Review Article

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# Role of Automation in Clinical Bacteriology: Enhancing "Actionable" Antibiograms

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Antimicrobial resistance (AMR) has emerged as one of the most critical public health threats of the 21st century, with projections estimating up to 10 million annual deaths and substantial global economic losses by 2050. Conventional antimicrobial susceptibility testing (AST) methods—such as disk diffusion, broth microdilution, and E-test—remain reliable but are constrained by labor intensity and long turnaround times, often delaying the initiation of effective therapy in critically ill patients. Recent advances in laboratory automation, including pre-analytical robotics, automated identification/AST platforms, digital imaging, and middleware solutions, are transforming clinical bacteriology workflows. These innovations enhance reproducibility, minimize human error, and enable the creation of "actionable antibiograms"—dynamic, real-time, unit-specific, and resistance-mechanism-linked reports that provide clinicians with timely, relevant, and context-specific guidance for empirical therapy and antimicrobial stewardship. This review highlights the evolution from traditional static antibiograms to actionable, data-driven tools, examines the clinical benefits of reduced time-to-effective therapy, and emphasizes their potential in strengthening AMR surveillance and improving patient outcomes, particularly within the Indian healthcare context where multidrug resistance poses a growing challenge.

**Keywords:**
Antimicrobial susceptibility testing (AST), Antimicrobial resistance (AMR), Automated laboratory systems

## Introduction

Antimicrobial resistance (AMR) is one of the greatest threats to public health in the 21st century. The review on antimicrobial resistance projected that by 2050, AMR could cause 10 million deaths annually and a cumulative cost to the global economy of up to USD 100 trillion if unchecked (1). Common bacterial pathogens such as *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, Methicillin-resistant Staphylococcus aureus (MRSA), and Vancomycin-resistant *Enterococcus* (VRE) increasingly exhibit multidrug resistance, limiting therapeutic options (2,3). Clinical microbiology laboratories play a central role in AMR detection and reporting. Traditional Antimicrobial Sensitivity Testing (AST) methods—disk diffusion, broth microdilution, and E-test—remain gold standards but are labour-intensive and time-consuming, often requiring 24–72 hours after culture positivity (4). In critically ill patients with sepsis, pneumonia, or bloodstream infections, such delays may result in suboptimal empirical therapy and adverse outcomes (5).

Laboratory automation offers a paradigm shift. Pre-analytical robotics, automated ID/AST platforms, digital imaging, and advanced middleware streamline workflows, reduce variability, and improve turnaround time (TAT). More importantly they enable the development of "actionable antibiograms": tailored, real-time susceptibility reports that are unit-specific, syndrome-based, and resistance-mechanism linked (6–8). Unlike static annual antibiograms, actionable antibiograms serve as dynamic clinical decision tools that can guide prescribing at the point of care.

This review examines the role of automation in bacteriology in developing actionable antibiograms, its clinical implications, limitations, prospects, and relevance in the Indian context.



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## Automation in Bacteriology Workflows

Automation encompasses pre-analytical, analytical, and post-analytical phases, each of which contributes to faster, standardized, and reproducible AST data essential for actionable antibiograms.

### Pre-analytical automation

The pre-analytical phase is prone to manual errors. Total laboratory automation (TLA) systems such as WASPLab (Copan) and BD Kiestra automate specimen inoculation, incubation, and imaging. Advantages include the consistent inoculum streaking, improving reproducibility of growth and AST. Automated incubation and digital imaging, allowing earlier colony detection (up to 12–18 hours earlier) and remote digital plate reading, enabling workflow decentralization (9).

### Analytical automation

Automated AST platforms reduce variability and provide rapid MIC determination. Key systems include: VITEK 2 (bioMérieux): Utilizes turbidimetric/fluorometric principles, provides MICs with AES alerts for ESBL, AmpC, or carbapenemase. BD Phoenix: Colorimetric/fluorescent AST with resistance mechanism flags. Microscan WalkAway (Beckman Coulter): Automated broth microdilution. Sensititre (Thermo Fisher): Customizable microdilution panels. Integration with MALDI-TOF MS (Bruker, bioMérieux) enables rapid organism identification (minutes), which, when paired with AST, accelerates time-to-report (10). AI-assisted AST tools such as Ab.ai demonstrate 97–98% categorical agreement with manual interpretation, further reducing human error (11).

### Post-analytical automation

Automated data handling is essential for transforming AST results into actionable antibiograms. LIS and middleware: Ensure validated results and automated interpretive comments. WHONET: Global open-source platform for AMR surveillance. AMASS (Automated tool for Antimicrobial Resistance Surveillance): Generates structured reports from LIS exports, particularly beneficial for low-resource settings (12). AI/machine learning: Predictive modelling of resistance trends for proactive antibiogram development (13).

## Actionable Antibiograms: Concept and Evolution

Traditional hospital antibiograms pool annual susceptibility data across an institution. Limitations include the lag in updates (6–12 months), the lack of granularity (ward-specific variation obscured) and limited clinical relevance (not syndrome- or mechanism-based).

### Evolution towards actionable antibiograms

Automation enables dynamic antibiogram formats such as Unit-specific antibiograms – ICU-specific antibiograms which reveal higher prevalence of MDR Gram-negatives compared to general wards (14); Syndrome-based antibiograms, which focus on infections such as ventilator-associated pneumonia, bloodstream infections, or urinary tract infections (15). Real-time antibiograms which are continuously updated thus reducing lag from months to days and the Resistance mechanism–linked antibiograms which incorporating AES alerts (ESBL, CRE, MRSA) with therapeutic suggestions (16) and lastly the user-friendly formats – Heatmaps, dashboards, and mobile apps improve clinical uptake (17).

**Table 1. Traditional vs Actionable Antibiograms**

| Feature | Traditional antibiogram | Actionable antibiogram |
|---|---|---|
| Frequency of update | Annual | Real-time / monthly |
| Level of data | Hospital-wide | Unit/ward-specific |
| Focus | General organism–drug pairs | Syndrome-specific, mechanism-linked |
| Clinical relevance | Limited | High |
| Utility in stewardship | Policy-level | Bedside decision-making |

## Clinical Impact of Automated Actionable Antibiograms

Actionable antibiograms play a crucial role in clinical practice by optimizing empirical therapy through alignment of prescribing with current resistance patterns, which can reduce inappropriate antibiotic use by up to 30%. In critical illnesses such as sepsis, where each hour of delay in appropriate therapy increases mortality by 7–10%, their impact on timely and accurate treatment is particularly significant. Beyond guiding therapy, actionable antibiograms strengthen antimicrobial stewardship programs by supporting formulary restrictions, tailoring of institutional guidelines, and facilitating timely de-escalation strategies. They also enhance outbreak detection, as resistance clusters such as carbapenem-resistant Enterobacterales in intensive care units can be identified within days rather than months. On a broader level, actionable antibiograms inform hospital policy and formulary decisions, allowing empirical therapy guidelines to be updated quarterly instead of annually. Collectively, these contributions translate into tangible patient benefits, including reduced ICU stay by two to four days and improved survival in bloodstream infections when management is guided by actionable antibiograms.

**Table 2. Examples of Automation Platforms in Clinical Bacteriology**

| System | Function | Advantages | Limitations |
|---|---|---|---|
| WASPLab/Kiestra | Pre-analytical TLA | Consistency, early colony detection | High cost, infrastructure demands |
| VITEK 2 | ID + AST | Rapid MICs, AES alerts | Limited panel flexibility |
| BD Phoenix | ID + AST | Reliable MICs, ESBL/AmpC alerts | Expensive consumables |
| MALDI-TOF MS | ID | Fast, accurate species ID | No AST capability |
| WHONET/AMASS | Surveillance | Free, supports LMIC settings | Requires LIS integration |
| Ab.ai | AI AST interpretation | High accuracy, reduces manual error | Still under validation |

## Indian Perspective on Actionable Antibiograms

India faces a unique and urgent AMR challenge. Data from the Indian Council of Medical Research – Antimicrobial Resistance Surveillance Network (ICMR-AMRSN) consistently demonstrate very high rates of resistance, particularly carbapenem-resistant *Klebsiella pneumoniae*, multidrug-resistant *Acinetobacter baumannii*, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant enterococci (VRE) (22). In some tertiary care centres, carbapenem resistance in *K. pneumoniae* exceeds 50%, and MRSA prevalence remains around 30–40%**.**

Currently, most Indian hospitals and laboratories prepare static, annual antibiograms for reporting to ICMR-AMRSN, which limits their clinical utility for day-to-day decision-making. Given the heterogeneity of resistance across states, hospitals, and even wards within a single facility, unit-specific and syndrome-based actionable antibiograms would be especially valuable in India.

ICMR has also issued empirical therapy guidelines for bloodstream infections and hospital-acquired infections. However, local resistance rates frequently diverge from national averages. Automation-driven, actionable antibiograms could enable customization of ICMR guidelines to the local context, improving the precision of empiric therapy.

Resource limitations are another major challenge in India. While full laboratory automation systems (e.g., WASPLab, Kiestra) may be unaffordable for many hospitals, low-cost digital and semi-automated solutions exist. The AMASS platform, piloted in Indian centres, has demonstrated feasibility for generating semi-automated antibiograms from LIS data with minimal manual input (12).

Finally, antimicrobial stewardship programs (ASPs) in India remain in their early stages. Inappropriate broad-spectrum antibiotic use, including carbapenems and colistin, is widespread. Actionable antibiograms—integrated with stewardship dashboards—could provide real-time feedback to prescribers and support ASPs in enforcing antibiotic restriction policies, de-escalation strategies, and hospital-specific formulary updates.

Thus, while actionable antibiograms are relevant globally, their clinical and policy impact could be especially profound in India, where AMR burden is high, stewardship programs are developing, and national surveillance networks like ICMR-AMRSN provide a foundation for scaling automated approaches.

## Challenges and Barriers

Several challenges hinder the widespread adoption of automation-driven actionable antibiograms. A major issue is data standardization, as susceptibility rates may vary significantly depending on whether CLSI or EUCAST breakpoints are applied (24). Another barrier lies in integration gaps, with incomplete interoperability between laboratory information systems (LIS) and electronic health records (EHR), particularly in Indian hospitals, limiting accessibility of antibiogram data at the point of care (25). Resource constraints are also critical, as the high cost of equipment, consumables, and maintenance restricts implementation in many low- and middle-income countries (26). Furthermore, clinical validation remains limited, with only a few randomized controlled trials available to confirm that actionable antibiograms directly improve patient outcomes (27). Finally, ethical and legal concerns exist, since automated expert system (AES) interpretive comments may not always align with local stewardship guidelines, potentially leading to conflicts in clinical decision-making and medico-legal implications (28).

## Future Perspectives

Looking ahead, several promising directions are emerging in the development of actionable antibiograms. One key advance is the use of AI-driven predictive antibiograms, which employ machine learning models to forecast emerging resistance patterns and guide empirical therapy decisions (29). Another innovation is the integration of pharmacokinetic and pharmacodynamic (PK/PD) principles into susceptibility reporting, allowing for more precise dosing recommendations tailored to individual patients (30). On a broader scale, cloud-based regional networks, such as the ICMR-AMRSN in India and EARS-Net in Europe, can facilitate real-time sharing of antibiogram data across hospitals and health systems, strengthening surveillance and policy-making (31). Future models may also support personalized antibiograms, which incorporate patient-specific variables such as comorbidities, immune status, and prior antibiotic exposure to provide individualized therapeutic guidance (32). Finally, extending the concept to One Health surveillance would enable integration of data from human, veterinary, and environmental microbiology, offering a comprehensive view of resistance trends and their drivers (33).

**Table 3. Clinical Applications of Actionable Antibiograms**

| Application | Example Impact |
|---|---|
| Empirical therapy selection | Faster initiation of appropriate antibiotics |
| Antimicrobial stewardship | Reduced carbapenem use by 20–40% |
| Outbreak detection | Early CRE/MRSA cluster identification |
| Policy/formulary updates | Quarterly revisions vs annual |
| Patient outcomes | Reduced mortality in sepsis, shorter ICU stay |

## Conclusion

Automation is transforming clinical bacteriology from
a manual, reactive discipline into a dynamic, data driven partner in patient care. By enabling actionable antibiograms—real-time, unit-specific, syndrome-based, resistance-mechanism linked—automation bridges the gap between laboratory data and bedside decision-making. These advances improve empirical therapy, support antimicrobial stewardship, and strengthen AMR surveillance.

The novelty of this review lies in explicitly connecting automation to the actionable antibiogram framework and situating it within the Indian AMR landscape. With India facing one of the world's highest burdens of multidrug resistance, actionable antibiograms—integrated with ICMR-AMRSN surveillance and national guidelines—could provide especially profound clinical and policy impact.

With robust validation and equitable access, automation-driven actionable antibiograms can significantly improve clinical outcomes and contribute not only to global AMR containment but also to India's national action plan against AMR.

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