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Benchmarking antimicrobial stewardship practices in secondary care hospital settings in India: A narrative review

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ABSTRACT

Antimicrobial resistance (AMR) poses a critical global health threat in India due to the high burden of infectious diseases and widespread misuse of antibiotics. Secondary care hospitals, being pivotal in the Indian healthcare system, require effective Antimicrobial Stewardship (AMS) programs to optimize antimicrobial use and combat AMR. However, significant barriers, such as limited resources, lack of trained personnel, and inadequate infrastructure, hinder AMS implementation. This narrative review evaluated the current state of AMS programs in secondary care hospitals in India. It examined their implementation, impact, challenges, and enablers. Successful case studies of AMS programs were analysed to highlight multidisciplinary approaches involving clinicians, pharmacists, microbiologists, and infection control teams. Key strategies, such as formulary restriction, prospective audit with feedback, antibiotic time-outs, and development of evidence-based guidelines, were identified and discussed. AMS programs have shown potential in improving antimicrobial usage, reducing AMR, and enhancing patient outcomes. Critical components for successful AMS implementation include leadership commitment, drug expertise, accountability, and continuous education. Identified challenges include inadequate funding, insufficient training, and resource limitations. Despite these barriers, examples of effective AMS programs demonstrate the feasibility of scaling these interventions with strong policy support and infrastructure development. Strengthening AMS programs in Indian secondary care hospitals is crucial for controlling AMR, improving patient outcomes, and preserving antimicrobial effectiveness. Overcoming existing barriers requires policy frameworks, funding, infrastructure development, and continuous training. Scaling up AMS efforts can significantly contribute to combating AMR at national and global levels. This review offers recommendations to rationalize AMS practices and enhance implementation in India.

1. INTRODUCTION

Antimicrobial resistance (AMR) is one of the most pressing global health threats of the 21st century [1]. Current antibiotics are failing to exhibit their bacteriostatic or bactericidal effects because of the ability of microorganisms to withstand the effects of antibiotics. AMR compromises the efficacy of antibiotics, antivirals, antifungals, and antiparasitic, leading to failure of medical treatments, prolonged illness, and increased mortality. According to the World Health Organization (WHO), AMR is predicted to cause 10 million deaths annually by 2050 if no significant actions are taken [2]. This silent pandemic endangers major advancements in modern medicine, including surgery, chemotherapy, and organ transplantation, which rely on effective antimicrobial drugs. In India, the AMR crisis

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is particularly severe, and the country faces a high burden of infectious diseases, coupled with widespread use and misuse of antibiotics. Factors contributing to the rapid spread of AMR in India include over-the-counter availability of antibiotics without prescription, inappropriate prescribing practices, lack of awareness among patients, and poor infection control measures in healthcare settings [3]. The situation is exacerbated by insufficient sanitation, inadequate infection prevention and control practices, and overpopulation, which create fertile ground for the spread of resistant pathogens. The Indian government has recognized AMR as a significant public health issue, prompting initiatives such as the National Action Plan on AMR (NAP-AMR) to address this growing threat (Fig. 1) [4].

This timeline highlights the evolution of India's response to AMR, beginning with the National Health Policy (2002), followed by the launch of the National Programme on Containment of AMR (2011). Key developments include the initiation of the ICMR Antimicrobial Resistance Surveillance and Research Network (AMRSN), the National Action Plan on AMR (2017), and subsequent state-level action plans. Together, these initiatives underscore India's growing commitment to AMS implementation across healthcare settings.

AMS programs are critical in the fight against AMR. AMS includes those coordinated interventions designed to promote and measure the appropriate use of antimicrobials through the selection of the optimal antimicrobial drug regimen, dose, duration of therapy, and route of administration [5]. The goals of AMS include achieving the best clinical outcomes related to the use of antimicrobials, minimize toxicity and other adverse events, reduce the costs of healthcare for infections, and limit the selection for antimicrobial-resistant strains. Effective AMS programs help to achieve the administration of the right antibiotic at the right dose, the right time, and for the right duration. This precision in antibiotic use helps in curbing the development and spread of resistant bacteria. AMS programs are crucial not only for preserving the effectiveness of existing antimicrobial agents but also for assuring those new antibiotics, increasingly difficult to develop, remain effective for as long as possible. Implementation is one of the cornerstones of the global responsive strategy to AMR. Secondary care hospitals in India are the hub of the healthcare system, entrenched between primary healthcare facilities and tertiary care centers [6]. These hospitals bear a significant load of infectious diseases and are "ideal" points for the use of AMS programs. In India's three-tier healthcare system, secondary care hospitals, including district and sub-district hospitals, are the crucial referral points for the primary health centres. However, they often face challenges such as limited resources, a lack of trained personnel, and insufficient infrastructure to implement AMS initiatives [7]. Although considerable efforts have been made to strengthen the tertiary care settings, often through the academic medical centres and government-funded projects, there is a noticeable gap in evidence regarding the operation of AMS in the resource-limited secondary care settings. Current literature focuses on the knowledge, attitude, and practice of healthcare professionals or outcomes of AMS in high-resource settings. Addressing these challenges is essential to enhancing the AMS capabilities of these hospitals, thereby reducing the spread of AMR.

The primary objective of this review is to evaluate the current state of AMS programs in secondary care hospitals in India and their effectiveness in controlling AMR. The review aims to, (1) assess the implementation and impact of AMS interventions in secondary care settings, (2) identify barriers and facilitators to the successful adoption of AMS practices, (3) examine the outcomes of AMS programs on antimicrobial prescribing patterns and resistance rates, and (4) provide recommendations for strengthening AMS initiatives to better combat AMR in secondary care hospitals. By focusing on these objectives within the context of secondary care hospitals, this review aims to optimize AMS efforts in India by highlighting the unique implementation challenges and identifying scalable, sustainable interventions that can ultimately improve patient

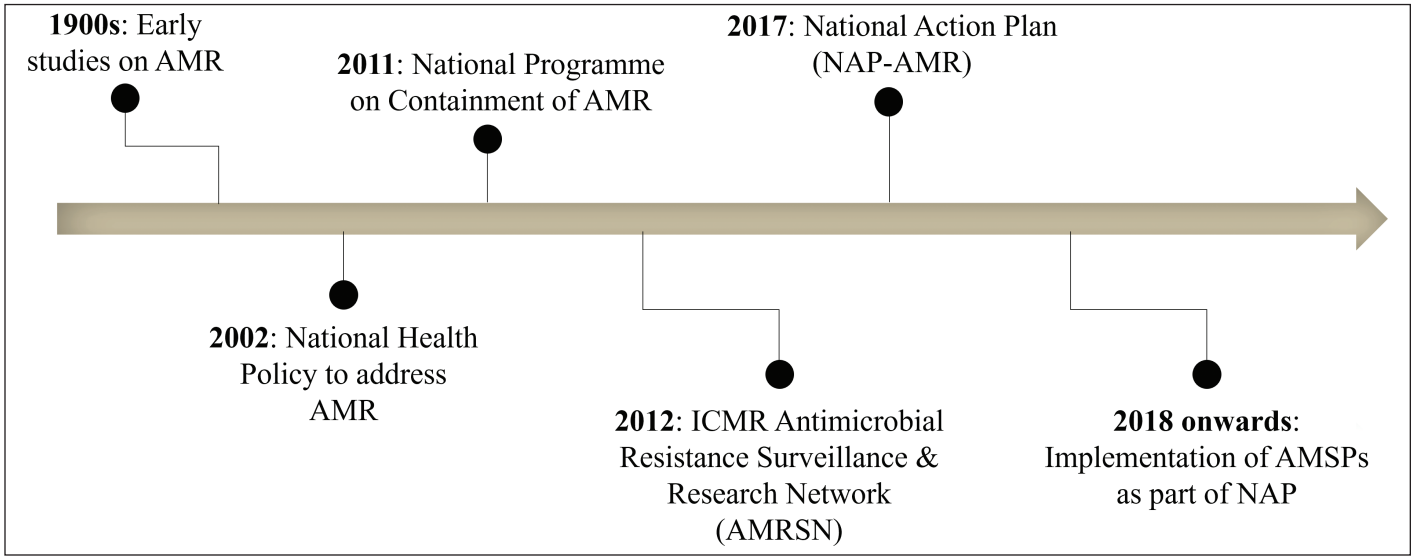

Figure 1. Timeline of antimicrobial stewardship in India Chronological timeline of major national initiatives and policies addressing AMR and promoting AMS in India.

outcomes and contribute to mitigating the AMR threat at both national and global levels.

2. MATERIALS AND METHODS

The review was conducted following a systematic approach using multiple relevant databases and electronic search platforms, including PubMed, Scopus, Embase, and Google Scholar, to retrieve all pertinent literature related to the topic. In addition to these databases, gray literature sources such as ResearchGate, theses, government reports, and relevant magazines were also explored to enhance the sensitivity and comprehensiveness of the review. The search strategy incorporated keywords such as "antimicrobial resistance," "antimicrobial stewardship," "secondary care centers" and "Republic of India" which were combined using appropriate Boolean operators (AND, OR) to optimize the search results. Duplicate records were identified and removed using Microsoft Excel 2016. All retrieved articles underwent a two-stage screening process: an initial review of titles and abstracts, followed by a full-text assessment for eligibility. Studies were included if they were set in Indian secondary care facilities as defined by the National Health Mission [8], regardless of study design, language, or publication date. To ensure a thorough exploration and avoid missing potentially relevant sources, we also performed manual Google searches and reviewed the bibliographies of included articles and other related works in the field. This supplementary step aimed to identify additional gray literature or unindexed materials. Any literature discussing the challenges, facilitators, or implementation of AMS interventions was considered for inclusion. A large volume of literature was identified, and significant findings were extracted, compiled, and synthesized based on their relevance to the topic, forming the foundation of this narrative review.

2.1. Status of AMS in Indian secondary care hospitals

The Indian healthcare system is complex, both in the public and private sectors, structured into primary, secondary, and tertiary levels [9]. Primary care facilities are the first contact facilities and include sub-centres, primary health centres, and community health centres. The secondary care hospitals are the backbone of the healthcare system, with specialized services being provided and serving as referral centres for primary care facilities. These may include district and sub-district hospitals with relatively better diagnostic and treatment facilities. The last ones are tertiary care hospitals, which are often attached to medical colleges and specialized institutions that offer very specialized medical care. In fact, secondary care hospitals form the mainstay of healthcare in India, helping manage the huge burden of infectious diseases in the country. They often serve as the first line of defence against many severe infections, hence they are very important in implementing AMS programs [10]. Indeed, several factors could play their roles in the effectiveness of AMS in these settings, such as the availability of resources, training of staff, and infrastructure.

AMS programs in the setting of secondary care hospitals in India are still at a nascent stage [11]. While the awareness for the implementation of AMS in tackling the threats of AMR is increasing, many hospitals must surmount formidable challenges to its full adoption. Chief among the barriers are the inadequate financial resources, staffing and lack of trained people, and infrastructure. In addition, the lack of continuous monitoring and evaluation systems to track and measure AMS practices for improvement challenges the establishment of AMSP in the Indian context. However, some secondary care hospitals have begun to take initiatives in implementing the AMS program [10]. This typically involves the constitution of AMS committees, formulation of hospital-specific antimicrobial policies, and training for healthcare workers in the rational use of antimicrobials. All these activities vary considerably across regions and hospitals in their extent and effectiveness. Despite the challenges, successful AMS programs have been documented in secondary care hospitals within the country. Such examples may serve as models for other hospitals seeking to initiate or optimize an AMS program. Presently, five key studies provide insight into the efforts made to establish AMS in Indian secondary care settings. The initial work by Mathew *et al.* [7] employed an exploratory approach to highlight structural and organizational barriers, such as a lack of leadership, limited interdepartmental coordination, and minimal institutional support that hindered AMS implementation. In contrast, Kotwani and Gandra [12] emphasized policy-level challenges, arguing that effective AMS implementation depends on coordinated efforts between government bodies and healthcare institutions. Notably, Naveena Gracelin Princy Zacchaeus *et al.* [10] demonstrated a more structured approach through the implementation of a hub-and-spoke model, wherein tertiary care hospitals provided mentorship and support to secondary-level facilities. Other than the antimicrobial surveillance, the above program incorporated the infection control measures and the regular training on this aspect to healthcare workers. It also had a component for the development of treatment protocols and active involvement of pharmacists in antimicrobial management. The hospital reported a reduction in the incidence of multidrug-resistant infections and improved compliance with AMS guidelines. These contrasting findings suggest that while AMS frameworks may be broadly applicable, their success is highly dependent on contextual factors such as institutional capacity, diagnostic infrastructure, and accountability systems. Moreover, although some facilities benefited from centralized training and audit-feedback mechanisms, others experienced setbacks due to frequent staff turnover, limited resources, and the absence of sustained support. Collectively, these insights highlight the need for adaptive, context-specific AMS strategies tailored to the unique operational challenges of secondary care hospitals in India. In addition, they demonstrate the importance of a multidisciplinary approach involving clinicians, pharmacists, microbiologists, and infection control teams. Table 1 presents key case studies conducted in secondary care settings across India since 2015, focused on the implementation of AMSP.

The status of AMS programs in India in secondary care hospitals shows an increasing recognition of their importance, but also important challenges to implementation. The literature presents examples of successful programs that have been established with adequate resources, training, and commitment. Scaling up such efforts across secondary care hospitals in India

Table 1. Summary of Literature on Antimicrobial Stewardship efforts across Indian secondary care settings

Author, Year	Title	Reference	Study design	Study setting	Key findings
Mathew *et al.* [7]	Challenges in Implementing Antimicrobial Stewardship Programmes at Secondary Level Hospitals in India: An Exploratory Study	7	Exploratory	Secondary care hospitals	Identified major AMS barriers: limited facilities, regulatory gaps, absence of AMS champions
Gautham *et al.* [13]	What are the challenges for antibiotic stewardship at the community level? An analysis of the drivers of antibiotic provision by informal healthcare providers in rural India	13	Qualitative	Community health centers	Inappropriate antibiotic use driven by patient pressure, economic needs, and pharma promotion
Kotwani *et al.* [12]	Strengthening antimicrobial stewardship activities in secondary and primary public healthcare facilities in India: Insights from a qualitative study with stakeholder	12	Qualitative	DHs and sub-DHs	Systemic gaps in leadership, lack of DTCs, and poor IPC practices hamper AMS efforts.
Zacchaeus *et al.* [10]	Establishing an effective antimicrobial stewardship program at four secondary-care hospitals in India using a hub-and-spoke model	10	Intervention	Secondary care hospitals	AMS intervention led to reduced DOT, hospital stay, and MDRO prevalence (ESBL, MRSA, VRE)
Debnath *et al.* [14]	Antimicrobial stewardship implementation in primary and secondary tier hospitals in India: interim findings from a need assessment study using mixed method design	14	Mixed method	Primary and secondary tier hospitals	Reported key implementation gaps: training, motivation, and AMR awareness among staff

will be critical for the control of AMR and improvement of patient outcomes. Robust policy support, adequate funding, and continuous education and training are essential components for the successful implementation and sustainability of AMS programs in these settings.

2.2. Key targets and goals for AMS establishment in India

AMS programs are designed to ensure the optimal use of antimicrobial agents in view of the increasing threat of AMR to protect patients' outcomes and ensure effective treatments that are safe and sustainable. Well-defined AMS targets include the reduction of inappropriate use of antibiotic practices, improvement of patients' outcome, reduction of antibiotic resistance, reduction of healthcare cost, and raising awareness among healthcare professionals and patients. Inappropriate use of antibiotics can be reduced by reducing the antibiotic prescription for nonbacterial infections, by reducing broad-spectrum antibiotic use, and by proper choice of antibiotics along with proper dosage and duration according to clinical evidence. Fundamentally, the purpose of AMS is to decrease resistant organism infections, improve antibiotic-related adverse events, and ensure timely treatment of infection with efficient antibacterial therapy in patients [14]. Furthermore, minimizing antibiotic resistance focuses on reducing the selection pressure that drives the development of resistance, which includes implementing infection control measures, surveillance of antimicrobial use and resistance patterns, and promoting the judicious use of antibiotics [15,16].

Several national and international guidelines provide the frameworks and targets for AMS programs. The World Health Organization's Global Action Plan (WHO-GAP) on AMR outlines five strategic objectives, one of which is the optimization of the use of antimicrobial medicines in human and animal health, strengthening knowledge through surveillance and research [17]. According to the Core Elements of Hospital Antibiotic Stewardship Programs by the Center for Disease Control and Prevention, some of the very important constituents of an effective AMS program include leadership commitment, accountability, drug expertise, action, tracking, reporting, and education [18]. Some of the major targets stipulated in the National Action Plan (NAP) on AMR in India include the implementation of AMS programs at all secondary and tertiary healthcare settings; standardization of guidelines of treatment practices; and strengthening surveillance systems on antibiotic use and resistance in the country [19].

Challenges in implementing AMS programs in the setting of secondary care hospitals in India are different, as they act as a link between primary and tertiary health care. The goals set for AMS in these hospitals include the establishment of AMS committees, development and implementation of guidelines on antibiotic treatment, periodic prescription audits and feedback, enhancement of microbiological diagnostics, education and training, infection control measures, and stakeholder engagement. Establishment of AMS committees involves the formation of multidisciplinary teams to oversee and guide AMS activities to ensure a coordinated approach to antimicrobial use. Development and implementation of treatment guidelines based on local resistance patterns and national recommendations ensure rational use of antibiotics, improving the practices of prescription by Kumar *et al*. [9] Regular audits and feedback support adherence to guidelines and pinpoint the shortcomings of AMS programs in India, which could be improved for their continued success in the future. It is necessary to strengthen microbiological diagnostics for enhanced laboratory capacity

for the accurate and timely identification of pathogens and their resistance profiles for guiding targeted therapy.

Promoting education and training involves regular sessions for healthcare providers on AMS principles, appropriate antimicrobial use, and infection control practices, alongside educating patients on the importance of completing prescribed antibiotic courses and the dangers of self-medication [9]. It also comprises patient education on the duration of antibiotic treatment and the adverse effects of self-medication. Improvement in infection control measures reduces the transmission of resistant pathogens in healthcare settings [20]. This has been considered one of the important components of any AMS program, including reduced transmission of Methicillin-resistant *Staphylococcus aureus* (MRSA). Finally, stakeholder engagement through collaboration with public health authorities, professional organizations, and community groups supports AMS initiatives and ensures a coordinated approach to combating AMR. Setting and pursuing these specific goals should make a significant contribution to the secondary care hospitals in India to the national and global effort to control AMR, improving patient care, and safeguarding the efficacy of antimicrobial agents for future generations [14,21].

3. COMPONENTS OF EFFECTIVE AMS PROGRAMS

3.1. Leadership commitment

Of all the elements of a successful AMS program, perhaps the most important is the commitment of top leadership because this will allow the provision of all needed resources, implementation of policies, and establishment of a culture promoting a sense of responsibility with regard to antibiotic use [22]. Good leadership ensures that AMS features high in the priorities of the healthcare institution, thus facilitating the formation and continuing support of an AMS team composed of at least an infectious disease specialist, a clinical pharmacist, and a microbiologist [23]. Leadership commitment offers both financial and administrative support, including staff training, implementation support, and information technology systems—necessary for the tracking of antibiotic use and resistance patterns [24].

Effective leadership also ensures accountability by identifying responsible individuals for overseeing AMS activities [25]. Most of the time, it involves a physician and a pharmacist who have the authority to take the lead in championing AMS efforts and ensuring adherence to the guidelines and protocols [26]. Moreover, leaders play an enormous role in the incorporation of AMS goals into broader organizational objectives; this aligns the stewardship efforts in improving overall patient safety and quality of care initiatives [27].

This is further strengthened by the willingness of health care leadership to sustain support of education and training programs for healthcare providers to ensure continuous and up-to-date knowledge about antimicrobial prescribing, including the principles of stewardship [28]. Moreover, leadership engagement is important for establishing a culture of continual improvement through which feedback from AMS activities is used to further refine and improve antimicrobial use practice. Leadership commitment is critical to AMS for both successful implementation and sustainability of stewardship programs. According to WHO, this commitment forms one of the bases of success towards the overarching goals of AMS, including reducing inappropriate antibiotic use, minimizing antimicrobial resistance, and improving patient outcomes [29].

3.2. Drug expertise in AMS

Another keystone of an effective AMS program is drug expertise, ensuring the optimal use of antimicrobial agents toward the goal of minimizing AMR. Such specialized knowledge embraces that of professionals in antimicrobial pharmacology and clinical microbiology, especially infectious disease specialists and clinical pharmacists. Their expertise is therefore crucial in guiding appropriate antimicrobial use through the development and implementation of evidence-based guidelines and protocols tailored to the local resistance patterns and clinical needs [30]. The infectious disease specialist truly understands the mechanisms of antimicrobial action and resistance and the clinical management of infections. They develop guidelines on treatment and review complex cases, offering consultation with expertise in optimizing antimicrobial therapy [31]. In addition, clinical pharmacists ensure antimicrobial prescriptions are accurate, appropriate, and evidence-based and provide critical input on drug dosing, drug interactions, and the selection of appropriate agents based on susceptibility profiles [32].

The presence of drug expertise in the AMS team makes prospective audits and feedback possible. Specialists in the review of antimicrobial prescriptions for assessment of guideline adherence and rendering of targeted feedback to the prescriber, really enhance more judicious use of antibiotics [33]. In addition, the formulary restriction reserving some antibiotics for specific indications or being issued only on prior approval of drug experts' disposition plays an instrumental role in controlling the use of broad-spectrum and last-resort antimicrobials [34]. Furthermore, drug expertise helps to provide continuous education and training of healthcare providers about new developments in antimicrobial therapy and patterns of resistance. This is of paramount importance in maintaining the high standards of antimicrobial prescribing initially achieved and empowerment of healthcare staff to make informed decisions about the use of antibiotics [27]. It assures that contemporary scientific evidence guides antibiotic use and clinical best practice, enhances capacity for effective audits and feedback, and provides support for ongoing education and training for healthcare providers. If this is taken into integrating specialized knowledge into the activities of AMS, it could improve the quality of antimicrobial prescribing in health institutions, reduce AMR, and improve final care to patients [35,36].

3.3. Accountability and responsibilities in AMS

Two major cardinal factors of an effective AMS program are the accountability and well-defined responsibilities. A well-developed AMS program, defines accountability by specifying people or teams responsible for overseeing and executing the stewardship activities, where structured services in managing antimicrobial use and resistance will have been developed [25,37]. This is attained by an AMS lead, usually a physician or a clinical pharmacist. The mandates put forward

include management of the implementation process, monitoring of its effectiveness, while leading in continuous improvements.

Responsibility in AMS programs involves developing and enforcing policies related to antimicrobials, conducting prospective audits, and providing feedback to prescribers. The leader of the AMS coordinates such activities, ascertaining adherence to guidelines and ensuring deviations, if any, are dealt with promptly [38]. This would also involve contacting the administration of the hospital to ensure adequate resources and support for AMS activities are available, therefore aligning stewardship goals within the greater context of the organization. Secondly, accountability must be established for the AMS team members with respect to their responsibilities regarding reviews of antibiotic prescriptions, assessment of guideline adherence, and participation in educational activities [39,40]. An example would be when clinical pharmacists review and advise on individual antibiotic therapies; consultation from infectious disease specialists may be needed in complex cases and resistance patterns. Besides the internal responsibilities, accountability also entails reporting and transparency. Regular reporting on AMS activities, including antibiotic use data, resistance patterns, and program outcomes, helps in maintaining stakeholder engagement and provides an impact assessment of stewardship efforts [41,42]. This kind of transparency will ensure that AMS activities are moving along the best practices and institutional goals and assist in the continuum of feedback and refinement for the program.

3.4. AMS actions as a core element of AMS programs

The AMS actions are an integral component of the AMS programs, with respect to the varied strategies aimed at optimizing the use of the antimicrobial agents in fighting AMR. These will instigate appropriate prescription of the antibiotics, monitor, and review their usage with respect to the availability of clinical evidence, and generally improve the antimicrobial practices among the healthcare settings. Key AMS actions include formulary restrictions, prospective audit and feedback, and antibiotic time-outs.

One of the common AMS strategies is formulary restriction, controlling antibiotic availability in a hospital formulary. This can be attained using policies that restrict the use of broad-spectrum or last resort antibiotics to specific indications or have prior approval from the AMS team before these drugs can be prescribed [42,43]. This prevents overuse of some of the powerful antimicrobials and reduces the emergence of resistant strains. Another key AMS action is prospective audit and feedback. In this process, antimicrobial prescriptions are assessed by AMS teams continuously for antibiotic appropriateness and feedback is given to the prescribing clinicians, with suggestions for modifications if necessary. Such a strategy not only helps in ensuring compliance with the set guidelines and standards but also helps in the continuation of improvement in practices relating to prescription through real-time intervention measures [44]. Antibiotic time-outs are clearly predefined, imperative reassessments of the need for further antimicrobial treatment 48–72 hours from its initiation. During this timeout, the current status of the patient and diagnostic information is reviewed to reassure oneself whether an antibiotic is still needed or if there needs to be a change in therapy [45]. This practice reduces the period of antibiotic use, which reduces the chance of developing resistance against it and lowers possible side effects from its long-term therapy. In addition, the AMS actions involve the formulation and implementation of evidence-based treatment guidelines that help health professionals make proper decisions in using antibiotics based on the local trend of resistance and as per best practice [46]. Education and training form part of the AMS actions, which help medical professionals to be up-to-date with respect to current guidelines, resistance issues, and optimal practices in prescription [47].

3.5. Education and training in AMS

Successful AMS programs must embody education and training as core elements that ensure healthcare professionals are informed regarding best practices in antimicrobial use and the principles of stewardship [47]. In this regard, such an effort would be extremely critical for promoting rational antibiotic prescribing and increasing awareness of AMR and would help foster a culture of continuous improvement in a healthcare setting. Educational efforts typically include formal educational trainings, workshops, and symposiums in which the mechanisms of resistance, proper antibiotic use, and effects of the misuse of antimicrobials on patient outcomes and the health of the public can be discussed. For example, Dyar *et al.* [28] have found that structured educational programs were helpful in increasing knowledge and practices about the use of antibiotics among health professionals. The research underlines the requirement for constructing a part of local resistance data and case studies to put the training into context. Training programs should be continued not only during initial but also in refresher courses so that healthcare providers are updated regarding the changing guidelines and evidence-based practices. Interactive methods, like case-based learning, simulations, and role-playing, increase engagement and improve information retention. Mendelson *et al.* [46] provide evidence that interactive educational approaches significantly improve healthcare professionals' adherence to AMS guidelines and their ability to apply knowledge in clinical settings. Tamma and Cosgrove [27] stress the need to combine AMS training with other regular professional development activities to link principles of stewardship with practice for its follow-up. Finally, education should be extended to nonclinical staff and patients. It is relevant that administrative and support staff also understand AMS principles for a supportive environment to exist for its activity. Pulcini *et al.* [48] have shown, quite clearly, that the education of nonclinical staff in the tenets of AMS makes them better supporters of the stewardship efforts at improving the overall value of the program. Patient education is focused on creating awareness about the correct use of antibiotics and the dangers of misusing them. Patients have also been educated on the need to complete the prescribed course of treatment. Davey *et al.* [33] reported that patient education using information leaflets and provision of information through direct communication improved compliance with the prescribed antibiotic course of treatment in patients and also decreased the trend of self-prescription. Education and training continue to be an essential element of the AMS program implementation.

They can offer the required education and competencies for healthcare professionals to become successful stewards and establish a culture of responsibility related to the use of antimicrobials.

3.6. Monitoring and surveillance in AMS

Monitoring and surveillance are major components of antimicrobial stewardship programs, which help in the optimization of antimicrobial use and management of AMR. These involve systematic tracking of patterns of antimicrobial use and resistance and surveillance of clinical outcomes data to help guide and improve stewardship strategies. This involves the collection and evaluation of data related to antimicrobial prescription habits and patient outcome data capture on a regular basis. This would entail monitoring the types and volumes of antibiotics prescribed and evaluating the compliance with treatment guidelines. Effective monitoring identifies inappropriate use patterns, such as using more broad-spectrum antibiotics, or other problems needing improvement [49]. For critically intensive interventions, intense surveillance of antimicrobial use in hospitals can identify trends in prescribing practices and guide targeted interventions to improve adherence to stewardship guidelines [50]. Surveillance involves systematic collection and analyses of data on antimicrobial resistance patterns in a health care setting [51]. This includes monitoring of the trend of resistance rates of pathogens, identification of emerging resistant strains, and tracking of the prevalence of particular mechanisms of resistance. The surveillance data are important in adapting AMS strategies to the local resistance profile and guiding empirical therapy decisions. Holmes *et al.* [52] concluded that, next to the detection of changes in the pattern of resistance, the presence of robust surveillance systems is of prime importance in customizing the efforts of stewardship toward fighting the challenge of resistance. Monitoring and surveillance enhance the effectiveness of AMS programs by providing actionable data for decision-making. For example, utilization data prospectively gathered through audit and feedback monitoring are used for the determination of appropriateness of antibiotic use, with the addition of real-time feedback to the clinician. Conversely, surveillance data are used in developing local treatment guidelines and ranking which antibiotics are to be restricted or reserved for certain indications [53]. Furthermore, standard reporting of the monitoring data from surveillance to healthcare providers and other relevant stakeholders keeps the efforts of AMS transparent and engaging. Such reporting does not only demonstrates the impact of stewardship activities but also creates a culture of accountability and continuum improvement [14,42]. For example, Tamma *et al.* [27] recently demonstrated that regular feedback on antibiotic use and resistance patterns with quarterly reports was associated with significant improvements in the quality of prescribing practices, reflected by an improved adherence to AMS guidelines [54].

All the components should be aligned with the objectives of the health equity, and policy implementation leads to the effective establishment of AMSP in the secondary care settings (Fig. 2)

4. CHALLENGES IN IMPLEMENTING AMS IN INDIAN SECONDARY CARE HOSPITALS

Some of the major challenges to the implementation and sustainability of the effectiveness of AMS programs in secondary care hospitals come from resource constraints, cultural and behavioural issues, lack of awareness and education, surveillance and data management systems, and regulatory and policy constraints. Each of the following points can have the

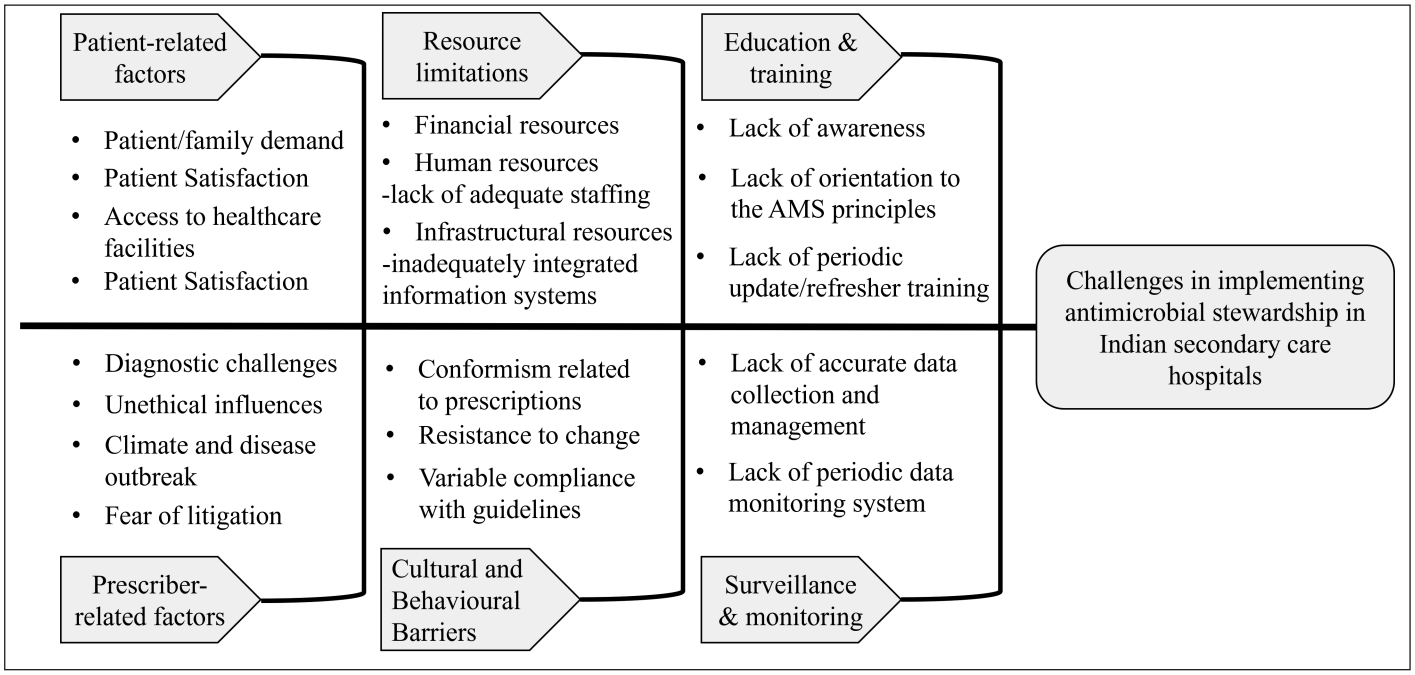

Figure 2. Components for the effective implementation of AMSP.

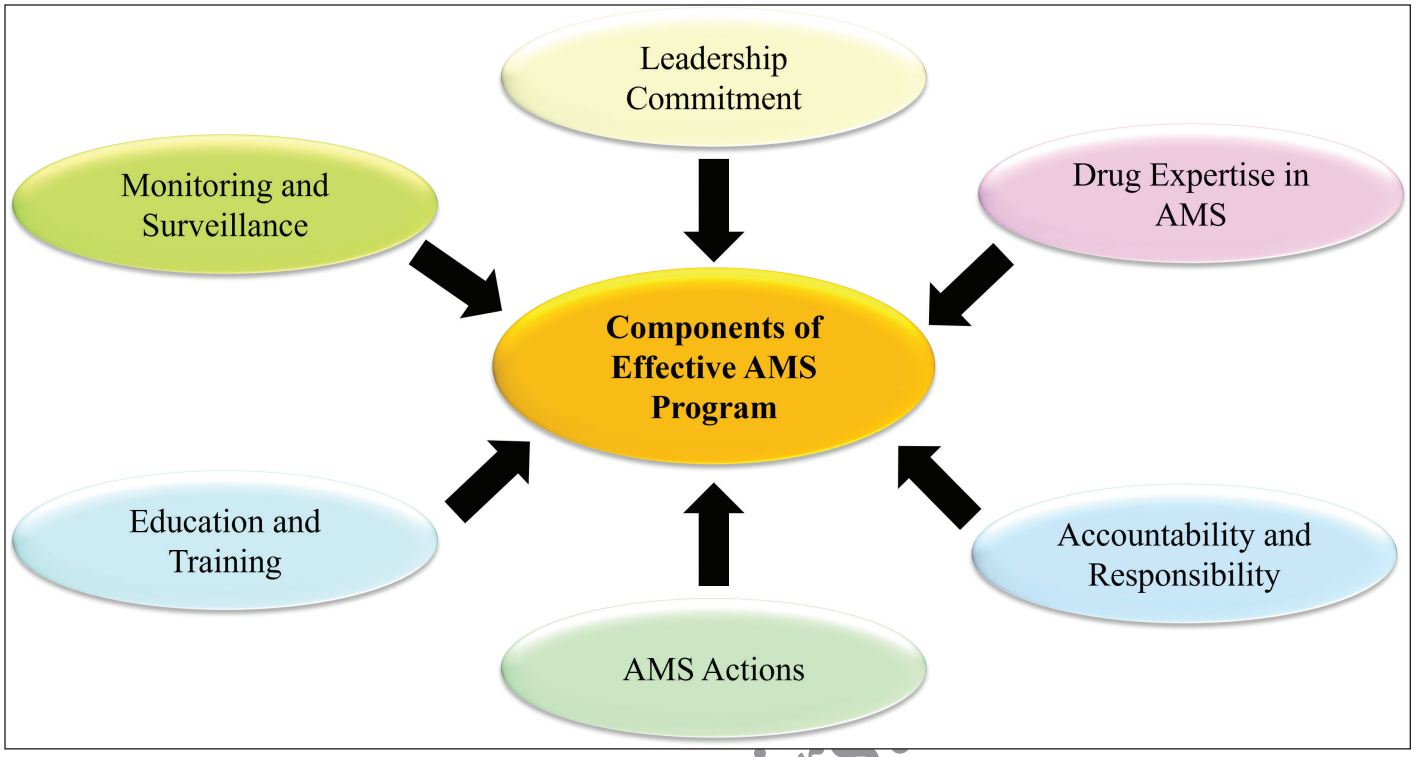

Figure 3. Challenges to establish AMSP in the Indian secondary care hospital settings.

most serious effect on the implementation and outcome of AMS initiatives, and all of them require a multifaceted approach with regard to secondary care settings (Fig. 3).

4.1. Resource limitations

One of the most important challenges that the secondary care hospitals in India face while implementing the AMS program is resource limitations. Broadly, problems may exist in financial, human, and infrastructural resources. Financial constraints affect a hospital while failing to allocate appropriate funds to AMS initiatives, such as hiring and maintaining specialized staff like clinical pharmacists and infectious disease specialists. If hospitals lack sufficient funding, they will find it very difficult to invest in all the tools and technologies needed, such as those that promote appropriate antibiotic use and track resistance patterns [7,55].

This is further compounded by the human resource limitations [56]. Significant secondary care hospitals lack appropriately trained staff to run an effective AMS program. An inadequate number of dedicated AMS staff allows for less-than-ideal oversight and support for antimicrobial prescribing practices [57]. This, therefore, has infrastructural limitations in regard to the implementation of AMS interventions with outdated or inadequately integrated information systems. It creates systems of importance in monitoring antimicrobial use and managing data about resistance patterns; inadequacies in such systems may really undermine the effectiveness of stewardship efforts [9,38].

4.2. Cultural and behavioural barriers

Cultural and behavioural barriers to the execution of AMS programs can take place at a very high level in healthcare providers [58]. Conformism related to prescriptions, aversion to change, and variable compliance with guidelines are common examples [57]. One of the prominent issues is the hierarchical pattern in decision-making, where senior clinicians have the authority to prescribe. This often discourages the junior doctors, nurses, or pharmacists from getting involved in decision making or provide inputs. This limits the interprofessional collaboration shared accountability. For instance, Dyar *et al.* [28] conducted a study on the assessment of habits of health providers. It was found that their profoundly cultivated patterns of practice of prescription were highly resistant to modification [28]. Therefore, the implementation of new AMS guidelines was a really complex task to amend such established behaviours. This resistance to change is often further accentuated by the hierarchical structure within healthcare settings, wherein subordinates are not very willing to question or alter the practice that their seniors have introduced. Moreover, this may lead to variations in prescribing practice due to the lack of agreement or clarity concerning the guidelines provided by the AMS [35]. That is, lacking uniformity in adhering to and interpreting the guidelines diminishes the effectiveness of the AMS program. For that matter, such cultural and behavioural drivers need to be overcome by creating a culture of stewardship encapsulating open dialogue, encouraging compliance, and supporting continuous professional development.

4.3. Lack of awareness and education

Another important barrier to implementation in many Indian secondary care hospitals is the lack of awareness and education among health professionals regarding AMR/AMS [59]. In this regard, healthcare professionals may not be fully

conversant with the principles of AMS and even the broader aspects of AMR as these bear on the general outcome of patients and public health. Such an educational gap may result in poor execution of AMS practices and poor adherence to established guidelines. Educational intervention studies have shown a significant effect on knowledge and practice regarding AMS. For example, Pulcini *et al.* [48] found in 2019 that appropriately targeted educational programs bring a large improvement in knowledge of the principles of AMS and the ability to apply these principles within a healthcare provider community in a clinical setting. Continuous education and training are required for keeping the community of healthcare providers up-to-date with the latest guidelines, evidence-based practices, and newly developing resistance patterns. This can really bridge these gaps in knowledge in terms of integrating education on AMS into routine professional development activities, hence making it continuous [9,60]. Though clinical training remains essential, nonclinical educational efforts are equally crucial in fostering a culture of collective responsibility. Alongside clinicians, administrative staff within healthcare settings should be educated on the goals and impact of AMS, as this can enhance institutional support and facilitate better resource allocation. Furthermore, continuous outreach and awareness campaigns targeting patients, community pharmacist, and local health workers can reinforce community engagement and promote the rational use of antimicrobials. These inclusive educational strategies strengthen the shared commitment of all stakeholders involved in AMS within and beyond the clinical setting.

4.4. Inadequate surveillance and data management systems

Effective AMS programs depend mostly on efficient monitoring systems for the surveillance of antimicrobial use and resistance patterns [61]. The lack of adequate surveillance infrastructure in most secondary care hospitals in India, however, has had a major impact on their ability to collect relevant data. Inadequate surveillance systems can complicate the collection of complete and accurate data and further hamper the assessment of AMS interventions and the identification of areas for improvement [62]. For example, the study by Tamma *et al.* [27] exemplifies how this rigorous surveillance system would be instrumental in monitoring trends in antibiotic use and resistance. In the absence of valid data, it is hard to take effective decisions related to antimicrobial prescribing and adapt strategies of AMS to the local resistance pattern [27]. Improved surveillance and data management capabilities are needed for both the successful execution of AMS programs and the assurance that stewardship works are evidence-based and targeted [14,42].

4.5. Regulatory and policy challenges

Regulatory and policy issues can also influence the implementation of AMS programs in secondary care hospitals [57]. For instance, standard guidelines or regulations on antimicrobial use may be absent, which can lead to inconsistencies about AMS practice in some regions [35]. For example, Davey *et al.* [33]. concluded that variable levels of support for and enforcement of policies across different healthcare settings can result in poor implementation of AMS programs and ineffective stewardship interventions. Moreover, gaps in policy or a lack of explicit regulation may delay AMS adoption and hinder effective stewardship implementations. The challenges can only be dealt with by developing and implementing standardized policies and regulations that support AMS efforts and promote compliance with best practices. This requires the healthcare institution, at many levels, to collaborate with policy makers and regulatory bodies in supporting an enabling environment for AMS and dealing effectively with the challenge of regulations [63]. India has made several efforts to address AMR through national policy frameworks that emphasize the establishment of AMS programs across all levels of care. However, implementation remains inconsistent due to fragmented regulatory enforcement and limited accountability mechanisms. The enforcement of Standard Treatment Guidelines (STGs) at the state level—facilitated through the formation of Drug and Therapeutics Committees (DTCs)—has strengthened stewardship efforts in some regions. For example, states like Kerala have initiated state-level AMR strategies, contributing to a more decentralized and context-specific policy environment that aligns with national AMS objectives. Despite these advancements, the regional variations and limited enforcement system continue to hinder progress, keeping many AMS initiatives in a nascent stage.

5. STRATEGIES FOR ACHIEVING AMS TARGETS IN RESOURCE-CONSTRAINT INDIAN HOSPITALS

A focused, well-planned, structured sustainability measure tailored specifically to the healthcare facilities can ensure the long-term success of AMS initiatives (Fig. 4).

5.1. Educational interventions for healthcare providers

The educational intervention is a critical part of AMS that seeks to improve the state of knowledge in both current and best practices in the use and management of AMR among healthcare professionals. These interventions usually rest on structured training programs, with defined curricula including key topics of mechanisms of AMR, rational use of antimicrobials, and impact of AMR on the health of patients and public safety [30,64]. These programs utilize varying instructional modalities, such as didactic lectures, interactive workshops, and case-based learning, to accommodate different ways of learning and provide adequate coverage of AMS principles. Continuing education and refresher courses are important in keeping such knowledge current, given the rapid rate of change in both AMR and antimicrobial guidelines [65]. The incorporation of AMS topics into routine professional development activities, such as Continuing Medical Education requirements and performance evaluations, helps to drive important concepts in AMS as part of the healthcare practice. Targeted educational campaigns focus on particular issues or themes identified through surveillance data or local resistance patterns and concentrate on key areas for improvements in antimicrobial use [66]. This may involve tailored workshops, educational posters, and electronic alerts on specific issues, such as the overuse of broad-spectrum antibiotics or inappropriate prescribing for viral infections. Interdisciplinary education is active participation by multiple health professions—doctors, nurses, pharmacists,

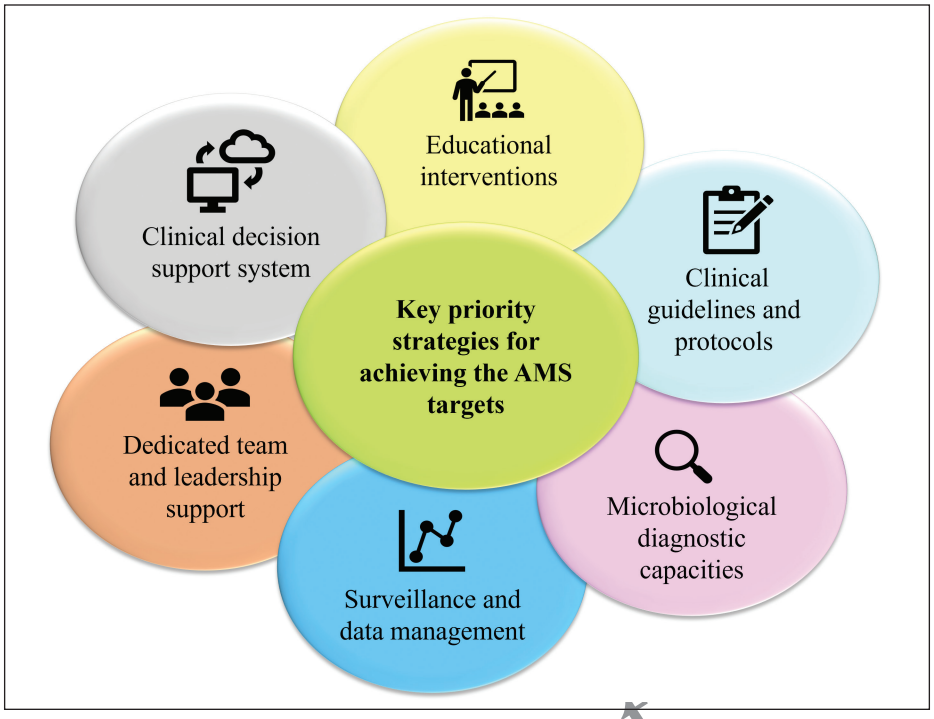

Figure 4. Sustainability measures for the establishment of AMSP in the Indian secondary care settings.

microbiologists—in collaborative training so that a coherent approach toward antimicrobial stewardship may be integrated [9,65]. Good communication and coordination in collaborative practice support a comprehensive AMS strategy. It is also important that AMS education be included in professional development to continue to foster support and resources for its providers. Further, evaluation and feedback mechanisms should be incorporated to ensure that educational interventions guide improvement regarding their effectiveness. In this regard, the health care institutions can utilize the assessment findings and participant feedback from reviews and updates of educational content in the AMS training to ensure impactful learning that will promote appropriate antimicrobial use and reduce AMR. Indeed, it is through such combined educational efforts that one supports the greater goal of optimizing antimicrobial use and mitigating the impact of AMR.

5.2. Development and implementation of clinical guidelines and protocols

The development and implementation of clinical guidelines and protocols are essential components of effective AMS programs, aimed at standardizing and optimizing antimicrobial use to combat AMR. Clinical guidelines are systematically developed statements that assist healthcare providers in making informed decisions about appropriate antimicrobial therapy based on the latest evidence and expert consensus [67]. The development process typically involves a comprehensive review of current research, clinical trial data, and resistance patterns to establish evidence-based recommendations. These guidelines should be periodically updated to reflect new evidence, emerging resistance trends, and advancements in antimicrobial therapy [31]. Protocols, provide specific, actionable steps for healthcare providers to follow in various clinical scenarios, such as the treatment of common infections, the management of sepsis, or the use of antimicrobial agents in special populations [68]. Effective protocols are designed to ensure consistency in practice, reduce variability in antimicrobial prescribing, and promote the use of narrow-spectrum agents when appropriate. The successful implementation of these guidelines and protocols requires a multifaceted approach. This includes integrating the guidelines into electronic health records (EHRs) to facilitate real-time decision-making, providing training and education for healthcare providers on the guidelines, and monitoring adherence through regular audits and feedback mechanisms [69]. Engagement of multidisciplinary teams, including physicians, pharmacists, and microbiologists, is crucial for ensuring that the guidelines are practical and applicable to diverse clinical settings. In addition, creating a culture of accountability and support within healthcare institutions encourages adherence to established protocols and guidelines. Regular evaluation and refinement of the guidelines and protocols are necessary to ensure their continued relevance and effectiveness [70]. This involves analysing clinical outcomes, resistance patterns, and provider feedback to identify areas for improvement and adapt the guidelines as needed. Furthermore, effective communication strategies are essential for disseminating guidelines and protocols across healthcare settings, ensuring that all relevant stakeholders are informed and engaged. By establishing clear and evidence-based clinical guidelines and protocols, healthcare institutions can standardize antimicrobial use, reduce unnecessary or inappropriate prescribing, and enhance overall patient outcomes, thereby contributing significantly to the broader goals of AMS and resistance mitigation [34,41,50].

5.3. Enhancing microbiological diagnostic capabilities

Enhancement of microbiological diagnostic capability is another important component of AMS, as it bears direct implications on the accuracy and appropriateness of antimicrobial prescribing. Improved diagnostic capacity can identify pathogens and their resistance more accurately and, therefore, lead to the implementation of more targeted treatment strategies. Rapid diagnostic tests based on polymerase chain reaction and mass spectrometry enable prompt detection of pathogens and resistance genes at the outset, thus facilitating appropriate therapy institution and avoidance of broad-spectrum antibiotics [71]. Comprehensive pathogen panels enable simultaneous testing for hundreds of pathogens and their associated resistance markers, increasing diagnostic yield so that clinicians are better positioned to address co-infections and polymicrobial infections [72]. These novel diagnostic tools do require an appropriate infrastructural setup in a clinical setting, like well-equipped laboratory facilities with personnel trained for the same purpose. Besides, implementation in EHRs makes all this data available for real-time access and supports clinical decision-making by providing relevant and timely information on pathogen identification and susceptibility profiles. Stewardship programs with a diagnostic stewardship component are vital in ensuring that diagnostic tools will use effectively with accurate result interpretation [73]. This would involve the development of protocols for the appropriate use of the diagnostic tests, training of healthcare providers in the interpretation of test results, and monitoring of the impact of diagnostic improvement on antimicrobial prescribing practices [74]. However, it does require the collaboration of a clinician, microbiologist, and informaticist to realize such enhanced diagnostic capabilities to their full potential. A multidisciplinary approach to the implementation of diagnostic improvement ensures appropriate translation into clinical workflows and attendant effects on antimicrobial stewardship and patient outcomes. By advancing microbiological diagnostic capabilities, healthcare institutions can achieve more precise and timely diagnoses, reduce the reliance on empirical antimicrobial therapy, and ultimately enhance the effectiveness of AMS programs, contributing to better patient outcomes and a reduction in antimicrobial resistance [75,76].

5.4. Strengthening surveillance and data management systems

The strengthening of surveillance and data management systems is relevant to the success of antimicrobial stewardship programs in effectively managing antimicrobial resistance [77,78]. Such strong surveillance systems would allow the health institution to continuously monitor and analyse patterns on antimicrobial use, resistance rates, and patient outcomes for stewardship strategies that inform key data and guide clinical decision-making [79,80]. In these systems, data on antimicrobial prescriptions, microbial resistance profiles, and infection rates are systematically collected and analysed to identify trends, detect outbreaks, or measure the impact of AMS interventions. Basic data monitoring approaches such as standardized prescription audit forms, antibiotic usage logs, and periodic antibiogram monitoring offer low-cost, practical solutions for initiating data collection in resource-limited settings. These strategies align with the objectives of the AMRSN initiated by Indian Council of Medical Research, which aims to track resistance patterns and support systematic surveillance [61]. Integrating such local efforts with national frameworks like AMRSN can enhance data quality, facilitate centralized reporting, enable benchmarking, and strengthen surveillance methodologies across secondary care settings. Advanced data management systems enable the integration of surveillance data into EHRs, making critical information available in real-time and thus supporting evidence-based prescribing practices. These systems provide data on the use of antimicrobials coupled with information regarding resistance patterns and patient outcomes so that responsible decisions about therapy, optimization of antibiotic use could take place [81]. Proper data management further helps in identifying areas of improvement that need to be worked on in the AMS program, such as the prescribing pattern, adherence to guidelines, and the effectiveness of stewardship initiatives [82]. This stage will require the development of strong data collection methodologies, ensuring the accuracy and completeness of the data, and using sophisticated analytical tools to analyse it—followed by the generation of actionable insights from the analysis [27]. A multidisciplinary approach to surveillance and data management systems involves collaboration between healthcare providers, microbiologists, and informaticists. This will ensure that data systems meet the requirements of many stakeholders and data are effectively applied to AMS strategies and clinical practice. Moreover, integration of surveillance data into public health reporting systems further strengthens the capacity for the monitoring of, and response to, AMR at larger geopolitical levels, thus informing national and global efforts against resistance. Appropriate infrastructure—advanced data analytics and secure data storage solutions are needed for the appropriate functioning of surveillance systems and for the integrity and accessibility of data [83]. Enhanced surveillance and data management systems can improve a healthcare institution's capacity for identifying the trends in antimicrobial resistance, monitoring its response to these, and optimizing the use of antimicrobials for improvement in patient outcomes, thereby enhancing the overall efficiency of the AMS programs.

5.5. Engaging multidisciplinary teams

Engagement of multidisciplinary teams is one cardinal approach to ensuring the effectiveness and success of AMS programs by providing collaboration on optimizing antimicrobial use and management of AMR. This will ensure an integrated approach to stewardship by diverse expertise, since each discipline offers something valuable in terms of input and skills toward the analysis of intricacies related to AMR [25]. A collaborative approach among healthcare professionals is essential for joint AMS efforts, as it ensures optimized antimicrobial use, adherence to infection control measures, and implementation of effective surveillance and feedback mechanisms, thereby enhancing patient safety and reducing the risk of healthcare-associated infections [30]. Effectively engaging multidisciplinary teams would involve structured collaborative and communication channels such as regular team meetings, joint educational sessions, and shared decision-

making processes. These interactions stimulate discussion and result in a cohesive way of implementing the goals of stewardship in each of the members to improve antimicrobial use and the mitigation of resistance [50]. Engaging multidisciplinary teams also involves monitoring and evaluating the impact of AMS efforts, using data to inform strategies and adjust as needed.

5.6. Utilizing technology

Technology, such as EHRs and clinical decision support, is instrumental in redesigning the principles of AMS. It changes the accuracy, efficiency, and effectiveness of antimicrobial prescribing practices and resistance management. EHRs are a 'one-stop-shop' repository for the storage of all patient data, bringing together clinical, laboratory, and microbiological information onto one platform that supports timely decision-making and seamless sharing of information between health practitioners [81]. EHRs with integrated AMS systems can track antimicrobial prescriptions, monitor resistance patterns, and look over the indicators of patient outcome in treatment—an integral area from which useful insights can be garnered about key trends in prescribing and opportunities for improvement. Moreover, EHRs also facilitate translation of such clinical guidelines or protocols into practice by embedding tools for decision support into the flow of work. These tools offer evidence-based recommendations, generate alerts for drug interactions and contraindications, and pop-up reminders for adhering to guidelines in an effort to reduce inappropriate prescribing and ensure that treatment decisions follow best practices [77,82]. Decision support systems, particularly those utilizing Artificial Intelligence- and machine learning-powered algorithms that can analyze large amounts of patient data to predict the outcome and provide therapeutic options, are claimed to be able to improve decision-making. They will help recognize patients who are most at risk for antimicrobial resistance, suggest alternative therapies, and adjust dosage regimens according to individual patient characteristics and resistance patterns [83]. In addition, predictive analytics applied in DSS enables antimicrobial use to be managed in anticipation of resistance trends by forecasting and executing targeted interventions. Use of technology further facilitates communication and collaboration among healthcare providers through integrated platforms and electronic messaging systems, ensuring the sharing and acting on information related to antimicrobial use and resistance [84]. Telemedicine and remote monitoring technologies also serve the purpose of increasing the reach of AMS programs by facilitating virtual consultations, remote patient monitoring, and education material dissemination in areas with access problems to specialized expertise [85]. The effective use of technology also includes its continual monitoring and assessment to understand its impact on the efforts of antimicrobial stewardship. This involves evaluating decision support tools for accuracy, analysing their effects on prescribing decisions, and working on ensuring that technology is used to complement—not replace—clinical judgment. Advanced technological solutions can further leverage healthcare institutions' precision, efficiency, promotion of adherence to best practices, and improved patient outcomes through an AMS program, thus collectively leading toward an effective and sustainable way to manage antimicrobial resistance.

While advanced technologies like artificial intelligence and machine learning hold promise for AMS, their implementation in resource-limited secondary care hospitals is often impractical due to infrastructural and technical constraints. For such settings, prioritizing low-cost, implementable measures can significantly enhance AMS efforts without requiring substantial investment. Manual audits and feedback systems are effective strategies for monitoring antimicrobial prescriptions and ensuring adherence to treatment guidelines. These can be conducted by existing staff with basic training, reducing the need for expensive automated tools. Simple data collection frameworks, such as spreadsheets or basic paper-based logs, can also support the tracking of antibiotic use and resistance patterns, facilitating periodic reviews.

Basic surveillance systems focusing on the most prevalent pathogens and resistance trends in the hospital patient population can provide actionable data. Collaboration with nearby tertiary care centers or microbiological laboratories can further enhance diagnostic capacities without requiring in-house infrastructure.

Educational programs targeting healthcare providers and staff form another cornerstone of practical AMS interventions. Training sessions on antimicrobial prescribing, infection prevention, and AMS principles can be conducted using available resources and tailored to the specific needs of the institution. Low-cost educational materials, such as posters and brochures, can raise awareness among both healthcare workers and patients about the importance of appropriate antibiotic use. By focusing on these feasible measures, secondary care hospitals can strengthen their AMS programs and combat antimicrobial resistance effectively, even with limited resources.

6. FUTURE DIRECTIONS AND RECOMMENDATIONS

The field of AMS is undergoing a significant transformation, driven by advancements in technology, increasing awareness of AMR, and a growing emphasis on personalized medicine. For secondary care hospitals, several emerging trends are shaping the future of AMS.

Probably the most promising trends in AMS involve the integration of artificial intelligence and machine learning. These technologies are really revolutionizing the way that antimicrobial stewardship is practiced by endowing providers with powerful tools for sifting through large volumes of data on patients. AI-powered decision support systems could provide real-time evidence-based recommendations at the point of care that are tailored to the individual patient. It is in view of this that these systems will enhance the precision of prescription practice and thus improve patient outcomes through patient-specific data and microbial profiling [86,87]. For example, the use of machine learning algorithms would predict trends in resistance patterns and come up with the best treatment options, thus significantly reducing the risk of inappropriate antimicrobial use[88]. In a similar vein, improvements in data analytics and real-time monitoring systems are key to AMS efforts into the future [89–91]. EHRs and integrated surveillance systems improve the collection of accurate and timely data on antimicrobial use and trends in resistance. The health workers will be able to trace this data in real-time, thereby fastening the process of

recognizing nascent trends of resistance quickly. Healthcare providers can then institute timely, focused interventions. This is an essential ability toward tailoring stewardship strategies to current resistance trends and enhancing the general aspects of the antimicrobial stewardship process.

Another future direction for AMS is the personalization of antimicrobial therapy. Health care providers can go further with tailoring in antimicrobial treatment according to the genetic characteristics of both a patient and pathogen as genomic medicine and the science of pharmacogenomics advance. This not only increases the effectiveness of treatment but also lowers the risk of resistance. Knowledge of individual differences in drug metabolism and pathogen genetics can enable the choice of the most appropriate antimicrobial agents for the treatment of patients, hence, more effective and personalized care. There will also be an increasing influence on how AMS efforts are conducted in the future by a more significant emphasis on patient-directed approaches and education. If patients are adequately educated about appropriate antibiotic use, possible side effects, and adherence to the prescribed antimicrobial regimen, then unnecessary antibiotic use can be significantly reduced. Future AMS strategies are likely to include more robust patient education programs and engagement activities to empower patients and promote responsible use of the antimicrobials [38,91].

Future AMS strategies will increasingly focus on strengthening infection prevention and control. It involves more stringent practices of infection control, next-generation disinfection technologies, and stronger healthcare-associated infection management policies and procedures. Such measures will help to reduce the risk of infection and, because of this reduction in infection, decrease the use of antimicrobials, reducing resistance and improving patient safety [48,54].

Finally, future AMS efforts will emphasize further the need for interdisciplinarity. It is critical to involve many healthcare professionals, like pharmacists, microbiologists, and infection control specialists, among others, to ensure a comprehensive approach towards antimicrobial management. It is important to have an interdisciplinary team since all areas will be considered in the management of antimicrobials: from prescribing practices to measures in infection control. This ensures that AMS programs are effective in their operations [90].

6.1. Recommendations for effective implementation of AMS

Policymakers help in promoting AMSP in several ways, such as strengthening regulatory environments through proper regulations on the sale and use of antibiotics, particularly over-the-counter sales, to reduce misuse and overuse. Policymakers need to strengthen research and innovation through investment in the development of new antimicrobial agents and alternative therapies, alongside improved diagnostic tools. It will also help support collaborative research initiatives and public-private partnerships that will build innovation and accelerate the development of efficacious solutions against AMR. Strengthening national and regional surveillance systems is another key priority; their expansion to more healthcare facilities, together with the incorporation of surveillance data into EHRs, will give a broader picture of patterns of resistance and antimicrobial use. Improved data collection and sharing will help in developing targeted interventions and updating clinical guidelines based on current trends [50].

It is healthcare providers who are on the frontline of antimicrobial stewardship, with much potential to really make a difference by changing evidence-based practices. Providers must adhere to the most up-to-date recommended guidelines on antimicrobial prescribing and integrate the best current research into daily practice. Ongoing education and training are key to staying current with respect to best practices and emerging trends in AMS. In addition, multidisciplinary interaction with other health professionals improves effective AMS. It is of great importance to ensure that the management plan for antimicrobials and resistance prevention has been fully covered by multidisciplinary participation. Patient education is another important aspect. Providers should emphasize patients' education on the appropriate use of antibiotics, their misuse risks, and compliance with treatment plans. Effective communication can help limit inappropriate antimicrobial use and increase responsible behaviour related to it among patients [38,41,91].

The role of the hospital administrator in the implementation and support of AMS programs is significant. Developing policies, protocols, and resources clearly and concisely for stewardship consists of initiating and maintaining efficient AMS programs. Investment in training and technology in support of AMS initiatives is an integral component of the success of such programs. In view of this, regular data collection, auditing, and feedback mechanisms for monitoring and evaluation are critical to the improvement and effectiveness of stewardship programs. A culture of valuing and prioritizing antimicrobial stewardship should be established. This has to be top led by administrators who lead by example in showing the importance of AMS through leadership support, staff engagement, and recognition of best practice. The aim is to increase adherence to the guidelines of AMS and to improve overall antimicrobial management by building a culture of stewardship within the hospital [42].

6.2. Importance of international collaboration and support

International collaboration and support are very important if proper efforts must be made towards combating AMR at the global level. AMR is, however, a border-crossing issue that needs cooperation from countries and regions in successful management. This would enhance the knowledge sharing and experiences, as well as the interchange of good practices in AMS. Such an exchange allows countries to find better approaches and adapt them according to the local context of the area, thus improving efficiency in stewardship. Joining global initiatives, such as WHO-global action plan on AMR, would provide access to international resources, guidelines, and support. It allows for adjustments of the national strategies in relation to global standards, with the engagement of countries occurring in a manner that boosts the development of a common approach to fighting AMR. International partnerships in research and development are another key platform that furthers knowledge of AMR and the discovery of new antimicrobial

agents and diagnostic tools. Resource-sharing and expertise-sharing through such joint research programs enhance the speed of finding new solutions to resistance [92]. Besides, international collaboration in surveillance efforts enhances monitoring and response capacity to trends in AMR globally. The coordinated surveillance systems provide a wealth of data on resistance patterns that can inform strategies at the global and national levels of AMS. Working with international organizations in global advocacy helps to raise awareness of AMR and calls for policy adjustments at national and global levels. Only through joined-up advocacy will it support the efforts for strengthening regulatory frameworks and creating more funding streams for AMS activities [93]. While international collaboration through initiatives such as the WHO GAP on AMR and One Health provides valuable frameworks, it is imperative to adapt these solutions to the specific challenges faced by secondary care hospitals in India. Resource limitations, infrastructural gaps, and varying levels of AMS awareness necessitate a tailored approach that reflects the ground realities of Indian healthcare.

For example, India's NAP-AMR aligns with WHO's strategic objectives but emphasizes region-specific strategies, such as capacity building in district hospitals and fostering intersectoral collaboration at the state level. Case studies, such as the AMS program implemented in a South Indian secondary care hospital, demonstrate the effectiveness of localized guidelines, prescription audits, and targeted training in reducing inappropriate antibiotic use [9,10]. These programs highlight the importance of multidisciplinary approaches involving clinicians, pharmacists, microbiologists, and infection control teams.

Similarly, regional AMS initiatives must prioritize context-specific challenges, such as addressing the over-the-counter availability of antibiotics and improving microbiological diagnostic capacities in resource-constrained hospitals. By leveraging global partnerships to inform these localized efforts, secondary care hospitals in India can achieve meaningful progress in antimicrobial stewardship without losing sight of their unique constraints.

The successful adaptation of global frameworks to the Indian context is critical for ensuring the relevance and sustainability of AMS programs. Policies and practices must be developed with a keen understanding of the local healthcare landscape, resource availability, and cultural factors to maximize their impact in combating antimicrobial resistance.

7. CONCLUSION

This review has identified, summarized, and critically examined key aspects of AMS in secondary care hospitals, outlining current practices, challenges, and future directions. While the review aimed to synthesize available evidence on the impact of AMS interventions, there remains a notable lack of robust quantitative data, particularly within the context of India and similar low- and middle-income countries. This limitation highlights the urgent need for future research focused on generating rigorous, standardized data to evaluate the effectiveness of AMS interventions. The current AMS initiatives in India have largely been established through foundational efforts such as prospective audit and feedback, formulary restrictions, and pre-authorization of selected antimicrobials, all of which promote rational prescribing and accountability among healthcare providers. Existing literature also offers successful examples demonstrating that multidisciplinary approaches, leadership commitment, and strategic educational interventions can effectively overcome implementation barriers. AMS in secondary care settings plays a vital role in mitigating the impact of AMR. Future studies should prioritize the use of consistent metrics such as AMR rates, hospital-acquired infection rates, and antibiotic consumption data to comprehensively assess the impact of stewardship programs, particularly in resource-limited environments. To advance AMS implementation in such settings, recommended strategic actions include strengthening interprofessional training, integrating basic monitoring tools with national frameworks like AMRSN, enforcing STGs through DTCs, and promoting institutional and administrative engagement. A coordinated, collaborative approach is essential to scale up AMS efforts, standardize national strategies, and ensure sustained progress in combating AMR. Through such collective actions, meaningful advancements in antimicrobial stewardship can be realized, helping to preserve the efficacy of life-saving antibiotics for future generations.

8. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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This study does not involve experiments on animals or human subjects.

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All data generated and analyzed are included in this research article.

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