REVIEW ARTICLE

Technology-Driven Approaches to Tackle the Antimicrobial Resistance: A Scoping review

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ABSTRACT

Antimicrobial Resistance (AMR) is an escalating global health threat that demands novel and strategic interventions to curb its progression. This review examines how technology-based interventions can help tackle antimicrobial resistance (AMR) within community settings Focused interventions include mobile apps for antibiotic education, telemedicine platforms for monitoring antibiotic use, artificial intelligence (AI) applications for AMR awareness, and the development of low-cost diagnostic kits to ensure rational drug use. These technologies promise to empower communities, improve healthcare delivery, and mitigate the misuse of antibiotics.

KEYWORDS

Antimicrobial Stewardship; Public Health; Telemedicine

INTRODUCTION

The modern antibiotic era began in 1928 with Alexander Fleming's fortuitous discovery, a breakthrough that has since saved countless lives by treating infections effectively.(1,2) The widespread and frequently unregulated use of antibiotics has contributed significantly to the rise of antimicrobial resistance and the growing danger posed by highly resistant bacterial strains.(3) Antimicrobial resistance (AMR) stands as a major global health concern in the 21st century. The rapid spread of resistant microbes is diminishing the effectiveness of essential treatments—including antibiotics, antivirals, antifungals, and antiparasitic agents—leading to higher rates of illness, death, and escalating healthcare costs across the globe.(4) Around the world, antimicrobial resistance is responsible for an estimated 700,000 deaths each year, and if current trends continue, this figure could surge to 10 million annually by the year 2050. This would impose an economic cost of roughly 100 trillion USD, encompassing productivity losses.(5) In India, AMR poses a significant health threat, with estimates from 2015 indicating that by 2050, it could lead to around 2 million deaths annually.(6)

Collaborative efforts are essential to formulate new policies and revitalize research strategies aimed at combating the escalating antimicrobial resistance (AMR) crisis.(2) For example, the U.S. Food and Drug Administration (FDA) has implemented guidelines specifying the permissible types, amounts, and usage frequencies of antibiotics.(7) In 2006, the European Union made a major policy move by fully banning the use of antibiotics in animal feed.(8) In contrast to the more stringent regulations implemented in Europe and the United States, Japan has chosen to tackle this issue through

a system based on recommendations rather than enforcement.(9) Meanwhile, China launched its National Action Plan to Contain Antimicrobial Resistance in 2016 as a part of its broader strategy.(10) Despite increased awareness and initiatives targeting AMR, the problem continues to escalate, underscoring the pressing need for robust and effective monitoring frameworks to curb its progression.(11)

India has implemented a series of strategic measures to address Antimicrobial Resistance (AMR). This effort commenced in 2010 with the creation of a National Task Force, which laid the foundation for the National Policy on AMR Containment introduced in 2011. Building on this, the National Programme on AMR Containment was launched in 2013. In line with the objectives of the Global Action Plan on AMR, the government rolled out the National Action Plan on AMR for the period 2017 to 2022. These initiatives include the establishment of surveillance networks, awareness campaigns, infection prevention guidelines, and monitoring antimicrobial use in tertiary hospitals. Additionally, national surveillance networks generate annual AMR reports, contribute to the Global AMR Surveillance System (GLASS), and organize cascading training programs on infection prevention and responsible antimicrobial use across all states and Union Territories (UTs).(12)

Despite existing regulations, antimicrobials remain readily accessible in India without prescriptions, contributing to widespread misuse. This issue is exacerbated by the ease of availability and low cost of antibiotics. During the 1st and 2nd waves of the COVID-19, antibiotic consumption surged significantly, despite the Ministry of Health issuing clear guidelines. In 2020, an estimated 16.29 billion doses of antibiotics were sold in the country. The proportion of adult doses increased from 72.6% in 2018 to 76.8% in 2020, with azithromycin sales rising from 4% to 5.9% over the same period. Notably, between June and September 2020, an excess of approximately 216 million adult doses and 38 million doses of azithromycin were distributed. In contrast, antibiotic consumption among adults has shown a decline in many developed nations. Addressing antimicrobial resistance (AMR) necessitates a multifaceted strategy that directly addresses its root causes .(13)

Since the release of the Jim O'Neill report, there has been a consistent recommendation across various documents to involve local organizations and governance structures in broadening the efforts to combat ABR. These documents also emphasize the need for meaningful and systematic engagement of communities.(14) A key challenge has been developing a suitable narrative around antimicrobial resistance (AMR) that resonates at the grassroots level, enabling meaningful community engagement and supporting a bottom-up strategy that aligns with national and regional action plans.(15) Additionally, studies have highlighted issues related to language and perception surrounding ABR.(16)

Recent research highlights that community-based strategies can significantly contribute to minimizing the misuse of antibiotics.(17) By emphasizing community participation, these approaches have proven particularly effective in tackling antimicrobial resistance (ABR) in low- and middle-income countries (LMICs), as they are grounded in local realities and promote practical, context-specific solutions.(18) For community engagement initiatives to succeed in addressing ABR, it is essential to gain insight into the local setting, build connections with key stakeholders, cultivate trust and motivation, and involve the community in dialogues around antibiotic use and resistance.(19)

Traditional approaches to combating AMR—such as public health campaigns and policy-driven regulations—are essential but insufficient in isolation. Leveraging technology offers an opportunity to strengthen these efforts and provide innovative solutions for AMR management at the grassroots level.

This review explores recent developments in digital technologies, including artificial intelligence, machine learning, and data analytics, with the goal of identifying innovative strategies that can strengthen the management of antimicrobial resistance (AMR). Understanding these technologies will help inform future policies and practices, enabling more targeted and efficient responses to AMR on a global scale.

Technology-Driven Interventions

The Role of Mobile Technology

Serious games have been employed to encourage proper antibiotic usage behaviors. Preliminary findings indicate that serious games can be a valuable tool for improving awareness and understanding of appropriate antibiotic use and antimicrobial resistance (AMR), especially in children and students. Nonetheless, since adults often have easier access to antibiotics and play a key role in shaping the health behaviors of younger individuals, it becomes essential to focus educational efforts on young adults to promote responsible antibiotic practices.(20) The Centers for Disease Control and Prevention (CDC) is actively leveraging social media to enhance public

understanding of antibiotics. To make learning more engaging, educational digital games can be created to inform children about antimicrobial resistance (AMR). These smartphone-compatible games, along with puzzles highlighting the appropriate use, advantages, and potential side effects of antibiotics, could be distributed in schools by public health agencies to strengthen awareness efforts.(21)

Several mobile applications have been developed to promote antibiotic education and awareness among communities:

- "e-Bug" (UK): This app targets school students in the UK, using online games to increase awareness about antibiotics and their proper use through educational resources .(22)
- AMR Treatment Guidelines (India): The "Treatment guidelines for antimicrobial use in common syndromes" app aims to rationalize antibiotic usage within the National List of Essential Medicines (NLEM) and ensure consistency in treating various infectious conditions.
- "SteWARdS Antibiotic Defence" app (Singapore): The app aims to raise public awareness about the proper use of antibiotics and the issue of AMR. Users engage with non-player characters to learn about correct antibiotic usage and effective recovery methods for uncomplicated upper respiratory tract infections .(23)
- CwPAMS app (Africa): introduced in Ghana, Uganda, Zambia, and Tanzania, is designed to enhance antimicrobial stewardship and promote better prescribing habits. It provides healthcare professionals with convenient access to infection management tools, enabling adherence to both national and international antimicrobial use guidelines.(24)

Role of Telemedicine in Monitoring and Reducing Antibiotic Misuse

The U.S. Department of Health and Human Services describes telehealth as the use of digital information and telecommunication technologies to deliver healthcare services remotely. This approach supports not only clinical care but also patient and provider education, public health initiatives, and healthcare administration. Telehealth improves healthcare accessibility and patient mobility by enabling live video consultations, remote monitoring through home or mobile devices, and the electronic collection and storage of health data. Telehealth can be categorized into different types: synchronous telehealth involves real-time interactions—such as phone calls or video chats—between patients and healthcare providers, while asynchronous telehealth, often referred to as "store-and-forward," allows the sharing of medical data, images, or messages for review at a later time.(25) With technological advancements, telemedicine has become more widely adopted across various healthcare sectors. Recent research indicates that utilizing telehealth to implement Antimicrobial Stewardship Programs (ASP) may enhance their accessibility and efficiency .(26-27)

Telehealth-based ASP leverages information technology, such as telephones, email, video conferencing platforms, and mobile apps, to provide antimicrobial prescription training to healthcare providers. This method is more inclusive and cost-effective compared to traditional ASPs, aiming to increase the accessibility and reach of these programs while contributing to the prevention of antimicrobial resistance .(28)

AI-Driven Interventions for tackling AMR

Recently, Artificial Intelligence (AI) has increasingly being recognized as a valuable asset

In addressing the challenge of antimicrobial resistance (AMR). AI-powered applications leveraging sequencing technologies have been instrumental in advancing our understanding of AMR .(29) Additionally, the integration of clinical data into clinical decision support systems facilitates healthcare providers in monitoring antimicrobial resistance trends, promoting judicious antibiotic use .(30) Moreover, artificial intelligence is widely utilized in identifying new antibiotics and investigating effective drug combination strategies .(31)

AI-Powered Tools

Carb-X

Carb-X (Combating Antibiotic-Resistant Bacteria) is an international initiative leveraging artificial intelligence (AI) to advance the development of novel antibiotics and therapies targeting resistant bacterial strains. In public health, Carb-X integrates AI to analyze vast datasets, including bacterial genomes and molecular structures, to pinpoint promising protein targets for antibiotic development. By streamlining various stages of drug discovery—from initial design and identification to accelerated development—this approach helps shorten the timeline for bringing new treatments to market. Carb-X plays a crucial role in tackling the pressing global issue of antimicrobial resistance .(32) This initiative has played a role in identifying new antibiotics, supporting global efforts to combat the growing threat of antibiotic-resistant infections, which are projected to cause millions of deaths around the

world. Through its use of AI, Carb-X is playing a crucial role in strengthening global health systems' preparedness for the rising threat of superbugs .(33)

BlueDot

BlueDot is an AI-powered platform that leverages machine learning techniques to identify infectious disease outbreaks in their early stages. It predicts the likelihood of disease outbreaks by analyzing extensive data from various sources, including global disease outbreak announcements, airline passenger ticketing data, and other official records .(34) The platform proved particularly effective during the COVID-19 pandemic, as it notified users about the outbreak in Wuhan, China, well before international health agencies like the World Health Organization (WHO) issued official alerts .(35,36)

Multisectoral Collaboration:

India has undertaken numerous collaborative efforts to address antimicrobial resistance (AMR) and enhance disease surveillance systems. A key collaboration with the India-US Centers for Disease Control and Prevention (CDC) has played a vital role in enhancing antimicrobial resistance (AMR) surveillance efforts. This partnership has led to the creation of standardized protocols for monitoring AMR and managing related data. Furthermore, it has enabled the adoption of WHONET software to streamline bacteriology testing across surveillance networks. Digital training sessions delivered through the ECHO platform have also been implemented to ensure consistency and quality in diagnostic practices. The Centers for Disease Control and Prevention (CDC) has extended its support to a healthcare-associated infection (HAI) surveillance initiative collaboratively undertaken by the Indian Council of Medical Research (ICMR) and the All India Institute of Medical Sciences (AIIMS). In addition, a collaboration with the United States Agency for International Development (USAID) has been instrumental in enhancing antimicrobial resistance (AMR) containment strategies across six states in India.

Under the Indo-Netherlands partnership, a pilot initiative was launched in Krishna district, Andhra Pradesh, to implement integrated AMR surveillance leveraging a One Health framework. Similarly, under the UK's Fleming Fund Phase 1 grant, with WHO India serving as the implementation partner, significant contributions were made to national AMR efforts. Key initiatives involved offering training on infection prevention and control (IPC), enhancing antimicrobial resistance (AMR) surveillance networks in three states, and carrying out a point prevalence study on antibiotic usage in tertiary healthcare institutions. Furthermore, India, in collaboration with Denmark, has formulated a comprehensive action plan aimed at enhancing technical cooperation in AMR management. Collectively, these international collaborations underscore India's steadfast commitment to combating AMR through robust global partnerships and effective surveillance systems .(37)

Challenges and barriers

Despite the advancements in technology-driven approaches to combating AMR, several challenges persist. A lack of adequate awareness and understanding of antimicrobial resistance among both healthcare professionals and communities—especially in low- and middle-income countries—acts as a barrier to the successful implementation of such interventions.

Inadequate technological infrastructure, coupled with a digital divide, restricts access to tools such as mobile apps and telemedicine, especially in rural and underserved areas. Fragmented data systems and the lack of standardized protocols impede effective AMR surveillance and integration of digital platforms. Financial constraints further limit the development and scaling of innovative technologies, while policy inconsistencies and delays in regulatory approvals undermine coordinated efforts. Additionally, cultural and behavioral barriers, including misconceptions about antibiotics and resistance to new technologies, complicate community engagement and behavior change efforts.

CONCLUSION

Antimicrobial resistance represents a critical public health challenge that demands a multifaceted and technology-driven response. While innovations such as mobile apps, telemedicine platforms, and surveillance systems offer significant potential, their impact is hindered by challenges related to awareness, infrastructure, financing, and policy. Overcoming these challenges is essential to fully leverage technology in the fight against antimicrobial resistance

RECOMMENDATION

To address the barriers in combating AMR, a comprehensive strategy that integrates education, infrastructure development, and policy reforms is essential. Public awareness campaigns and digital tools must be tailored to diverse populations, emphasizing multilingual and culturally relevant approaches. Investments in healthcare

infrastructure, particularly in rural and underserved areas, alongside standardized protocols for AMR surveillance, are crucial to enhancing data integration and accessibility. Strengthened regulatory frameworks and international collaborations can support resource mobilization and the enforcement of judicious antimicrobial use. Lastly, leveraging telemedicine and participatory community engagement can drive behaviour change and ensure the sustainable implementation of antimicrobial stewardship programs.

Authors Contribution

All authors have contributed equally.

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Conflict of Interest

There are no conflicts of interest.

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The authors haven't used any generative AI/AI assisted technologies in the writing process.

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