated deaths 8.22 million a year. Cumulatively, about 39 million deaths are expected to be directly caused by AMR between 2025 and 2050.

Table 4: Global deaths from bacterial antimicrobial resistance (millions per year)

Year	Deaths attributable to AMR	Deaths associated with AMR
1990	1.06	4.78
2019	1.27	4.95
2021	1.14	4.71
2050 (forecast)	1.91	8.22

Source: GRAM Collaborators, The Lancet 2024. The fall from 2019 to 2021 is attributed to COVID-19 era reductions in other respiratory infections.

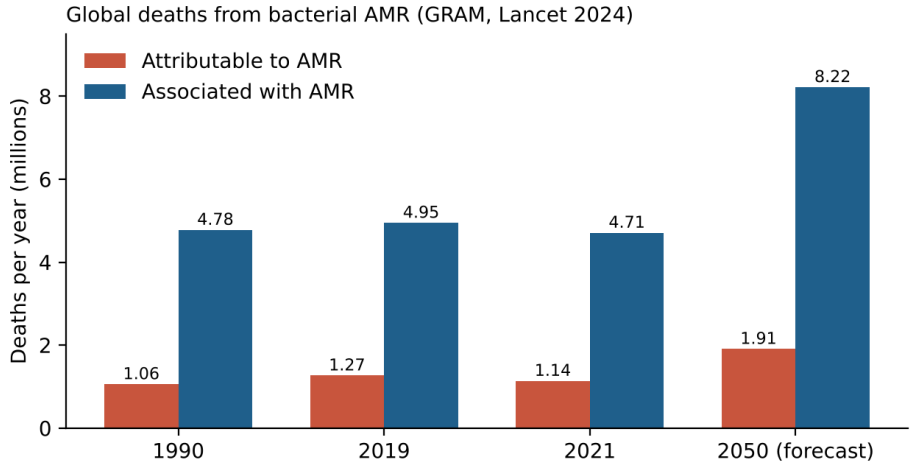


Fig 4: Global deaths attributable to and associated with bacterial AMR, 1990–2050. Data: GRAM, The Lancet 2024.

Discussion

The findings confirm a sustained, multi-year erosion of antibiotic activity against the organisms that cause most hospital-acquired infections in India. Three points stand out.

First, carbapenem resistance is now mainstream rather than exceptional. With fewer than 40% of K. pneumoniae isolates and only about 12% of A. baumannii isolates susceptible to carbapenems, a carbapenem given empirically to a septic ICU patient will often be ineffective. Delayed effective therapy in sepsis is strongly linked to higher mortality, so this trend has direct consequences for survival.

Second, resistance is concentrated in hospitals. ICMR data consistently show lower susceptibility in inpatient and ICU isolates than in outpatient isolates, and an ICMR-linked study found that carbapenem resistance in hospital-acquired Klebsiella and Acinetobacter infections appeared before it was seen in community infections. This supports the view that hospitals, through heavy antibiotic use, invasive devices and cross-transmission, act as amplifiers of resistance.

Third, India's resistance mechanisms shape treatment choices. Metallo-β-lactamases, especially NDM, and OXA-48-like enzymes are common in Indian Enterobacterales. This matters because some newer agents, such as ceftazidime-avibactam used alone, are not active against metallo-β-lactamase producers. Knowing the carbapenemase type is therefore as important as knowing whether an isolate is carbapenem-resistant.

Implications for clinical treatment strategies

Based on these resistance patterns and current international guidance (Infectious Diseases Society of America, 2024)[7], the following approaches are recommended. Table 5 summarises pathogen-specific options; final choices should always follow local antibiograms, susceptibility results and specialist advice.

Table 5: Suggested treatment options for major resistant hospital pathogens

Resistant pathogen	Preferred options	Key considerations
ESBL-producing Enterobacterales	Meropenem or ertapenem (serious infection)	Avoid piperacillin-tazobactam for bloodstream infection
CRE – KPC / OXA-48	Ceftazidime-avibactam; meropenem-vaborbactam*	Meropenem-vaborbactam not active against OXA-48
CRE – NDM (metallo-β-lactamase)	Ceftazidime-avibactam + aztreonam; cefiderocol	Rapid test for carbapenemase type is essential
Difficult-to-treat P. aeruginosa	Ceftolozane-tazobactam; ceftazidime-avibactam; cefiderocol	Choose by susceptibility testing
Carbapenem-resistant A. baumannii	Sulbactam-durlobactam + carbapenem; high-dose ampicillin-sulbactam combinations	Colistin only as part of combination when no alternative
MRSA	Vancomycin; linezolid; daptomycin (not for pneumonia)	Reserve linezolid; monitor vancomycin levels

*Adapted from IDSA 2024 guidance on antimicrobial-resistant Gram-negative infections and standard MRSA guidance. *Availability varies in India.*

Beyond drug selection, several system-level strategies are needed:

- **Local antibiograms for empirical therapy:** each hospital, and ideally each ICU, should publish a yearly antibiogram so that empirical regimens match local resistance rather than national averages.
- **Rapid diagnostics:** molecular or immunochromatographic tests that identify carbapenemase genes (KPC, NDM, OXA-48) within hours allow early switching to the right agent.
- **Antimicrobial stewardship:** prospective audit and feedback, de-escalation within 48–72 hours, shorter evidence-based durations, and prioritising WHO AWaRe Access antibiotics[9]. GLASS[4] reports that Access antibiotics are only about half of global use, well short of the 70% target for 2030.
- **Infection prevention and control:** hand hygiene, device care bundles for VAP, CLABSI and CAUTI, contact precautions, environmental cleaning and active screening for carbapenem-resistant organisms in high-risk units.
- **Prevention and new drugs:** GRAM[5] estimates that developing new drugs against Gram-negative bacteria could avert about 11 million AMR deaths between 2025 and 2050, while better infection care and antibiotic access could avert far more.

Limitations

This analysis relies on aggregated surveillance data, mainly from tertiary-care centres, which may over-represent severe and referred cases. Surveillance networks also report HAIs together with community infections in some datasets, and laboratory methods and participating centres change over time. Regional percentages from GLASS are approximate and reflect variable reporting quality between countries. Patient-level outcomes such as mortality by resistance type could not be assessed.

Conclusion

Antimicrobial resistance in hospital-acquired bacterial infections in India has reached a level where carbapenems can no longer be relied upon for empirical treatment, particularly in ICUs. K. pneumoniae and A. baumannii are the most concerning organisms, and P. aeruginosa resistance continues to climb. Effective treatment now depends on rapid identification of resistance mechanisms, careful use of newer agents, strong stewardship, and rigorous infection control. Sustained national surveillance and investment in new antibiotics remain essential to prevent the projected rise in AMR deaths.

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