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The Effectiveness of a Hospital-Based Antimicrobial Stewardship Program: A Three-Year Observational Study

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Highlights of the Study

- Evaluation in a tertiary care hospital assessed the consumption of antibiotics, prescribing compliance, infection control, resistance trends, and clinical outcomes.
- Multidisciplinary stewardship program improved antibiotic use, reduced resistance, and strengthened infection control.
- Process and outcome indicators demonstrated improvements, most of which were not statistically significant, and there is scope to further optimize prophylaxis duration and post-discharge care.

Keywords
Antimicrobial resistance · Antimicrobial Stewardship Program · Multidisciplinary intervention · Antibiotic consumption · Resistance surveillance · Low- and middle-income countries · Defined daily dose · Infection control

Abstract

Objective: The aim of the study was to evaluate the impact of a policy-driven Antimicrobial Stewardship Program (AMSP) on antibiotic consumption, prescribing compliance, infection control, resistance trends, and clinical outcomes in a tertiary care hospital in India over a 3-year period. ***Subject and Methods:*** A retrospective cross-sectional study compared pre-AMS (nurse-led) and post-AMS (multidisciplinary) phases (2022–2025). Indicators included antibiotic use, defined daily doses (DDD), days of therapy (DOT), policy compliance, resistance rates, and clinical outcomes. Statistical significance was set at $p < 0.05$. ***Results:*** Overall antibiotic use decreased, with DDD/1,000 patient-days declining from 2,599.3 to 2,413.3 with $p = 0.974 > 0.05$ and DOT from 1,474.4 to 1,394.6 with $p = 0.991 > 0.05$. Policy compliance rose marginally (78%–80%; $p = 0.412$) but declined in the second post-AMS year. De-escalation improved initially (46%–80.3%) but later dropped to 65.2%. Surgical prophylaxis agent selection improved (88%–94%; $p = 0.044$), while duration adherence remained low. Resistance rates for vancomycin-resistant *Enterococcus* and CRE decreased

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(44%–26% and 47%–42%, respectively) without statistical significance. Standardized mortality ratio (SMR) declined (1.28–0.62; $p < 0.001$), but all-cause mortality slightly increased (3.54%–3.63%). Readmissions (60.7–126.5/1,000 discharges) and intensive care unit (ICU) transfers (0.319–0.381/1,000 admissions) rose post-AMS. ***Conclusion:*** AMSP implementation was associated with process improvements and favourable trends in resistance and SMR, but most changes were not statistically significant. Increased readmissions, ICU transfers, and inconsistent compliance highlight the need for sustained interventions and patient-level risk adjustment.

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Introduction

Antimicrobial resistance (AMR) is one of the world's most pressing health concerns, fuelled mainly by the indiscriminate and abusive use of antibiotics both in the clinical and community settings [1]. The World Health Organization (WHO) has also termed AMR as among the greatest global health threats. It is estimated that by 2050, 10 million annual deaths could occur if current trends are left to progress [2]. Due to this pending crisis, antimicrobial stewardship (AMS) has been advocated on a global scale as the main strategy to minimize antimicrobial use [3]. AMS refers to coordinated interventions that guarantee the use of the right antimicrobial agent, dose, route, and duration and thereby reduce toxicity and side effects and optimize clinical outcomes [4]. In hospitals, Antimicrobial Stewardship Programs (AMSPs) have been utilized to dampen off-label prescribing, slow down resistance, and maintain guideline use [5]. The Centers for Disease Control and Prevention (CDC) estimates that US-based hospitals utilize approximately 30% antibiotics that are unnecessary, with direct implications towards the development of resistant pathogens [6].

An effective AMSP implementation generally involves a multidisciplinary team. It incorporates both front-end strategies, including formulary restriction and prior authorization, as well as back-end strategies such as prospective audit and feedback (PAF) and Pathogen-Directed Therapy (PD-AMSP) [7]. Both clinical and microbiological observations are paramount when assessing the efficacy of AMSP [8]. Process measures like hospital antibiotic policy compliance, timing and selection of surgical antimicrobial prophylaxis (SAP), diagnostic stewardship, and compliance with central line (CL) or ventilator (VT) bundle are most often used for measuring AMS implementation [9]. Outcome indicators are antibiotic use, expressed in the form of defined daily dose (DDD) or days of therapy (DOT) per 1,000 patient-days, priority pathogen resistance patterns, standardized mortality ratio (SMR), and 30-day readmission [10].

Extended improvements in AMSP are documented in high-income countries alone, whereas surveillance data from low- and middle-income countries (LMICs) like India are scarce because of a deficiency of organized surveillance systems, uneven hospital infrastructure, and absence of digital stewardship tools [11]. In India, institutional compliance and outcome reporting are variable in the face of attempts by the Indian Council of Medical Research (ICMR) and National Action Plan on AMR to provide stewardship [12]. Second, AI-facilitated platforms for real-time audit, monitoring of policy compliance, and microbiological surveillance are a new area of interest in LMICs [13].

Although AMSPs have shown success in numerous environments, their success is not always guaranteed. Implementation in low-resource settings frequently encounters obstacles; resource constraints, variability in compliance, and absence of robust surveillance can impact their effectiveness [14]. Cultural and behavioural issues such as prescriber behaviour and hierarchical clinical structures can also impede adherence [15]. Variability in baseline resistance patterns as well as fragmented healthcare systems may also influence the generalizability of outcomes [16]. These considerations highlight the importance of context-specific approaches in replicating similar programs elsewhere.

Addressing this, the present study was carried out to evaluate the real-life implementation of a policy-designed AMSP in an Indian tertiary teaching care hospital. To be more precise, the present study compares process and outcome measures along a 3-year timescale, with a nurse-led pre-AMS period and a multidisciplinary team-led post-AMS period. The results seek to present evidence on the clinical and microbiological outcomes of stewardship interventions within resource-constrained hospital environments and on the broader activity of AMR containment in LMICs.

Methods

Study Design and Setting

This retrospective cross-sectional study was conducted in the Department of Microbiology and Infection Control at a tertiary care hospital in eastern India, covering a period from June 2022 to May 2025. The

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study was divided into two phases. The pre-AMS phase (June 2022 to May 2023) reflected a nurse-led antimicrobial stewardship approach aligned with the International Council of Nurses (ICN) standards. The post-AMS phase (June 2023 to May 2025) marked the implementation of a policy-driven AMSP coordinated by a multidisciplinary institutional AMS team. This team employed structured stewardship rounds, PAF, and pathogen-directed AMS (PD-AMS) as core intervention strategies. The Ethical clearance was obtained from the Institutional Ethical Committee (PHH&RCLCREC/4402/2024). Only anonymized programmatic data were used, and no direct patient interaction occurred.

Patient Selection and Data Collection

The study included all patients who had received antibiotics for 24 h or more with a suspicion of infection, regardless of the site of infection. Patients were excluded if they had been on antibiotics for less than 24 h, had a history of exposure to multiple antibiotics, had been hospitalized within the last 30 days, or had multidrug-resistant (MDR) organisms detected from body site in the past 30 days.

Supplementary Figure 1 (for all online suppl. material, see https://doi.org/10.1159/000549754) illustrates the patient selection process. Of 2,500 records screened, 2,183 met inclusion criteria (605 in pre-AMS and 1,578 in post-AMS phases) after excluding patients without antibiotic exposure (n = 221) and those with <24 h of antibiotic use (n = 96). All patients who received antibiotics during the study period were evaluated under two stewardship strategies. The PAF approach was applied during daily AMS ward rounds, where the AMS team reviewed empirical antibiotic prescriptions and provided immediate feedback – either verbally or in writing – to the treating clinicians [17]. The PD-AMS approach was focused on patients with culture-proven infections. Microbiologists reviewed culture results and offered patient-specific, evidence-based antibiotic recommendations either at the bedside or via telephone. Follow-up assessments were conducted to measure compliance with AMS recommendations. Clinical data including demographics, infection site, diagnosis, empirical or definitive antibiotic therapy, stewardship interventions, and rationale for restriction were collected using structured forms. Antibiotic consumption, care bundle, hand hygiene compliance, and AMR data were recorded within the Ibhar platform, an AI-powered application used to support AMS decision-making [18]. Patient records were de-identified by hospital data confidentiality protocols. The accuracy of data within the Ibhar platform was ensured through a combination of automated integration, in-built validation rules, and manual confirmation steps.

Microbiology Data

Demographic and disk diffusion data were imported directly from the Laboratory Module in the Hospital Management Information System (HMIS). Additionally, data from microbiology equipment have provision for transfer through the Vitek API, minimizing manual data entry errors. The Ibhar platform incorporates over 30 in-built rules to identify suspicious antimicrobial susceptibility testing (AST) results and more than 100 validation rules applied to datasets used for antibiogram generation and MDR organism analysis. Any AST data flagged as an exception required on-screen verification and confirmation prior to inclusion in analytical datasets. The Ibhar Clinical Microbiology (CMR) platform has been validated using data from over 100 hospitals across India, with the WHO, India Office, serving as the technical partner and JIPMER Medical University as the nodal agency.

Infection Prevention and Control Data

For Infection Prevention and Control (IPC) surveillance, data were entered via point-of-care mobile applications capturing direct observations such as hand hygiene practices and device- or symptom-based criteria. Healthcare-acquired infection (HAI) algorithms within the platform combined these observations with diagnostic results, including culture and other relevant laboratory tests. Identified cases and associated data were manually reviewed and confirmed on-screen by authorized IPC personnel before final acceptance for analysis.

AMS Intervention Process

The AMSP incorporated both front-end and back-end stewardship strategies. Front-end strategies included formulary restriction and preauthorization before antibiotic initiation. Back-end strategies involved therapy optimization after prescription, including dose adjustment, escalation or de-escalation, spectrum narrowing, intravenous-to-oral switch, and discontinuation of inappropriate or duplicate therapy [17]. Interventions were classified by the type of antibiotic use: prophylactic, empirical, and targeted. Diagnostic stewardship was evaluated by measuring the proportion of blood and site-specific cultures collected before antibiotic initiation. Adherence to SAP was assessed based on compliance with institutional guidelines regarding agent selection, timing, and duration.

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Process Indicators

Key process indicators included antibiotic consumption, measured using DDD and DOT per 1,000 patient-days. Additional indicators included compliance with the hospital's antibiotic policy, rates of escalation, de-escalation, spectrum adjustment, and compliance with SAP protocols. Infection control process metrics were assessed through adherence to CL, urinary catheter, and VT bundles, as well as hand hygiene compliance. Indicators were calculated using standard numerator-denominator methods and are further defined in online supplementary Table A1.

Outcome Indicators

Clinical outcome indicators included all-cause mortality, mortality associated with HAIs, average length of hospital stay, and the SMR. Microbiological outcomes included resistance patterns for MDR, extensively drug-resistant (XDR), and pan-drug-resistant (PDR) organisms, *Clostridioides difficile* infection (CDI) rate, and overall, HAI rate. Full indicator definitions are presented in online supplementary Table A2.

Statistical Analysis

Continuous variables were presented as medians with interquartile ranges, and categorical variables were reported as frequencies and percentages. Outcome indicators were stratified by study phase (pre-AMS vs. post-AMS) to assess changes in stewardship compliance, infection control practices, and resistance trends. The chi-square test or Fisher's exact test was used for categorical variables, and the Mann-Whitney U test was applied for non-normally distributed continuous variables. A two-tailed p value <0.05 was considered statistically significant. Data were analysed using Microsoft Excel and R version 3.3.2 (R Foundation for Statistical Computing). No adjustment for confounders (e.g., patient severity, intensive care unit [ICU] admission) was possible due to lack of patient-level data.

Results

Antibiotic Consumption Trends

Overall, antibiotic use demonstrated a steady decline across the 3-years, reflecting successful antimicrobial stewardship (AMS) implementation. The DDD per 1,000 patient-days decreased from 2,599.3 in the pre-AMS phase (2022–2023) to 2,413.3 in post-AMS year 2 (2024–2025), indicating a 7.1% reduction in antibiotic consumption (Table 1, online suppl. Fig. 2). Restricted antibiotics similarly showed a DDD decline from 1,094.2 to 980.7. Notably, the usage of linezolid, vancomycin, imipenem, ertapenem, minocycline, polymyxin B, and tigecycline decreased, while meropenem and teicoplanin usage increased, possibly reflecting a shift in empirical prescribing and case severity (online suppl. Fig. 2). The mild reduction in overall DDD was found to be insignificant ($p = 0.955 > 0.05$, eta-squared = 0.019).

DOT per 1,000 patient-days for overall antibiotics also fell from 1,474.4 to 1,394.6 during the same time period, indicating reduced patient exposure to antimicrobials. The use of restricted antibiotics decreased from 578.7 to 570.5 DOT/1,000 patient-days. DOT increased for colistin, meropenem, and teicoplanin, while it decreased for ertapenem, fosfomycin, imipenem, linezolid, minocycline, polymyxin B, tigecycline, and vancomycin. These shifts suggest optimized antimicrobial selection and duration guided by the AMS team (Table 1).

AMS Interventions and Policy Adherence

Post-AMS implementation, adherence to the hospital antibiotic policy, although improved marginally in the early post-AMS phase (June 2023 to May 2024), rose from 78% to 80%; however, it was not statistically significant ($p = 0.412$, eta-squared = 0.007). Audit data showed the highest compliance with "continue empirical therapy advice" (96.9%) and spectrum adjustment interventions (100%) in 2024–2025. De-escalation compliance rose from 46% (nurse-led AMS, 2022–23) to 80.3% in the early post-AMS period (2023–24), but then declined to 65.2% the following year, indicating ongoing challenges in narrowing therapy despite microbiological evidence (online suppl. Fig. 3). Among de-escalation strategies, the highest adherence was noted for removal of overlapping antibiotics (69.6%), redundant combinations (67.8%), and spectrum narrowing (66.7%) (Table 1).

Infection Control Indicators

Infection prevention efforts demonstrated substantial gains. SAP agent selection compliance improved from 88% to 94% ($p = 0.044$, eta-squared = 0.129), while duration compliance remained low 57%–51% ($p = 0.705$, eta-squared = 0.039), highlighting an area for focused improvement (Table 1).

CL care bundle compliance markedly improved, with documentation of "readiness to remove" reaching 99.4% and "alcohol hub decontamination" increasing from 80.3% to 98.9% (online suppl. Fig. 4). For urinary catheter bundles, peak compliance was seen in "closed

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Table 1. Three-year comparative analysis of antimicrobial stewardship interventions: utilization metrics, compliance rates, and clinical outcomes in a tertiary care setting (2022–2025)

Indicator/parameter	Antibiotic/metric	2022–2023 (pre-AMS)	2023–2024 (post-AMS year 1)	2024–2025 (post-AMS year 2)	Interpretation/trend
DDD/1,000 – overall antibiotics	–	2,599.3	2,399.3	2,413.3	Reflects reduced overall antibiotic consumption; improved AMS across department
DDD/1,000 – restricted antibiotics	Linezolid, ↓vancomycin, ↑meropenem	1,094.2	956.1	980.7	Decrease in restricted antibiotic usage. ↓linezolid, ↓vancomycin; ↑meropenem, ↑teicoplanin suggesting AMS-guided shifts
DOT/1,000 – overall antibiotics	Total	1,474.4	1,426.8	1,394.6	Reflects prudent prescribing
DOT/1,000 – restricted antibiotics	↑Colistin, ↓Fosfomycin	578.7	571.3	570.5	Improved control of restricted Antibiotics
Compliance to policy (%)	All Abx classes	78%	80%	79%	Improved adherence
AMS (nurse-driven)	AMS Rate (Empirical, Escalation, De-escalation)	Empirical: 82.36%, de-escalation: 46.45%	–	–	High empirical accuracy, low de-escalation
Timely cessation SAP (%)	Duration adherence	57%	52%	51%	Persistently low compliance. Duration management remains challenging
Choice of SAP Agent (%)	Agent adherence	88%	94%	91%	Improved selection adherence
Culture sent before antibiotics	Diagnostic stewardship	87%	94%	97%	Marked improvement in culture of cultures
UC bundle – compliance	Jug use, closed drainage	89.9%	99.1%	99.7%	Exemplary improvement in catheter care bundle adherence
VT bundle	Cuff pressure Monitored	81.8	99.4	99.5	ICU protocol compliance enhanced drastically post-AMS.
Hand hygiene compliance	Neonatal ICU (NICU), Paediatric ICU (PICU), ITU	NICU: 81%, PICU: 76%, ITU: 69%	NICU: 84%, PICU: 75%, ITU: 75%	NICU: 86%, PICU:79%, ITU: 77%	Overall Hand hygiene adherence rate (HHAR) best in NICU; ITU needs attention
>3 antibiotics for >3 days (%)	All patients VB	1.58%	0.79%	0	Unsafe usage of multiple antibiotics eliminated
All-cause mortality	Total patients	3.54%	3.59%	3.63%	Slight increase; requires focus
HAI mortality (%)	Infection-related deaths	27.97%	39.05	35.86	Reduction reflects improved infection control with AMS.
ALOS (days)	All admitted patients	4.762	4.352	4.275	Shorter stays due to AMS

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Table 1 (continued)

Indicator/parameter	Antibiotic/metric	2022–2023 (pre-AMS)	2023–2024 (post-AMS year 1)	2024–2025 (post-AMS year 2)	Interpretation/trend
Readmissions in 30 days	Per 1,000 discharges	60.708	116.04	126.48	Concerning rise post-discharge
Ward to ICU transfers	Rate	0.319	0.347	0.381	Increasing ICU demand
ADRs due to antibiotics	ADR rate	0.00008	0.00016	0.00017	Slight risk increase
AMR (%)	MDR; XDR; PDR	MDR+MDR possible XDR: 40.63% XDR+ XDR possible PDR: 25.11%	MDR+MDR possible XDR: 36.50% XDR+ XDR possible PDR: 15.52%	MDR+MDR possible XDR: 32.94% XDR+ XDR possible PDR: 11.67%	Strong AMS impact on resistance
CDI rate (%)	Hospital-wide	0.18%	0.15%	0.13%	Improved IPC and AMS reduced *Clostridioides* infections
HAI benchmark (%)	Hospital-wide	0.26%	0.23%	0.17%	Consistent decline, marking strengthened infection control
VRE prevalence (%)	Enterococcus spp.	44%	–	26%	Large drop in Enterococcal resistance. Reflects successful AMS and HH programs
CRAB (carbapenem-resistant *Acinetobacter baumannii*) rate (%)	Carbapenem resistance rate	95.24%	–	87.72%	The proportion of CRAB isolates decreased from 95.24% in 2023 to 87.72% in 2024, indicating a reduction in carbapenem-resistant *A. baumannii* cases over the year
MRSA (methicillin-resistant *Staphylococcus aureus*) *rate (%)*	*Oxacillin or Cefoxitin* resistance among *Staphylococcus aureusisolates*	35.48%	–	36.17%	The proportion of MRSA isolates slightly increased from 35.48% in 2023 to 36.17% in 2024, indicating a marginal rise in methicillin-resistant *S. aureus* cases This suggests that MRSA prevalence remained relatively stable over the year with no significant change

VRE, vancomycin-resistant *Enterococcus*; VT, ventilator; ALOS, average length of hospital stay; UC, urinary catheter.

drainage system" (99.7%) and "separate collection jug" (99.7%), while "perineal care" remained lower at 87.9%. VT bundle adherence also improved significantly; "cuff pressure monitoring" rose from 81.8% to 99.5%, and "PUD prophylaxis assessment" compliance increased from 59.5% to 88.3% (Table 1). Hand hygiene compliance improved across all units, with NICU consistently leading (from 81% to 86%), followed by PICU (79%) and ITU (77%), reflecting ongoing institutional emphasis on infection prevention.

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Clinical Outcomes

The proportion of patients receiving three or more antibiotics for more than 3 days declined sharply post-AMS, from 1.58% to 0%, indicating rationalized antimicrobial use (Table 1). The SMR dropped significantly from 1.28 to 0.62 ($p < 0.001$, eta-squared = 0.388) (online suppl. Fig. 5).

In contrast, all-cause mortality increased slightly from 3.54% to 3.63%. Though this was not statistically significant ($p = 0.368$), this trend may reflect underlying complexities in the patient case mix, highlighting the need for ongoing risk stratification and care optimization. Similarly, 30-day hospital readmission rates rose from 60.7 to 126.5 per 1,000 discharges, suggesting persistent gaps in discharge planning and post-discharge monitoring. Transfers from wards to the ICU also increased from 0.319 to 0.381 per 1,000 admissions, underscoring the importance of early identification of clinical deterioration and proactive AMS involvement in high-risk cases.

Resistance Trends and HAI Outcomes

Resistance trends showed improvement across multiple organisms. Vancomycin-resistant *Enterococcus* prevalence declined from 44% (88/200 isolates) to 26% (52/200) ($p = 0.121 > 0.05$, Cohen's d = 2.449), with the largest drop occurring in the final year (online suppl. Fig. 6). Carbapenem-resistant *Enterobacteriaceae* (CRE) fell from 47% to 42%, and NDM gene detection dropped from 50% to 42%. Overall, multidrug resistance (MDR+MDR possible XDR) decreased from 40.6% to 32.9%, and extensive drug resistance (XDR+ XDR possible PDR) from 25.1% to 11.7% (Table 1). Rates of CDI improved steadily from 0.18% to 0.13%, while HAI benchmarks dropped from 0.26% to 0.17%, confirming the broader impact of stewardship on hospital-acquired infections (online suppl. Fig. 7).

A comprehensive summary of key antimicrobial stewardship (AMS) performance metrics across the study period is presented in Table 1. This table aggregates data from all major domains covered in the Results section, including antibiotic consumption, policy compliance, infection control indicators, clinical outcomes, and resistance trends offering a consolidated view of year-wise improvements and persistent challenges under the AMS framework.

Online supplementary Table A3 shows a comparison of antimicrobial resistance categories between intensive care and general wards. Although non-MDR isolates were lower in ICU (24.47 ± 4.12) than in general wards (32.28 ± 5.39), and XDR + XDR Possible PDR isolates were higher in ICU (32.33 ± 10.93) compared to general wards (21.53 ± 9.21), none of the differences reached statistical significance (all p values >0.05). This indicates that there is no statistically significant difference in the distribution of resistance patterns between ICU and general wards.

Online supplementary Table A4 presents a comparison of antimicrobial resistance categories across different hospital alliances. While some variations are observed, for instance, MDR + MDR Possible XDR appears higher in the Paediatrics Alliance (49.65 ± 14.23) compared to the Medical Alliance (39.47 ± 8.22), and XDR + XDR Possible PDR is higher in the medical alliance (25.70 ± 9.28) than in Paediatrics (16.74 ± 10.30) none of the differences are statistically significant (all p values >0.05). This indicates that there is no significant variation in resistance patterns among the alliances. Although the mean HAI rate is slightly higher in intensive care (0.12 ± 0.05) than in general wards (0.09 ± 0.03), the difference is not statistically significant ($p = 0.315$), indicating that there is no significant difference in HAI rates between intensive care and general wards.

Discussion

Interpretation of Findings and Comparative Analysis

This observational study provides a comprehensive evaluation of a hospital-level AMSP at a tertiary care centre in eastern India with measurable improvements evident in antibiotic consumption, policy compliance, infection control practices, and resistance trends over a 3-year period. These findings contribute to the growing body of literature endorsing AMS implementation in (LMICs, where antibiotic overuse is a dominant driver of antimicrobial resistance (AMR) and where real-world implementation trials are limited. One of the most important observations was the reduction in the overall use of antibiotics, as evidenced by both the reduction in DDD and DOT per 1,000 patient-days. Our study also observed a 7.2% reduction in overall DDD, along with ongoing decline in use of restricted antibiotics, including linezolid, vancomycin, and polymyxins, which are typically reserved for resistant infections which is consistent with the study by Swamy et al., [19]. These cutbacks are critical because global evidence in the period 2000–2010 revealed carbapenem use increased by 45% and polymyxin by 13% [20], which are both last-resort drugs. Indian studies also emphasize strict adherence to AMSP due to the extensive use of antibiotics, particularly in ICU [21, 22]. Such trends reflect a call for speed in containment by stewardship. However, it is important to

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note that most of these improvements, including reductions in DDD, DOT, and resistance rates, did not reach statistical significance ($p > 0.05$). These trends should, therefore, be interpreted as directional rather than definitive, and caution is warranted in attributing causality. Conversely, certain outcome indicators showed unfavourable trends. Readmission rates and ICU transfers increased post-AMS, and all-cause mortality rose slightly. The rise in readmission rates and ICU transfers may indicate gaps in continuity of care and discharge planning. These unintended consequences could stem from premature discharge decisions aimed at reducing length of stay or from inadequate post-discharge follow-up, both of which are critical in complex infection cases. Future AMS strategies should integrate transitional care planning and risk stratification to mitigate these effects. Moreover, the slight increase in all-cause mortality, although not statistically significant, warrants closer scrutiny. It may reflect residual confounding due to patient severity or delayed escalation in high-risk cases. Future AMS interventions should incorporate severity-adjusted protocols and early warning systems to prevent deterioration [23]. The observed trends, including reductions in antibiotic use and resistance, as well as increases in readmissions and ICU transfers, may have been partly driven by changes in patient demographics, case severity, or hospital practices during the study period, underscoring the need for risk-adjusted analyses in future research. Evidence from LMIC settings indicates that while antimicrobial stewardship interventions often improve compliance and reduce antibiotic use; however, they do not consistently translate into better patient outcomes such as reduced mortality or readmissions, highlighting gaps in post-discharge care and the need for integrated AMS and transitional care models [24].

Diagnostic stewardship in the form of early collection of clinical samples for culture, prior to initiation of antibiotics, also improved but not to optimal levels. Pre-therapy culture collection is a pillar in AMS that provides microbiological evidence enabling targeted therapy and effective de-escalation [25]. Lack of it could risk encouraging unnecessary broad-spectrum usage and inhibiting clinical decision-making [26]. Behavioural change of clinicians, although an extremely difficult task, can be induced by dedicated motivational councillors alongside with AMS team to carry out these behavioural change-related interventions. Our findings reinforce the value of ongoing education, automation of culture ordering in electronic prescribing systems, and integration with nursing workflows to increase diagnostic yield [26, 27].

SAP measures varied. Choice of agent did increase to 94% compliance, but timing adherence was below par for the duration of the study period. This inconsistency is usually reported in the literature and often arises due to ambiguity in postoperative dosing intervals or lack of ownership by surgical teams [27]. Educational outreach, standardization of protocols, and tighter integration with perioperative checklists are required to ensure improvement in both agent choice and timing [28].

Decreases seen in CRE and vancomycin-resistant *Enterococci* further underscore the long-term microbiological gains of stewardship. Resistance patterns fell 5–18% over the study, consistent with estimates of AMS interventions to decrease resistant isolate prevalence by 20–40% if sustained for several years [29]. Implementation of infection control bundle for CLs and VTs assisted in reducing the HAI benchmark rate (0.26%–0.17%) and CDI rates. The results align with global evidence that AMS and IPC programs are supporting one another in the prevention of HAIs [30].

Strengths and Limitations

This study provides a comprehensive evaluation of a real-world, policy-driven AMSP in a tertiary care hospital in an LMIC setting, addressing a critical evidence gap. It demonstrates measurable improvements in antibiotic consumption, compliance with institutional policy, infection control practices, and resistance trends over a 3-year period. Integration of AI-based dashboards (Ibhar platform) enabled systematic data collection and monitoring of stewardship indicators, supporting transparency and reproducibility.

Yet, there are some limitations to the study. First, it was performed in a single tertiary care hospital and perhaps cannot be generalized to AMS use in other settings with alternate resources, staff mix, or antibiotic prescription policies. Second, although overall clinical end points such as mortality and SMR were examined, patient-specific variables such as severity of infection, duration of therapy, and cure rates were not. In addition, the individual contributions of AMS team members and inter-unit variation in compliance were not even measured, and this might have affected uniformity of intervention. Outcomes may have been influenced by unmeasured confounders such as patient severity, ICU admission rates, and changes in hospital practices. Future studies should incorporate risk adjustment and patient-level data.

Regarding the Ibhar platform, while it facilitated structured data capture and validation, its accuracy

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depends heavily on clinician input and manual confirmation steps, which introduces potential for human error. Despite in-built validation rules, discrepancies in microbiology data transfer or incomplete entries could affect reliability. Integration challenges also exist, such as limited interoperability with electronic medical records, lack of automated linkage with severity scoring systems, and variable adoption by clinical team, which may constrain real-time decision support. These limitations should be considered when interpreting the observed trends and underscore the need for robust integration strategies in future AMS implementations. Most observed improvements, including reductions in antibiotic consumption and resistance rates, were not statistically significant, underscoring the need for cautious interpretation.

Conclusion

This research confirms the need for collaborative policy-driven AMSP to maintain declining trends in antibiotic use, enhancing policy compliance, and optimizing microbiological results in a low-resource hospital environment. Despite substantial improvement, there was some fluctuation in de-escalation compliance over time, with overall rates still quite elevated compared to pre-AMS levels. SAP length and discharge outcomes verify the necessity for ongoing education, inter-professional practice, and integration of AMS into broader hospital quality improvement initiatives. As India and other LMICs continue with scale-up of stewardship activities, on-the-ground assessment such as this will continue to be vital to form policy, direct resource allocation, and guide best practices in AMR control.

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Statement of Ethics

This study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Institutional Ethics Committee of Peerless Hospital and B.K. Roy Research Centre, Kolkata (Approval No. PHH&RCLCREC/4402/2024). As the study used anonymized, retrospective programmatic data without direct patient interaction, the requirement for informed consent was waived by the committee.

Conflict of Interest Statement

The authors declare no conflicts of interest related to this study.

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Author Contributions

Partha Guchhait, Bhaskar Narayan Chaudhuri, and Satadal Das conceptualized the study. Partha Guchhait, Bhaskar Narayan Chaudhuri, Avijit Das, and Rumpa Das Banerjee collected and analysed the data. Partha Guchhait and Tamanna Saha drafted the manuscript. All authors reviewed and approved the final version of the manuscript.

Data Availability Statement

The datasets generated and/or analysed during the current study are not publicly available due to hospital data confidentiality policies but are available from the corresponding author on reasonable request. Aggregated and anonymized data used for analysis were stored within the Ibhar platform, in compliance with institutional data governance standards.

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