UNIVERSITY OF CAMBRIDGE
Department of Public Health and Primary Care

Effectiveness of Digital Antimicrobial Stewardship Initiatives in Community Healthcare Settings Across Low- and Middle-Income Countries: A Systematic Review

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Questions for reflection

1. Which aspects of this assignment have you learned the most from? (and/or) What are you happiest with?
   A: I learnt the most from synthesising findings from different studies into a coherent framework as it taught me how to critically interpret diverse evidence. I'm happy that this is the first known multi-stakeholder review of digital antimicrobial stewardship initiatives conducted in community settings in low- and-middle income countries as it has global relevance.

2. How have you incorporated feedback from peers/supervisors/ previous assignments into this assignment?
   A: I incorporated feedback by improving the structural clarity and analytical depth, especially in the synthesis and discussion sections, ensuring the findings were more coherent, contextually grounded based on comments from my supervisor.

Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

Statement of Length

This dissertation complies with the 15,000-word limit established by the degree committee, which includes footnotes but does not include tables, figures, legends, appendices, the abstract or the bibliography.

Acknowledgement

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Acronyms and Abbreviations

ALMANACH	-	ALgorithm for the MANAgement of CHildhood illness
ALRITE	-	Acute Lower Respiratory Illness Treatment and Evaluation
AMR	-	Antimicrobial resistance
AMS	-	Antimicrobial stewardship
AWaRe	-	Access, Watch, Reserve antibiotic class
CDC	-	Centers for Disease Control and Prevention
CHW	-	Community Health Worker
CwPAMS	-	Commonwealth Partnerships for Antimicrobial Stewardship
DDD	-	Defined daily dose
ECDC	-	European Centre for Disease Prevention and Control
eIMCI	-	Electronic Integrated Management of Childhood Illness
ePOCT	-	Electronic point-of-care testing tool
ESBL	-	extended-spectrum β-lactamase
GLASS	-	Global Antimicrobial Resistance and Use Surveillance System
HIC	-	High income country
IMCI	-	Integrated Management of Childhood Illness
LMIC	-	Low and middle income country
MRSA	-	Methicillin-resistant Staphylococcus aureus
M-TIBA	-	Mobile Telephone-based Healthcare Data and Payment Exchange Platform
OTC	-	Over the counter
PDA	-	Personal Digital Assistant
PV	-	Participatory Video
PRISMA	-	Preferred Reporting Items for Systematic reviews and Meta-Analyses
R&D	-	Research and development
RCT	-	Randomized Controlled Trial
SSA	-	Sub-Saharan Africa
WHO	-	World Health Organization

Contents

Abstract

Background:
Antimicrobial resistance (AMR) poses a critical threat to health systems globally, with the highest burden borne by low- and middle-income countries (LMICs), where inappropriate antibiotic use is widespread in community healthcare settings. Despite growing recognition of antimicrobial stewardship (AMS) as a key strategy to combat AMR, most interventions remain hospital-focused. Digital health tools offer promising, scalable solutions to strengthen AMS at the community level in LMICs. However, their effectiveness remains inadequately synthesised.

Objective:
To systematically assess the effectiveness, implementation feasibility contextual and behavioural factors influencing digital AMS interventions in community healthcare settings across LMICs.

Methods:
This review followed the PRISMA guidelines and included studies published between January 2000 and May 2025. Seven databases (PubMed, Embase, Scopus, Web of Science, Cochrane Library, WHO Global Index Medicus, TRIP Database) and grey literature sources were searched. Studies were eligible if they evaluated digital AMS interventions involving patients, providers or policymakers in LMIC community settings. Risk of bias was assessed using RoB 2 for RCTs, ROBINS-I for observational studies and CASP for qualitative designs. Narrative synthesis and subgroup analysis were conducted using a RE-AIM-informed analytical framework.

Results:
Twenty-four studies from 18 LMICs were included, with most interventions targeting healthcare providers. CDSS tools such as ePOCT, ALMANACH and eIMCI consistently reduced antibiotic prescribing rates (4%–84% reduction) from13 studies and inappropriate prescribing (12 studies), with moderate to high evidence certainty. Clinical outcomes (9 studies) confirmed non-inferiority or improvements in recovery rates. Behavioural improvements in provider knowledge, confidence and caregiver engagement were observed in 12 studies. However, data on antimicrobial resistance trends, antibiotic class selection and cost-effectiveness were limited.

Conclusion:
Digital AMS interventions, demonstrate substantial potential to improve prescribing quality and clinical outcomes in LMIC community settings. Future efforts should prioritise economic evaluations, scalability and integration with health systems to ensure sustainable impact on AMR.

(295 words)

1. Introduction

1.1 The Global Burden of Antimicrobial Resistance (AMR)

Widely referred to as the 'Silent Pandemic', antimicrobial resistance (AMR) has emerged as a defining global health risk of the 21st century claiming over a million lives annually [1, 2]. It arises when microbes including bacteria, viruses, fungi and parasites develop the ability to withstand antimicrobial agents designed to kill them, rendering standard treatments ineffective [2-4]. This phenomenon results in longer illness durations, treatment failures, increased medical costs and heightened mortality rates [2]. Although AMR spans a wide range of pathogens and drugs, this review will focus specifically on antibiotics, given their central role in community healthcare and their disproportionate contribution to the global resistance burden [1]. Antibiotic resistance now threatens progress across all age groups. While AMR-related mortality in children has declined by over 50% since 1990, older adults have become increasingly vulnerable, with deaths among those aged 70 and above rising by more than 80% during the same period [1].

This growing burden is reflected in specific pathogen–drug combinations, with Methicillin-resistant *Staphylococcus aureus* (MRSA) accounting for approximately 130,000 deaths in 2021, up from 57,200 in 1990 [1, 5, 6]. Similarly, Carbapenem resistance among Gram-negative organisms saw the largest rise in AMR mortality, increasing from 127,000 to 216,000 deaths globally between 1990 and 2021, more than any antibiotic class over that period [1]. This has led to increasing reliance on last-resort drugs like colistin, which are expensive, less available and associated with significant toxicity and resistance development themselves. Forecasts for the coming decades are alarming. Without interventions, deaths associated with AMR may reach 10 million annually, surpassing current cancer mortality [7]. Cumulatively, this could result in nearly 39 million direct deaths between 2025 and 2050 or three deaths every minute [1].

The economic repercussions are equally disturbing. A World Bank analysis estimated that by 2030, AMR could reduce global GDP by up to 3.8%, while health system costs might increase by US $1 trillion annually by 2050 [8]. More recent modelling suggests global health expenditures could increase by US $66 billion per year, escalating to US $159 billion by 2050 under a business-as-usual scenario [9]. Even high-income countries (HICs) are feeling the impact. In the United States, antibiotic-resistant infections incur US $21-34 billion in healthcare expenses and over eight million extra hospital days per year [10]. Likewise in Europe, resistance-related healthcare costs may reach US $3.5 billion annually, which is seven times more than that needed to manage Tuberculosis [11, 12]. Globally, treatment-resistant infections often require expensive alternative therapies and prolonged hospitalization, adding US $29,000 per episode in some cases [13, 14].

Beyond mortality and economic strain, AMR threatens the very foundations of modern medicine. Routine procedures such as surgery, chemotherapy and transplants rely on effective antimicrobials for infection prevention. The loss of these drugs could derail decades of medical progress and signal a reversal to a 'pre-antibiotic era' [15, 16]. The drivers behind this crisis are multifaceted including overprescription, suboptimal antibiotic stewardship, lack of rapid diagnostics and extensive use of antibiotics in agriculture, that work synergistically to accelerate resistance [3, 4, 17, 18]. Concurrently, development of new antibiotic pipelines lags behind the pace of resistance emergence, exacerbating this global threat [19]. In recognition of the gravity of AMR, international bodies have initiated concerted actions. The establishment of the Global Antimicrobial Resistance Surveillance System (GLASS) [20] by the World Health Organization (WHO) and inclusion of AMR on other global development agendas underscore the growing political commitment [21, 22]. However, the scale of the threat continues to outpace current global responses. Strategic, multi-sectoral interventions including improved stewardship, accelerating diagnostics and drug development and enhancing surveillance are urgently needed to curb the projected humanitarian and financial toll.

1.1.1 The AMR Landscape in Low- and Middle-Income Countries (LMICs)

LMICs, particularly in sub-Saharan Africa (SSA) and South Asia, bear a disproportionate burden of AMR, accounting for nearly 90% of global AMR-related deaths [1, 23] (see Figure 1). Compared to HICs, the consequences in LMICs are more severe with resistant infections associated with higher mortality and twice the risk of ICU admission [24]. This burden is driven by a complex interplay of health system, socioeconomic, environmental and policy factors [25-27]. Inadequate pharmaceutical governance and high drug costs [15] have facilitated the widespread sale of over-the-counter (OTC) antibiotics without prescriptions, often by untrained vendors or through informal outlets [28-30]. Such practices are especially prevalent in rural and underserved areas, where financial hardship and sociocultural norms frequently delay access to formal care, increasing reliance on informal providers [31, 32]. Non-prescription antibiotic use ranges from 38% to 93.8% [32, 33], with one South American review reporting 78% of pharmacies in South America engaging in this practice [34]. Such misuse contributes to subtherapeutic dosing, incomplete treatment and accelerated resistance [35], a trend further intensified during the COVID-19 pandemic, particularly in countries lacking robust antimicrobial stewardship (AMS) frameworks [36].

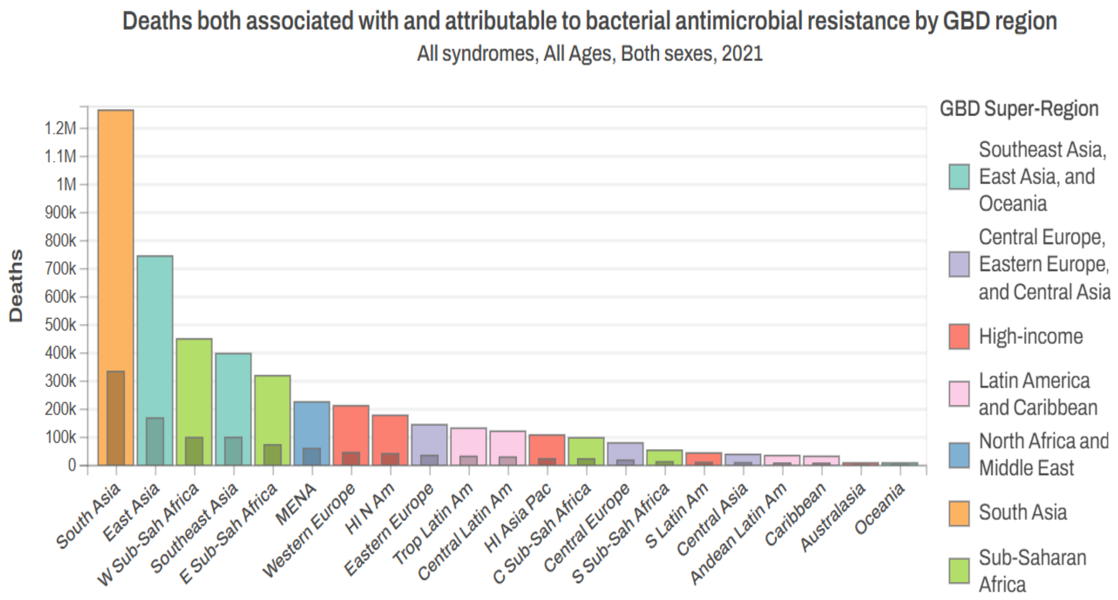


Figure 1: This figure illustrates the global burden of deaths attributable and associated to AMR, showing a predominance in Asia and Africa. It was created using the data from the Institute For Health Metrics And Evaluation platform [37]

Despite the widespread adoption of national AMR action plans, over half of LMICs do not report antibiotic consumption data, reflecting critical implementation gaps [38]. These shortcomings are largely attributed to inadequate financing and the absence of stewardship infrastructure in primary care [39, 40]. Surveillance systems are similarly underdeveloped, often characterised by fragmented laboratory networks, inconsistent reporting and insufficient data infrastructure [4, 39, 41]. In the Asia-Pacific region for example, only a handful of countries have established even rudimentary AMR surveillance systems [42]. This shortfall has routinely been highlighted by the WHO's GLASS initiative, which noted limited and incomplete surveillance contributions from LMICs, in contrast to their higher-income peers [20]

Compounding these challenges are the environmental dimensions of AMR, particularly the unchecked use of antibiotics in agriculture [17]. In LMICs, livestock antibiotic consumption is poorly monitored and largely unregulated, with projections indicating an increase from 131,000 tonnes in 2013 to over 200,000 tonnes by 2030, driven predominantly by rising demand in these regions [43]. Antibiotic runoff from farms contaminates soil and water systems, selecting for resistant organisms and creating environmental reservoirs that endanger human health [44, 45]. These ecological threats are mirrored by critical gaps in the global research and development (R&D) pipeline [15]. Current innovation efforts remain skewed on pathogens prevalent in high-income settings, with limited incentives to address resistant organisms common in LMICs. Concurrently, initiatives to strengthen local antibiotic manufacturing and procurement systems in these settings remain inconsistent and insufficiently aligned with local health system needs [46].

Despite these sobering challenges, promising progress is emerging. Countries such as Bangladesh and Vietnam have implemented national surveillance pilots, regulatory reforms and workforce training to enhance AMS capacity [47, 48]. Targeted vaccination programmes such as those for pneumococcal and typhoid diseases have also helped reduce antibiotic use and resistance in these settings [49, 50]. Additionally, regional collaborations and global One Health initiatives, which integrate human, animal and environmental health are also slowly strengthening AMR governance and coordination [51-53]. While these developments offer hope, they must evolve into sustainable, system-wide strategies that are contextually adapted to the complex realities of LMICs.

1.2 Antimicrobial Stewardship (AMS): Concepts, Evolution and Evidence

AMS is defined as a set of coordinated strategies designed to improve and measure the appropriate use of antimicrobials by promoting optimal drug selection, dosing, duration and route of administration [54, 55]. First conceptualised in the late 1990s, AMS emerged as a response to the accelerating pace of resistance development and the dwindling supply of novel antimicrobials [56]. Its foundational goal was to conserve existing treatment options while ensuring effective care. A major milestone occurred in 2015 with the launch of the WHO's Global Action Plan on AMR, which designated AMS as a strategic priority [57]. By 2022, 76% of HICs and 42% of LMICs had adopted national AMS guidelines, highlighting growing global commitment to stewardship [58]. This momentum has been reinforced by complementary international efforts, including those led by the Foundation to Prevent Antibiotic Resistance (PAR) [59] and the A Clinically-Oriented Antimicrobial Resistance Surveillance Network (ACORN) [60], which have supported the advancement of stewardship initiatives worldwide.

Originally centred on formulary restrictions, AMS has since evolved into multifaceted and multidisciplinary programmes incorporating patient and clinician education, audit and feedback and the utilisation of decision support tools [61]. In hospital settings, these interventions have demonstrated significant clinical benefits. A 2020 programme reported a reduction in antibiotic consumption from 320 to 233 defined daily doses (DDDs) per 1,000 patient-days, alongside an 85% decline in *Clostridioides difficile* infections [62]. A 2019 systematic review also linked AMS to an 18.1% reduction in mortality and a shortened hospital stay by over three days [63]. In paediatrics, AMS initiatives have effectively reduced broad-spectrum antibiotic use, particularly third-generation cephalosporins [64, 65]. Although limited, evidence from primary care settings also points to the potential of AMS interventions to reduce inappropriate antibiotic prescribing and curb multidrug-resistant organism colonisation [66-68].

AMS interventions have also consistently demonstrated substantial cost savings, with reductions ranging from 10% to 60% per programme [69, 70]. In Canada, mean antimicrobial costs declined from $18.40 to $14.53 per patient-day [71], while a single hospital in Spain saved nearly one million Euros over five years [72]. Despite these promising results, AMS remains largely hospital-focused, with little application in LMIC community settings due to numerous challenges for intervention implementation [40]. Nevertheless, evidence from hospitals suggests that AMS can also reduce unnecessary antibiotic prescribing in community care. In response, consensus guidelines have emphasised adaptable core components such as institutional commitment, education and monitoring mechanisms as foundations for scalable AMS [73, 74]. Crucially, successful implementation depends on multidisciplinary collaboration, requiring the sustained engagement from clinicians, nurses, pharmacist and most importantly patients [75]. Strengthening such integrated approaches is vital to advancing stewardship in resource-constrained health system contexts.

1.2.1 The Critical Role of Community Healthcare in Antimicrobial Use

Community healthcare, often the first point of contact within health systems, plays a pivotal role in shaping patterns of antibiotic use. In many countries, particularly LMICs, ‘community care’ encompasses not only primary care settings like clinics, pharmacies and general practices but also elements of secondary care including smaller district and sub-district hospitals [76]. Although these facilities are technically categorized as hospital-level, they often provide frontline, community-level care due to health system fragmentation and limited tertiary access [77]. Globally, up to 80% of antibiotics are prescribed in community settings, making them a critical target for AMS interventions [78]. In HICs, over 70% of antibiotic consumption occurs outside hospital settings [79, 80]. This proportion is higher in LMICs mainly because of the greater burden of communicable diseases [81]. Respiratory tract infections, despite being largely viral and self-limiting are the leading cause of antibiotic prescriptions, with up to 50% of patients with acute cough receiving antibiotics unnecessarily [82]. Following closely behind, urinary tract infections along with common skin and dental conditions also drive high antibiotic prescribing volumes in primary and lower-level secondary care [83, 84].

A major driver of inappropriate prescribing in LMICs is the widespread lack of diagnostic capacity, forcing clinicians to rely on symptom-based diagnosis and empirical treatment [7]. Prescribing practices are further influenced by patient expectations, reputational concerns and financial incentives linked to medication sales [47, 75]. Concurrently, self-medication is widespread, with individuals using leftover drugs, discontinuing treatment prematurely or sharing antibiotics, driven by low health literacy, cost barriers and prevailing norms [8, 15, 33]. Evidence suggests that community antibiotic use drives the selection of AMR by promoting the proliferation of resistance genes in both pathogenic and commensal organisms. For instance, prior outpatient antibiotic use is associated with colonisation by extended-spectrum β-lactamase (ESBL)-producing *Enterobacteriaceae* [85, 86]. Similarly resistant urinary pathogens like *Escherichia coli* have also become increasingly common in outpatient care [87].

Community-based AMS interventions have however yielded some encouraging results. Delayed prescribing strategies for respiratory tract infections have significantly reduced unnecessary antibiotic consumption without compromising clinical recovery [88]. Educational and communication-focused interventions within general practice settings have achieved up to 50% reductions in inappropriate prescribing [89, 90], while broader community stewardship efforts have been shown to improve public understanding of AMR and enhance adherence to prescribing guidelines [91]. To further promote rational antibiotic use, the WHO introduced the AWaRe classification system, which groups antibiotics into Access (first-line, low resistance potential), Watch (higher resistance risk) and Reserve (last-resort) options [92]. Despite these promising interventions, AMS efforts in LMICs remain underdeveloped due to lack of implementation tools, insufficient provider training and inadequate alignment with local formularies.

1.3 Harnessing Digital Health Tools to Strengthen AMS

Digital health innovations have become central to modern AMS strategies, enhancing the precision, timeliness and reach of interventions aimed at optimising antimicrobial use. The WHO defines digital health as "the use of digital technologies to improve health" [(93)]. These encompass clinical decision support systems (CDSS) which guide prescribing and can be embedded in electronic health records (EHRs) or accessed via mobile devices [(94)], mobile health (mHealth) applications to support patient education, adherence and symptom tracking [(15)] as well as telehealth platforms to facilitate remote consultations [(95)]. More recently, artificial intelligence (AI) tools using machine learning have been employed to analyse clinical and microbiological data, enabling prediction of infection risk and recommending appropriate antibiotic therapy to reduce misuse [(31, 96)]

In HICs, digital AMS has evolved substantially, particularly in hospital settings over the past two decades. Initial efforts centred on computerized prescribing alerts within EHR systems, providing clinicians with reminders or restriction protocols based on antibiotic classes [(97)]. These have since advanced into sophisticated CDSS that integrate microbiology, pharmacy and patient-specific data to generate real-time recommendations on drug choice, dose and duration [(98)]. Evidence supports their effectiveness in enhancing guideline adherence and reducing unnecessary antibiotic use[(94)]. For instance, in an Australian intensive care unit, CDSS implementation led to significant reductions in overall antibiotic consumption, including agents from the WHO 'Watch' and 'Reserve' categories, such as third-generation cephalosporins and carbapenems, which are critical for minimizing resistance development [(99)]. Similarly, American hospitals that evaluated the effect of digital decision support through audits observed decreased vancomycin prescribing without compromising patient outcomes [(100, 101)]. AI-based tools have also enhanced AMS through improved laboratory-clinical integration. The use of predictive analytics in molecular diagnostics have enabled earlier pathogen identification and resistance profiling, reducing turnaround times compared to traditional, labour-intensive microbiology techniques, allowing for earlier de-escalation or escalation of therapy [(102)].

In outpatient and resource-limited settings, non-CDSS mobile tools and other digital applications are gradually widening access to AMS support. Smartphone-based platforms offering localised antibiotic guidelines, dosing calculators and pathogen-specific advice are now in use across more than 90 countries [(103)]. Notable examples include the 'Rehydration Calculator' application in Bangladesh, which supports diarrhoeal disease management [(104)] and the Commonwealth Partnerships for Antimicrobial Stewardship (CwPAMS) application, used in Ghana, Uganda, Zambia and Tanzania, which has improved prescriber confidence and reduced deviation from guidelines [(105)]. In remote or smaller community hospitals, tele-AMS platforms have further expanded stewardship reach. In one program, antibiotic use was reduced from 30–50% to under 5%, with improved adherence to local formularies [(95)]. Digital surveillance systems also play a crucial role in monitoring AMS outcomes. Integrated dashboards can now track antimicrobial consumption, resistance trends and compliance metrics in real time [(106)]. The English Surveillance Programme for Antimicrobial Utilisation and Resistance (ESPAUR) exemplifies this approach, enabling national-level monitoring and feedback that contributed to a sustained reduction in community antibiotic use in England [(107)].

Cognizant of the strategic value of such digital approaches, global health institutions have increasingly advocated for their adoption. The WHO, the Centers for Disease Control and Prevention (CDC) and the European Centre for Disease Prevention and Control (ECDC) have all issued technical guidance on integrating digital tools into national AMR action plans [(74, 93, 108)], while platforms like the Digital Health Atlas has helped facilitate the coordinated implementation of such initiatives [(109)]. As the digital health ecosystem matures, its integration with AMS priorities offers a powerful mechanism for improving antibiotic use, advancing diagnostics, supporting clinical decision-making and enabling robust, scalable monitoring systems.

1.3.1 Opportunities and Challenges for Digital AMS in LMICs

Digital health interventions hold transformative potential for improving AMS in LMICs. The increasing ubiquity of mobile technologies, coupled with lessons learned from previous digital health successes in malaria and HIV/AIDS control, lays a strong foundation for expanding digital AMS across varied healthcare contexts [110, 111]. For instance, SMS-based systems for malaria surveillance in Zambia and Kenya have been shown to facilitate early outbreak detection and timely treatment deployment, reducing transmission and mortality [112, 113]. Similarly in HIV care, electronic patient monitoring systems improved adherence to antiretroviral therapy and follow-up rates, while teleradiology initiatives have enhanced tuberculosis diagnostics in rural areas [114, 115]. These precedents underscore the scalability and adaptability of digital tools to support infectious disease control and stewardship.

At the patient and community level, digital platforms have been employed to raise awareness and influence health-related behaviours. Telemedicine applications, virtual health assistants [116], social media health campaigns [117] and interactive online games [118] have effectively disseminated information on appropriate antibiotic use, the risks of self-medication and the importance of adherence. These tools have shown considerable success in promoting behaviour change, particularly when delivered through culturally sensitive and linguistically appropriate platforms, demonstrating measurable improvements in health literacy and reductions in unnecessary antibiotic demand.

For health system administrators and policymakers, digital tools provide critical infrastructure to strengthen AMS through enhanced surveillance, data-driven decision-making, cross-sector collaboration and scalability. Electronic platforms support real-time monitoring of antibiotic use, resistance patterns and AMS intervention outcomes across care levels and regions. The Africa CDC-led AMR Surveillance Network exemplifies this, linking over 20 countries via a centralised dashboard that integrates laboratory and prescription data to inform regional responses [119]. Advanced analytics, including big data and geographic information systems, enable predictive modelling of AMR hotspots and optimisation of supply chain logistics, facilitating timely, evidence-informed decisions. Digital tools also promote cross-sectoral integration and scalability across LMICs [31]. For example in Nepal, the introduction of digital AMR portals has improved the timeliness, accuracy and interoperability of its health system data [120].

However, the successful implementation of digital AMS interventions in LMICs is contingent upon navigating a constellation of challenges spanning infrastructure, financing, cultural and behavioural dynamics as well as regulatory and institutional frameworks. Infrastructural limitations such as unreliable electricity, poor internet connectivity and inadequate hardware maintenance remain critical barriers, particularly in rural settings [121]. Even when digital platforms are available, interoperability issues between proprietary systems and fragmented vertical programmes hinder effective integration [122]. Financial sustainability also remains precarious, as many digital AMS initiatives rely on short-term donor funding without secure government budget allocations or incorporation into national health financing frameworks [123].

Culturally, hierarchical dynamics and provider scepticism toward technology may impede the uptake of digital tools [124, 125]. Adoption barriers are further compounded by limited digital literacy, increased perceived workload and concerns about deskilling among frontline providers [126]. On the regulatory front, weak regulatory environments contribute to privacy concerns, lack of standardisation and unclear accountability in AMS data management [127, 128]. Moreover, over-reliance on trial-based models without national scale-up strategies risks producing siloed, unsustainable efforts [129. While not a silver bullet for AMR, digital AMS interventions when effectively integrated, represent a powerful lever to enhance antimicrobial governance and evolve from promising pilots to enduring, population-level impact.

1.4 Rationale and Significance of This Review

AMR poses a critical and escalating threat to global health, jeopardising decades of progress in infectious disease control, surgical safety and universal health coverage. Although the majority of antibiotic prescribing occurs in outpatient and community healthcare settings [78], stewardship efforts to date have largely concentrated on hospitalised patients [100, 101]. This imbalance represents a significant oversight in addressing inappropriate antibiotic use, particularly within communities where it is most prevalent. Digital health interventions have demonstrated potential in reducing inappropriate antibiotic use in HICs, offering improved diagnostic support, provider guidance and patient education. Notably, LMICs have already leveraged digital tools with measurable success in malaria control [110], HIV management [111] and epidemic surveillance [119], underscoring the feasibility of similar approaches in community-based AMS.

Despite these encouraging precedents, only a few existing studies have disaggregated findings by type of digital tool or target user group whether patients, providers or policymakers. This lack of granularity constrains the ability of stakeholders in LMICs to make evidence-informed decisions regarding context-appropriate and cost-effective digital AMS investments. There remains an urgent need to systematically assess the effectiveness, scalability and contextual relevance of digital AMS interventions within LMIC community settings. This requires examining the factors that shape implementation success, including infrastructure, digital literacy and regulatory environments.

This systematic review was therefore designed to address these critical knowledge gaps. Its scope is intentionally broad, encompassing a wide range of digital health interventions relevant to patients, healthcare providers and policymakers. To the best of current knowledge, it is the first systematic review to adopt a multi-stakeholder approach, explicitly grouping and analysing findings by end-user category in these setting. This structure enables a nuanced understanding of how digital tools influence prescribing behaviours, clinical decisions and health system dynamics across levels of care.

By focusing exclusively on studies conducted in LMICs within community healthcare settings, this review seeks to determine not only the effectiveness of digital AMS tools but also the mechanisms through which they operate, the contexts that enhance their impact and the barriers that hinder their adoption. In doing so, the review seeks to inform future research agendas and provide strategic guidance to national governments, global donors and implementation partners to support the development of scalable, context-sensitive digital AMS strategies that strengthen LMIC health systems and contribute to the global AMR response.

1.5 Aims and Research Questions

This study aims to synthesise the findings from available literature and add to the evidence base by providing a more comprehensive and nuanced understanding of the effectiveness of digital AMS initiatives in community healthcare settings in LMICs. By evaluating their impact not only on antibiotic prescribing patterns, resistance trends and patient outcomes but also the pathways through which these changes occur, this review seeks to provide actionable insights for healthcare providers, researchers and policymakers. More importantly, it further examines the contextual factors that shape the implementation and sustainability of these interventions in resource-constrained settings.

The principal and secondary research questions identified after conducting a pilot search are:

Primary Research Question:

1) How effective are digital interventions in improving antibiotic use among patients, influencing providers' prescribing practices, and guiding policymakers in community healthcare settings in LMICs?

Secondary Research Questions:

2) What are the pathways through which effective digital interventions influence patient and provider behaviours and antibiotic resistance trends in community settings?
3) What are the facilitators and barriers to implementing digital AMS initiatives in LMICs, and how can these be optimised?

2. Methods

2.1 Study Approach

This systematic review employed a structured and rigorous methodology based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The review synthesised evidence on the effectiveness of digital AMS interventions in community healthcare settings across LMICs. It followed a protocol that has been pre-registered and awaiting approval from the International Prospective Register of Systematic Reviews (PROSPERO, ID: 1071419), ensuring transparency and replicability. The study focused on both implementation and clinical outcomes, including antibiotic prescribing patterns, resistance trends, patient outcomes and health system implications.

2.2 Information Sources

To ensure comprehensive coverage of the available literature, a systematic search was done using the following major academic databases including PubMed, Embase, Scopus, Web of Science, Cochrane Library, WHO Global Index Medicus and TRIP Database. These sources were selected for their breadth of coverage in global health, clinical medicine, implementation science and health systems research.

A pilot search was initially conducted across these databases to refine the strategy and assess the volume and nature of relevant studies. In addition, Google Advanced Search was employed to identify grey literature, including reports and policy briefs from the WHO, ministries of health and other global health organisations.

The search included studies published between January 1, 2000 and May 23, 2025, reflecting the period during which relevant digital health interventions began to emerge and expand. To ensure a comprehensive analysis, the reference lists of included studies and relevant systematic reviews were also screened to identify additional eligible publications.

2.3 Search Strategy

A structured search strategy was developed using both controlled vocabulary, including Medical Subject Headings (MeSH) terms and free-text keywords to capture studies across four core domains, namely antimicrobial stewardship, digital health interventions, community healthcare in LMICs and stakeholder groups including patients, providers and policymakers.

Search terms included combinations such as 'antimicrobial stewardship', 'antibiotic resistance', 'digital health', 'clinical decision support systems', 'mHealth', 'community health services' and 'low- and middle-income countries' among others. Boolean operators, truncations and proximity operators were used to optimise sensitivity and specificity.

The search strategy was refined with the assistance of Ms. Veronica Phillips, a medical librarian at the University of Cambridge and was peer-reviewed using the Peer Review of Electronic Search Strategies (PRESS) checklist [(129)] to ensure accuracy and completeness (see Appendix 3 for the full search list).

To enhance comprehensiveness, forward and backward citation screening of included articles and relevant reviews was conducted. This iterative process aimed to trace the development of digital AMS interventions and identify foundational studies and emerging evidence in the field.

2.4 Inclusion/Exclusion Criteria and Rationale

Eligibility criteria were developed using the Population, Intervention, Comparison and Outcome (PICO) framework to ensure clarity and relevance [(130)]. The review included studies involving patients, providers or policymakers in community healthcare settings across LMICs. In recognition of contextual differences in LMIC health systems, community healthcare was broadly defined to encompass not only primary care clinics but also outpatient services delivered outside tertiary hospitals such as community health centres, pharmacies, drug stores and mobile health units in this review. Lower-level district or sub-district hospitals were also included if they functioned as first-contact care providers without inpatient or specialist services. Interventions based exclusively in secondary or tertiary hospital settings were excluded, unless they explicitly spanned both secondary and community levels of care.

Eligible interventions included a wide range of digital AMS tools such as CDSS, mHealth applications, telemedicine platforms, AI-enabled systems and other digital technologies. Comparators included usual care, non-digital AMS approaches, or absence of intervention. Studies were included in the synthesis if they reported on at least one primary or secondary outcome related to antimicrobial use, including changes in prescribing practices, antibiotic class selection, resistance trends, clinical outcomes, cost-effectiveness or implementation feasibility. The full eligibility criteria are detailed in Table 1.

Table 1: Full Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Studies published in English. • Peer-reviewed articles and grey literature with accessible full-texts. • Either randomised controlled trials (RCTs), observational studies including quasi-experimental, case-control, cohort, cross-sectional or ecological studies and qualitative studies. • Studies published from the year 2000 onward to reflect recent developments in digital health. • Studies conducted in low- and middle-income countries (LMICs) as defined by the World Bank. • Studies evaluating digital antimicrobial stewardship (AMS) initiatives involving digital tools such as mobile health applications, clinical decision support systems, telemedicine, electronic health records or artificial intelligence (AI). • Interventions targeting community healthcare settings including primary care clinics, outpatient centres, lower-level hospitals). • Studies involving healthcare providers, patients or policymakers in community settings. • Studies reporting outcomes on antibiotic use, clinical effectiveness, awareness, resistance trends or economic impact	• Studies published in languages other than English. • Studies conducted in high-income countries. • Articles published before the year 2000, reflecting outdated practices in digital health. • Interventions focused exclusively on hospital or tertiary care settings. • Non-digital AMS approaches including manual audits or in-person training programs. • Studies without reported outcomes related to antibiotic use, resistance or patient health. • Non-original research articles, such as reviews, editorials or opinion pieces. • Studies focusing on veterinary or agricultural antibiotic use rather than human health. • Duplicate publications of the same study, unless the most comprehensive version is retained. • Studies with insufficient information or missing key data for analysis.

2.5 Screening and Selection Process

Two reviewers (myself and a medical student) independently screened and filtered titles, abstracts and full-text articles based on the predefined eligibility criteria. Deduplication of references were done using EndNote and subsequently imported into Rayyan, a web-based platform designed to streamline systematic review screening [(131)]. Rayyan was used to blind initial reviewer decisions and accelerate the identification of potential conflicts. Whenever disagreements arose during the full-text screening stage, the two reviewers engaged in discussion to resolve them. In cases where consensus was not reached, an independent third reviewer provided adjudication and made the final inclusion decision. The entire selection process is visually summarised in the PRISMA Flow Diagram [(132)] in Figure 2, which outlines the number of records identified, screened, excluded and included at each stage of the review.

2.6 Data Collection Process and Data Items

Data extraction was done using a standardised template created in Microsoft Excel® (Microsoft Corporation, Redmond, WA, 2024), developed specifically for this systematic review. Both reviewers independently extracted data from each eligible study to ensure consistency and minimise bias. The results of each extraction were compared, discrepancies discussed and disagreements resolved through consensus. In cases where consensus could not be reached, a third reviewer was available to adjudicate. Study authors were not contacted for data clarification and no automation tools were used for extraction due to the heterogeneity and complexity of the reported interventions.

The main data extraction domains included study author and year, country, study design, setting, population, disease focus, intervention type, comparator, outcomes assessed and key findings. All reported data relevant to each predefined outcome domain were extracted, including multiple measures, time points and analyses. When multiple outcomes within a domain were reported, the most comprehensive and clinically relevant data were prioritised, particularly those aligning closely with the review's primary or secondary outcomes as listed below:

Primary Outcomes

1) **Change in antibiotic prescribing rates**
Proportion of patient encounters resulting in an antibiotic prescription, before and after intervention.

2) **Reduction in inappropriate antibiotic prescribing**
Includes prescribing without clinical justification, use of antibiotics for viral infections or poor alignment with guidelines.

3) **Use of broad-spectrum vs. narrow-spectrum antibiotics**
Shifts in antibiotic class selection.

Secondary Outcomes

4) **Clinical outcomes: infection resolution, adverse events and hospital referrals**
Safety and effectiveness markers indicating quality of care.

5) **Trends in antimicrobial resistance at the community or facility level**
Longer-term indicator of AMS impact, usually reported indirectly.

6) **Knowledge, attitudes or behaviour toward antibiotic use among healthcare providers and/or patients**
Reported through surveys or interviews, linked to behaviour change.

7) **Feasibility and acceptability of digital AMS interventions in routine practice**
Implementation outcomes capturing usability, satisfaction as well as barriers and enablers.

8) **Cost or cost-effectiveness of digital AMS interventions**
Where economic evaluation is included or discussed.

In cases of missing or unclear information, contextual clues from the full text were used to make reasoned assumptions, documented in the extraction file. Studies lacking critical outcome data with no possibility of inference were excluded from the synthesis. This structured, rigorous approach enabled us to capture the complexity and diversity of digital AMS interventions across LMIC community healthcare settings while maintaining analytical consistency and methodological transparency.

2.7 Ethics Statement

Ethical approval was not required for this systematic review as it involved analysis of publicly available primary data from previously published studies and did not directly involve any human participants or collection of identifiable personal data.

2.8 Risk of Bias Assessment

A rigorous risk of bias assessment was undertaken to evaluate the internal validity and credibility of the evidence across included studies. To ensure methodological robustness and minimise subjective interpretation, two reviewers independently appraised all studies, with discrepancies resolved through discussion or adjudication by a third reviewer. Different tools were used based on study design to ensure appropriate and methodologically sound appraisal.

For randomised controlled trials (RCTs), the revised Cochrane Risk of Bias tool (RoB 2) was used [133]. This tool assesses five domains which were bias arising from the randomisation process, deviations from intended interventions, missing outcome data, measurement of outcomes and selection of the reported result. Each domain was graded as 'low risk', 'some concerns' or 'high risk' leading to an overall study-level judgement.

For non-randomised studies, the Risk Of Bias In Non-randomised Studies of Interventions (ROBINS-I, version 2) was employed [134]. It consisted of seven domains, including confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement and reporting bias. Overall risk was classified as 'low', 'moderate', 'serious' or 'critical'.

Qualitative studies were assessed using the Critical Appraisal Skills Programme (CASP) checklist [135]. Ten domains were evaluated, including clarity of aims, methodological appropriateness, design relevance, recruitment strategy, researcher–participant relationship, ethical considerations, data collection and analysis rigour, transparency of findings and research value. Responses were rated as 'Yes', 'No' or 'Can't Tell' culminating in a structured appraisal summary.

Using differentiated tools tailored to each study design enabled a more rigorous and targeted assessment of bias, reflecting the heterogeneity of study types. This approach also aligns with Cochrane Review guidelines, considered the gold standard for systematic evaluations. In contrast, applying a single tool across all designs such as CASP alone risks overlooking study-type-specific biases and may weaken overall reliability. Full bias assessments are summarised in Appendix 4. These assessments informed the interpretation of findings and contributed directly to the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) certainty ratings for each outcome presented in this review.

2.9 Certainty of Evidence Assessment

Certainty of evidence for each quantitative outcome using the GRADE framework [136] for quantitative studies. This approach enabled a systematic evaluation of the strength of the body of evidence across studies by considering five key domains namely, risk of bias, inconsistency, indirectness, imprecision and publication bias. Qualitative outcomes were assessed using the GRADE- Confidence in the Evidence from Reviews of Qualitative Research or GRADE-CERQual approach [137] which focused on methodological limitations, coherence, adequacy and relevance.

Both reviewers independently conducted the GRADE and GRADE-CERQual assessments for all primary and secondary outcomes. Overall certainty of evidence for each outcome was categorised as 'high', 'moderate', 'low' or 'very low'. Disagreements were resolved through discussion and when necessary, by consulting a third reviewer to reach consensus. This approach allowed for a comprehensive and transparent appraisal of the confidence in the findings, ensuring that resulting policy and practice recommendations were grounded in the best available evidence while remaining sensitive to contextual realities in LMIC settings.

2.10 Data Synthesis/Analytical Framework

A narrative synthesis was employed to evaluate and interpret findings from the included studies, guided by an analytical framework adapted from implementation science, specifically the Reach, Effectiveness, Adoption, Implementation and Maintenance (RE-AIM) framework [138]. This approach facilitated a structured examination of digital AMS interventions across three key stakeholder levels namely patients, providers and policymakers. To ensure analytical rigour, interventions were holistically mapped across four interrelated components including inputs, processes, contextual enablers and barriers and outcomes. This logic model was used to guide the thematic organisation and interpretation of data.

Inputs referred to the foundational elements of each intervention. These included the type of digital health tool implemented, the presence of supporting infrastructure including digital job aids, training resources, decision algorithms and the extent of alignment with existing healthcare workflows or national guidelines. Processes captured the mechanisms through which these inputs were expected to function, such as fidelity of implementation, user engagement and behavioural uptake. Specific process indicators included usability of the digital interface, integration with clinical workflows, the availability of training and supervision and the presence of behavioural prompts such as alerts or structured decision pathways.

Contextual enablers and barriers were defined as the broader environmental and systemic conditions that may influence implementation and effectiveness. These included infrastructural factors such as internet connectivity and electricity supply, policy and governance environments including national digital health strategies and leadership support, cultural receptivity to digital tools and the digital literacy levels of end-users. Outcomes encompassed both implementation and clinical results, including changes in antibiotic prescribing rates, appropriateness of prescribing, patient or provider knowledge and indicators related to acceptability, feasibility and sustainability.

A structured summary table was developed to classify studies by key characteristics including context, population, design, intervention type and outcomes. This facilitated comparative analysis and enabled identification of patterns in effectiveness and implementation feasibility. Data preparation involved checking for internal consistency, verifying outcomes and resolving discrepancies through triangulation with other sections of the included studies. Missing or unreported outcomes were documented as limitations. Due to substantial methodological and contextual heterogeneity, narrative synthesis and subgroup analysis was selected over meta-analysis, as variations in intervention format, delivery mode, intensity and implementation context precluded statistical pooling. Robustness was examined by assessing whether thematic patterns were consistent across studies of varying methodological quality and regional contexts. Findings consistent across high- and low-risk-of-bias studies were considered more generalisable and reliable for informing policy and practice.

3. Results

3.1 Study Selection

A comprehensive search was conducted across seven major databases including PubMed, Embase, Scopus, Web of Science, Cochrane Library, WHO Global Index Medicus and TRIP Database, along with Google Advanced Search, relevant websites, institutional repositories and hand searches for grey literature. A total of 961 records were identified through database (n=852) and grey literature searches (n=109). After removing 189 duplicates using EndNote, 772 titles and abstracts were screened by two independent reviewers against predefined eligibility criteria. Of these, 427 records (360 database and 67 grey literature sources) were excluded for lacking relevance to AMS, digital health or LMIC contexts. Full texts of 345 articles (n=303 from databases and n= 42 from grey literature search) were then assessed for eligibility. A further 321 studies were excluded for reasons including absence of a digital AMS intervention (n=93), setting outside LMICs (n=68), focus outside community healthcare (n=59), not focusing on bacterial infections (n=43) and insufficient or poorly reported outcome data (n=58). Reasons for exclusion at this stage were systematically documented to ensure transparency. In total, 24 studies met the inclusion criteria and were included in the final synthesis. These studies provided empirical insights into the effectiveness, implementation and scalability of digital AMS tools within LMIC community healthcare settings. The full study selection process is visually summarised in the PRISMA flow diagram in Figure 2.

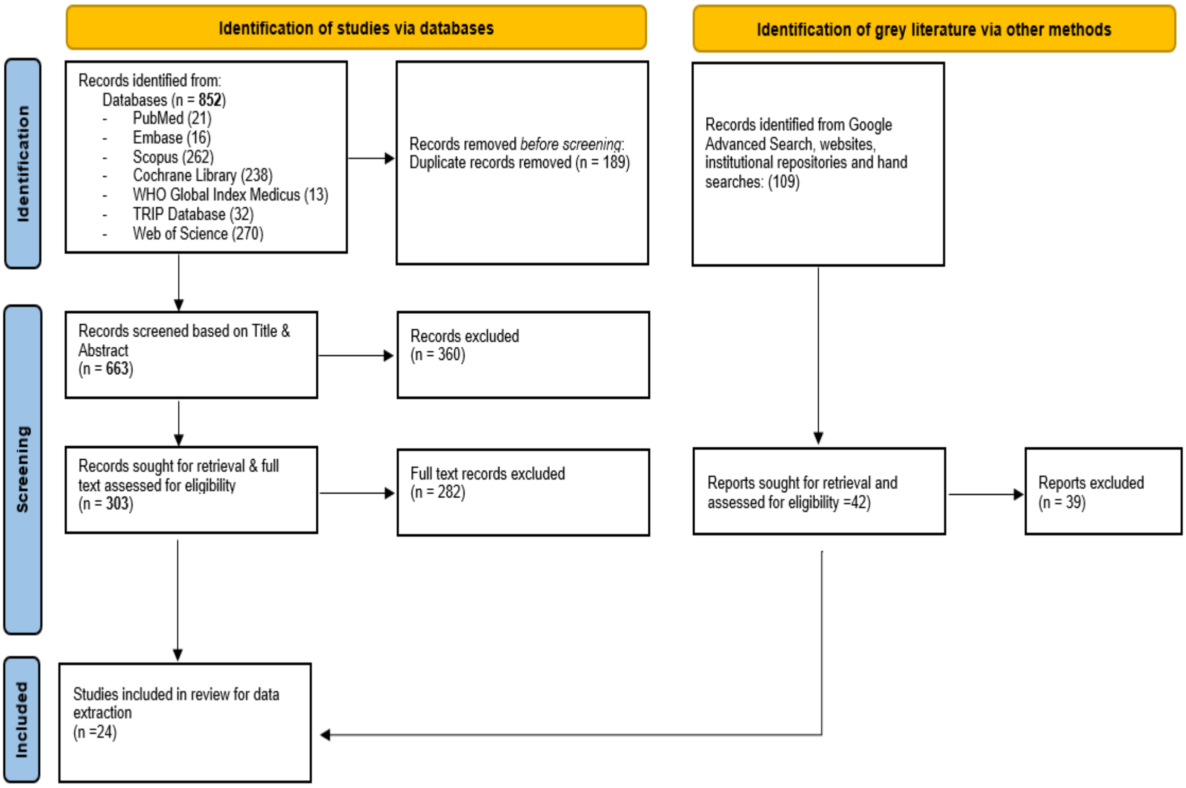


Figure 2: PRISMA 2020 Flow Diagram illustrating the study selection process. The left-hand side details the search strategy conducted across seven databases, with subsequent screening performed on Rayyan. The right-hand side presents the outcome of grey literature searches performed using Google Advanced Search, websites, institutional repositories and hand searches.

3.2 Risk of Bias in Studies

A rigorous risk of bias assessment was conducted using appropriate tools tailored to study design. A summarized version is provided in Table 3 while a detailed risk of bias assessments using each tool is provided in Appendix 4. The Cochrane RoB 2 tool was applied to the nine included RCTs, five of which employed a cluster-randomised design. Of these, four had 'some concerns' due to potential bias in outcome measurement, limited reporting in pilot settings, lack of trial pre-registration and unclear allocation concealment [139-142]. Only one cluster RCT, Steinhardt et al [143] was judged to be at low risk across all domains. Three non-inferiority RCTs were included. The 2020 trial by Tan et al [144] and the 2019 RCT by Keitel et al. [145] had 'some concerns' due to its subgroup analysis design, which raised issues around selective inference and generalisability. In contrast, Keitel et al. 2017 [146] was judged to have a low overall risk of bias. The remaining trial, a parallel-group RCT was also considered low risk [147]. Taken together, three of the nine RCTs were rated as low risk, while six presented moderate concerns, primarily attributable to methodological transparency and design-specific challenges.

Eight non-randomised observational studies were assessed using the ROBINS-I tool, including one mixed-methods study whose quantitative component was evaluated with ROBINS-I and qualitative aspects with the CASP tool. This study was judged to have a serious risk of bias due to the absence of a control group [148]. Among the seven remaining observational studies, four employed pre-post designs. One was rated as moderate risk [149], while the other three had serious risk of bias [150-152], again primarily because of the absence of control groups. One study used a cross-sectional design [153] and another employed a quasi-experimental observational method [154]. Both were judged to carry a serious risk of bias, largely due to the absence of a control group and residual confounding. The final study employed a controlled non-inferiority design and was rated as having a serious risk of bias, mainly due to the absence of a robust comparison group [155]. Importantly, although most of the observational studies were marked as having 'serious' bias, this classification stemmed predominantly from study design limitations particularly the lack of control groups rather than issues such as missing data, deviations from intended interventions or selective reporting.

Eight studies in total, including the mixed-methods study, were assessed using the CASP checklist for qualitative research. All eight were derived to be of moderate to high quality [148, 152, 156-162]. Common limitations included insufficient reflexivity, limited generalisability and a reliance on self-reported data, which may introduce response or recall bias. Crucially, none of the RCTs were rated as having a 'high' risk of bias and no observational or qualitative studies were judged to have 'critical' overall risk. This indicates a reasonable level of methodological robustness across the evidence base, despite common limitations in control design and reporting clarity in some studies.

3.3 Study Characteristics

3.3.1 Geographies

A total of 18 LMICs were represented across the 24 studies included in this review. The majority of studies were conducted in Sub-Saharan Africa (SSA) (n = 21). Within SSA, East Africa featured most prominently, led by Tanzania with 10 studies [139, 141, 142, 144-147, 155, 158, 161], followed by Kenya (n = 2) [148, 149], Uganda (n = 2) [140, 159] and Somalia (n = 1) [152]. Malawi, which is geographically situated in Southeastern Africa but often included within broader East African public health classifications, contributed one study [143]. West Africa was also well represented, with six individual and multi-country studies encompassing nine countries including Senegal (n = 3) [149, 157, 162], Burkina Faso (n = 3) [157, 160, 162], Ivory Coast (n = 2) [157, 162], Mali (n = 2) [157, 162], Nigeria (n = 2) [150, 154], Niger (n = 1) [162], Togo (n = 1) [162], Guinea (n = 1) [162] and Guinea-Bissau (n = 1) [162]. Notably, two of these multi-country studies included Gabon, a Central African country [157, 162]. Despite this diversity of African representation, there were no studies identified from North Africa. The remaining three studies were conducted in South and Central Asia, specifically in India (n = 1) [153], Nepal (n = 1) [156] and Afghanistan (n = 1) [151]. Importantly, there were no studies from East Asia, the Middle East, Europe, Latin America or the Caribbean, highlighting significant regional underrepresentation in the current evidence base for digital antimicrobial stewardship interventions in LMIC community healthcare settings.

3.3.2 Healthcare Settings

All 24 studies were situated within formal community healthcare infrastructures across LMICs. These included a range of facility types such as government-run primary health clinics, rural health centres, sub-district level hospitals and urban outpatient departments. Among them, eight studies were conducted exclusively in urban or peri-urban environments, reflecting the growing interest in digital health interventions within densely populated and digitally connected areas [141, 142, 144-146, 148, 156, 158].

Another eight studies spanned both rural and urban sites, offering a comparative lens on implementation across differing resource contexts [139, 143, 147, 149, 151, 153, 155, 159]. Six studies were confined to rural settings, typically in remote or underserved regions where antimicrobial stewardship challenges are particularly acute [140, 150, 152, 154, 160, 161]. Importantly, two studies were pre-implementation assessments and did not involve a defined clinical setting [157, 162]. These were categorised as *'pre-implementation (no clinical setting)'*, as they gathered stakeholder insights in anticipation of deployment but without direct healthcare delivery. Notably, no study was conducted in informal or semi-formal environments such as village health posts, mobile clinics or through unregulated drug vendors, highlighting a persistent gap in the literature. This suggests a prevailing emphasis on structured, facility-based healthcare systems as the primary site for the design and evaluation of digital interventions across LMICs.

3.3.3 Study Design

The included studies employed a diverse range of methodological designs tailored to assess the effectiveness, implementation and contextual dynamics of digital AMS interventions in LMICs. A total of nine studies were RCTs. Of these, five were cluster RCTs evaluating intervention effects at the facility or provider level [139-143], three employed non-inferiority designs to compare the effectiveness of different digital tools [144-146] and one was a traditional parallel-group RCT between a digital intervention and standard of care [147]. These trials were predominantly conducted in outpatient or primary care settings and assessed outcomes such as antibiotic prescribing accuracy, clinical recovery and adherence to treatment protocols. Another seven studies were observational in nature. This category included four pre-post intervention studies without control groups [149-152], one cross-sectional study [153], one observational quasi-experimental study [154] and one controlled non-inferiority interventional study [155]. These designs were often used to examine implementation effectiveness in real-world settings where randomisation was not feasible.

Seven studies adopted qualitative methodologies. Six of these used in-depth interviews, either alone or in combination with focus group discussions, to explore user perceptions, feasibility and behavioural determinants of intervention uptake [156-161]. The remaining qualitative study employed structured questionnaires and roundtable discussions as part of a pre-implementation assessment [162]. Finally, one study utilised a mixed methods approach, integrating quantitative data on antibiotic prescribing patterns with qualitative insights from interviews with clinicians and patients [148]. This design enabled a more holistic understanding of both behavioural and system-level influences on digital AMS implementation. Together, these varied methodological approaches reflect the multifaceted nature of digital AMS interventions, allowing for both rigorous impact assessment and nuanced analysis.

3.3.4 Target Population

The reviewed studies demonstrated a strong emphasis on provider-directed digital health interventions. A total of 21 out of 24 studies were designed to support healthcare providers in AMS. Within this category, 11 studies specifically targeted clinicians, mainly general practitioners operating in outpatient or community-based settings [139, 141, 142, 144-147, 149, 155, 158, 161]. An additional nine studies employed broader, multi-cadre approaches, engaging a diverse range of frontline health professionals beyond doctors including nurses, midwives, community health workers (CHWs), environmental health officers, branch health officers and pharmacists, reflecting the interdisciplinary nature of AMS implementation in LMIC community settings [143, 150-152, 154, 157, 159, 160, 162]. One study uniquely focused exclusively on CHWs, underscoring their centrality in delivering care in resource-limited environments [140]. By contrast, only two studies targeted policymakers as their primary audience. One evaluated a digital intervention that combined patient-facing components with policy-level antimicrobial stewardship strategies to promote community engagement and empowerment [156], while the other focused on predictive algorithms to enhance data transparency, surveillance and supply chain analytics for decision-making [153]. Notably, no study focused exclusively on patients as the sole end-users of digital AMS tools. However, one study employed a mixed-target approach, engaging both patients, specifically those presenting with respiratory symptoms and suspected infections and providers, whose perceptions of the digital tool's usability and impact were also evaluated [148].

While digital interventions primarily supported provider decision-making, the majority of participants enrolled across studies were patients, as outcomes were measured at the patient level to assess intervention impact. Fourteen studies included a total of 138,254 patient participants, chiefly children under five years old highlighting the high burden of paediatric infectious diseases in community settings and the need for rational prescribing practices [139, 141, 143-152, 154, 155]. Additionally, four studies focused on caregivers, with 836 caregiver participants either engaged independently or jointly with providers [142, 153, 156, 161]. Finally, six studies reported data explicitly on providers as study participants, involving a total of 363 healthcare workers [140, 157-160, 162]. This distribution underscores a provider-centric orientation in the design and evaluation of digital AMS tools, while also emphasising the indirect yet substantial impact these interventions have on patient populations. Future digital AMS strategies would benefit from more inclusive targeting approaches that explicitly incorporate the perspectives of patients, caregivers and health system stewards to improve relevance, reach and equity.

3.3.5 Disease Types

All studies primarily addressed bacterial infections, either explicitly or through broader syndromic management frameworks that encompassed multiple infectious disease categories. While several interventions focused specifically on bacterial pathogens, many also engaged with integrated care models that included viral and parasitic illnesses, particularly in resource-limited primary care settings where diagnostic capabilities are constrained. Among the bacterial diseases, respiratory tract infections were the most commonly addressed, with 18 studies mentioning conditions such as upper respiratory tract infections (URTI) and lower respiratory tract infections including pneumonia [139-141, 143-152, 154, 155, 159, 160, 162]. These conditions are frequent drivers of antibiotic use in community healthcare and were central to many CDSS algorithms. Gastrointestinal infections were the second most prevalent focus, featured in 15 studies, several of which included symptoms like diarrhoea and vomiting [139, 141, 143, 144, 146-148, 150, 151, 154, 155, 159, 160, 162]. Notably one of these studies highlighted the use of antibiotics for intestinal parasitosis [152].

Other common bacterial conditions targeted included skin and soft tissue infections (n=7) [139, 146, 148, 150, 155, 160, 162], ear, nose and throat infections (n=7) [139, 146, 148, 150, 151, 155, 162] and urinary tract infections (n=6) [139, 141, 146, 148, 160, 162]. Less commonly addressed conditions included conjunctivitis (n=3) [139, 151, 160], typhoid fever (n=3) [146, 150, 155], central nervous system infections (n=2) [146, 162], sexually transmitted infections (n=2) [148, 162], sepsis (n=1) [149] and surgical site infections (n=1) [162]. Six studies were not disease-specific but rather focused AMS at a systems level [142, 153, 156-158, 161]. These studies evaluated digital interventions linked to overarching frameworks such as the WHO's Integrated Management of Childhood Illness (IMCI), which manage febrile illness using syndromic algorithms that do not immediately distinguish between bacterial, viral or parasitic aetiologies. Collectively, the disease foci reflect a prioritisation of conditions associated with high antibiotic utilisation, reinforcing the importance of targeted AMS strategies in the rational management of community-acquired infections in LMICs.

3.3.6 Digital AMS Interventions: A variety of inputs

A wide spectrum of digital AMS tools was described, tailored to address the priorities of patients, providers and policymakers in LMIC community healthcare settings. The most frequently evaluated category of intervention was CDSS deployed across desktop interfaces, tablets personal digital assistants (PDAs) and mobile phones, which featured in 19 studies. These tools primarily targeted healthcare providers and were designed to deliver real-time, guideline-based clinical recommendations to optimise diagnosis and antibiotic prescribing. Within the CDSS category, the ALgorithm for the MANAgement of CHildhood illness (ALMANACH) tool, designed to support management of febrile illnesses in children under five was the most frequently evaluated, featured in seven studies and was integrated into various digital platforms to facilitate point-of-care decision-making [141, 150-152, 154, 155, 158].

Another five studies focused on electronic Point-of-Care Testing Tool (ePOCT), a more advanced CDSS iteration with expanded diagnostic algorithms [139, 144-147]. Electronic Integrated Management of Childhood Illness (eIMCI) was assessed in three studies, enhancing IMCI implementation through structured, electronic workflows [142, 160, 161]. One study assessed the Acute Lower Respiratory Illness Treatment and Evaluation (ALRITE) mobile application, based on the IMCI guidelines, which featured a decision-support tool, automatic respiratory rate counter and a clinical score to guide bronchodilator use in children [159]. A further three studies investigated more general CDSS platforms tailored to local antibiotic prescribing norms and syndromic management protocols [149, 157, 162]. These interventions consistently demonstrated improvements in prescription appropriateness, guideline adherence and provider confidence, especially in primary care and rural health settings.

The second most common type of intervention was non-CDSS mHealth applications, evaluated in two studies. The first involved both patients and providers, using the Mobile Telephone-based Healthcare Data and Payment Exchange Platform (M-TIBA) that recorded clinical visits and tracked prescribed antibiotics, helping to support more informed and consistent care [148]. The other study, also aimed at providers included sending SMS reminders to encourage timely and appropriate case management by frontline health workers [143]. These tools supported continuity of care and improved patient-provider communication, although their effectiveness was sometimes constrained by infrastructural and literacy-related challenges.

Additionally, two studies explored the use of online videos. One study used tablet-based training videos on pneumonia to build the capacity of CHWs using locally produced educational content [140]. The other supported community members in creating participatory videos on AMR [156], serving as a tool for policy engagement by fostering local ownership and amplifying community voices in AMR awareness efforts. Lastly, only one study examined the use of machine learning models designed to monitor over-the-counter antibiotic purchases. This tool, aimed at policymakers, enabled surveillance of antibiotic usage patterns outside formal clinical settings, offering insights into community-level dispensing trends and informing regulatory responses [153]. Together, these interventions reflect a growing diversification in the digital AMS landscape, with CDSS forming the cornerstone of provider-oriented tools, while innovative platforms such as mHealth apps and AI-driven surveillance are beginning to expand reach to patients and policymakers.

Table 2: Data extraction table targeting patients and providers, providers (sole focus) and policymakers (sole focus)

Author, Year	Country	Settings	Study Type/ Population	Intervention	Outcomes Studied	Key Findings
Patient + Provider Studies (n=1)						
Mekuria et al, 2019 [148]	Kenya	Private not-for-profit outreach clinics in urban Nairobi slums	Explanatory sequential mixed-methods study involving 21,913 patients with 36,210 clinic visits	M-TIBA mobile phone-based digital healthcare data and payment exchange platform	Antibiotic use for ARI diagnoses, types prescribed, and clinician/patient attitudes and reasons for overprescription	78.5% of ARIs treated with antibiotics, mainly Amoxicillin (45%)
Provider Studies (n=21)						
Langet et al, 2025 [149]	Kenya, Senegal	Primary healthcare facilities in Kakamega, Kitui and Uasin Gishu counties in Kenya and in the Thiès districts region in Senegal	Quasi-experimental pre-post study of 50,580 sick children aged 0–59 months	Implementation of pulse oximetry and Clinical Decision Support Algorithms (CDSAs)	Urgent referrals, antibiotic prescription rates, SpO_2 levels, referral completion, hospital admissions, caregiver-reported recovery and severe complications	Antibiotic prescriptions dropped by 14.6% (1–59 days) and 22.6% (2–59 months) post-intervention in the post-intervention period
Hürlimann et al, 2024 [152]	Somalia	7 health facilities in South-Central Somalia	Pre-post observational study of 1,250 children aged 2–59 months	ALMANACH - IMCI-based digital clinical decision support system	Reduced antibiotic prescriptions including less inappropriate URTI use and improved IMCI adherence	Antibiotic prescriptions fell from 58.1% to 16.0%, inappropriate URTI use dropped 30-fold, and danger sign checks rose from 1.3% to 99%
Tan et al, 2024 [147]	Tanzania	Rural and semiurban primary healthcare facilities in Mbeya and Morogoro regions	Cluster RCT (parallel group, cross-sectional) with 450 children aged 2–59 months (225 intervention, 225 control)	ePOCT+ digital clinical decision support algorithm + point-of-care tests (CRP, haemoglobin, pulse oximetry) + training + mentorship	Mean assessment of 14 key IMCI signs, antibiotic prescription rate, appropriateness of antibiotic use and quality of counselling and history-taking	Primary outcome improved (46.4% vs 26.3%), antibiotic use dropped (37.3% vs 76.4%) and appropriate prescribing rose (81.9% vs 51.4%)
Peiffer-Smadja et al, 2024 [157]	Senegal, Ivory Coast, Burkina Faso, Mali, Gabon	Hospital-based and community healthcare settings	Qualitative implementation study (semi-structured interviews) with 21 stakeholders including clinicians, microbiologists, AMR experts and coordinators	Antibioclic Afrique – CDSS for antimicrobial prescribing	Identified CDSS implementation barriers and facilitators	Barriers included inconsistent prescribing training, workflow resistance, OTC access and absent guidelines. Facilitators were physician targeting, partnerships, training and academic channels

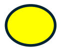
Tan et al, 2023 [139]	Tanzania	Rural and semiurban primary healthcare facilities in Mbeya and Morogoro regions	Cluster RCT involving 44,306 children aged 0–14 years	ePOCT digital clinical decision support algorithm with integrated point-of-care tests (CRP, haemoglobin, pulse oximetry), training and mentorship	Antibiotic prescription at first visit, clinical failure by day 7, death, reattendance, hospitalization, referrals and follow-up medications	Antibiotic use dropped (23.2% vs 70.1%, aRR 0.35); no difference in clinical failure (3.7% vs 3.8%), death, or hospitalization; unplanned reattendance slightly reduced
Schmitz T et al, 2022 [154]	Nigeria	Primary health care facilities in rural Adamawa State, North-Eastern Nigeria	Quasi-experimental observational study with 1,929 children aged 2–59 months	ALMANACH digital clinical decision support system	Caregiver-reported day 7 recovery, prescription rates (oral/parenteral), referrals, diagnosis and follow-up communication	Day 7 recovery was higher (85.4% vs 71.4%), with more referrals, better diagnosis communication and follow-up advice. Parenteral antibiotic use increased while oral antibiotic rates were similar (30.0% vs 34.0%)
Ellington et al, 2021 [159]	Uganda	Primary health centres (rural and peri-urban) in Jinja District	Exploratory qualitative study with 28 health workers and 3 administrators	Acute Lower Respiratory Illness Treatment and Evaluation (ALRITE) mHealth tool	Perceived acceptability, usability, feasibility, impact on decision-making and patient interaction and implementation barriers	ALRITE was found usable and helpful for support and training, with barriers like limited device access, stockouts, and provider–patient dynamics
Peiffer-Smadja et al, 2020 [162]	Burkina Faso, Togo, Senegal, Mali, Gabon, Guinea, Guinea-Bissau, Ivory Coast, Niger	Primary care healthcare workers in West Africa	Qualitative pre-implementation study involving 47 healthcare professionals (mostly from Burkina Faso)	Workshop introducing CDSS (Antibioclic) with questionnaire and roundtable discussion	Identification of CDSS implementation barriers and facilitators and perceptions of its impact on prescribing, knowledge and AMR surveillance	100% of participants believed CDSS would improve prescribing quality and guideline adherence; 91–94% saw benefits for patient care, error reduction and AMR control while 81% felt it would save consultation time
Tan et al, 2020 [144]	Tanzania	Public outpatient primary care clinics in Dar es Salaam	Post hoc subgroup analysis of RCT involving106 febrile children aged 2–59 months	ePOCT clinical decision algorithm using anthropometric measures (weight-for-age, MUAC)	Clinical failure by Day 7, antibiotic prescription, hospital referral and admission, severe adverse events	Clinical failure was lower with ePOCT (1.8%) than ALMANACH (16.7%; RR 0.11, 95% CI 0.01–0.83); ePOCT had higher Day 0 antibiotic use (98.2% vs 47.9%) and referral rates (98.2% vs 14.6%)
Bernasconi et al, 2019 [150]	Nigeria	6 primary Health Care Centres (PHCCs) in Adamawa State, a post-conflict region	Implementation research (pre-post comparison) involving 424 consultations for children aged 2–59 months	ALMANACH: electronic CDSS based on IMCI	Improvements in quality of care including danger sign screening, correct diagnosis and treatment, appropriate antibiotic use	Improved danger sign screening (60% vs 37.1%), rise in correct treatment (29.5% to 48.4%) and antibiotic use dropped (77.7% to 69.8%). Nearly all caregivers (99.2%) found digital consultations more thorough

Keitel et al, 2019 (145)	Tanzania	Urban public outpatient clinics in Dar es Salaam	Subgroup analysis of a noninferiority RCT involving 1726 children aged 2–59 months	CRP-informed strategy using ePOCT algorithm (CRP ≥80 mg/L plus clinical features)	Clinical failure by day 7 and antibiotic prescription at day 0, secondary hospitalization, death by day 30	Clinical failure was lower in the intervention group (2.9% vs 4.8%) by day 7; Day 0 antibiotic use was significantly reduced (2.3% vs 40.4%; RR 0.06, 95% CI: 0.04–0.09), and severe adverse events by Day 30 were fewer (0.5% vs 1.5%)
Bessat et al, 2019 (160)	Burkina Faso	Primary healthcare facilities (CSPS) in rural Yako and Toma districts	In-depth interviews and focus group discussions of 21 primary healthcare workers	Electronic Integrated Management of Childhood Illness (eIMCI) via the REC tool	Health workers' views on tool usability and antibiotic impact in addition to system changes, AMR knowledge, and training feedback	eIMCI was highly accepted and viewed as useful for managing antibiotic use. AMR/AMS were addressed, though knowledge gaps remained among lower-trained staff
Steinhardt et al, 2019 (143)	Malawi	105 outpatient health facilities in seven districts of southern Malawi	Cluster RCT with 2360 patients, including children under 5	Text message reminders to health workers on malaria case management (arm 1) or on malaria, pneumonia and diarrhoea (arm 2)	Correct management of uncomplicated malaria, including testing, treatment and counselling. Also covers appropriate care for pneumonia and diarrhoea including antibiotic use and health worker knowledge and practices	Antibiotic use for pneumonia in children rose overall but dropped slightly in Arm 2 (effect size −4.1%). Patient dosing knowledge significantly improved in Arm 2 (DiD +18.2%, p=0.012)
Bernasconi et al, 2018 (151)	Afghanistan	3 primary health centres (urban and rural) in Kabul province	Pre-post implementation study with 8047 children (implementation) and 599 (baseline), aged 2–59 months	ALMANACH – a tablet-based digital CDSS integrating IMCI guidelines	Antibiotic prescription rate, quality of diagnosis and treatment adherence to guidelines	Antibiotic prescription dropped from 63.9% to 21.8% (p<0.01), malnutrition screening increased from 1.8% to 4.4%, deworming increased from 7.5% to 50.2%, Wrong antibiotic use reduced by >50%
O'Donovan et al, 2018 (140)	Uganda	3 sub-counties in Mukono District (Mpatta, Nakisunga, Mpunge)	Pilot RCT involving 129 Community Health Workers (CHWs)	Tablet-based training using locally made educational videos on pneumonia	Change in knowledge acquisition (MCQ test scores) and clinical assessment performance. CHW feedback and satisfaction with tablet-based training	Both groups had improved in test scores post-training, but the difference wasn't significant (t = 1.15, p = 0.254). Most CHWs found tablets useful for training, though some faced technical issues (n = 9)
Rambaud-Althaus et, 2017 (141)	Tanzania	9 urban primary healthcare facilities in Dar es Salaam	Pilot cluster-RCT with 504 acutely ill children aged 2–59 months	Use of ALMANACH clinical decision support tool	Assessment completeness, antibiotic prescribing, classification accuracy, treatment appropriateness and danger sign recognition	Danger sign checks: 74% (electronic) vs 41% (paper) vs 3% (control), antibiotic prescriptions: 25%, 26%, 70% respectively. Appropriate management: 63% (electronic), 62% (paper), 37% (control)

Keitel et al, 2017 [146]	Tanzania	9 outpatient clinics in Dar es Salaam	Non-inferiority RCT with 3192 children aged 2–59 months	e-POCT algorithm using host biomarker POCTs (CRP, PCT, Hb, oximetry, glucometer, mRDT)	Clinical failure by day 7, antibiotic prescription on day 0, primary referrals, severe adverse events by day 30 (hospitalizations/deaths)	e-POCT reduced clinical failure (2.3% vs 4.1%), severe adverse events (0.6% vs 1.5%) and antibiotic use (11.5% vs 29.7%) compared to ALMANACH. e-POCT also cut clinical failure by 49% and antibiotic use from 94.9% to 11.5%
Shao et al, 2015 [155]	Tanzania	4 health facilities in Dar es Salaam	Controlled non-inferiority study with 1,467 children aged 2–59 months	ALMANACH mobile decision support algorithm implemented on smartphones	Proportion of clinical cure at day 7 and 14. Antibiotic prescription rate, re-consultation rate, danger sign identification	Clinical cure in ALMANACH group was 97.3% vs 92.0% in control, antibiotic prescription reduced by ~50% with ALMANACH. 130/842 (15.4%) in ALMANACH and 241/623 (38.7%) in control arm were diagnosed with an infection in need for antibiotic
Shao et al, 2015 [158]	Tanzania	6 public primary health facilities in Dar es Salaam	Qualitative study using interviews and focus groups with 40 primary health workers (24 interviews, 16 focus group participants)	ALMANACH algorithm implemented via smartphones and tablets	Health worker perceptions of uptake and usability of ALMANACH via mobile devices. Perceived effects on antibiotic prescribing, diagnostic accuracy, workflow, trust, technical usability and health system barriers	Health workers found ALMANACH useful for diagnosis and reducing unnecessary antibiotics. Barriers included longer consultations, staff shortages, dual documentation and limited incentives
Perri-Moore et al, 2015 [142]	Tanzania	6 government clinics in Dar es Salaam	Cluster RCT involving 41 providers and 172 caretakers (eIMCI) vs. 25 providers and 180 caretakers (pIMCI) for children aged 2–59 months	Electronic IMCI-derived decision support protocol with embedded counselling messages and summary screen	Provider explanation and caregiver recall of key treatment and follow-up details, including illness understanding, medication use and return visit instructions	eIMCI improved provider communication (98.8% vs. 77.8%) and caretaker recall of condition and return instructions (22.9% vs. 50%) but not recall of medication frequency or duration
Mitchell et al, 2012 [161]	Tanzania	4 districts in the Pwani Region, including Bagamoyo, Morogoro Town, Mkuranga and Morogoro Rural	Qualitative pilot nested in quantitative implementation study with 11 providers and 20 caretakers across 12 Ministry of Health centres	Electronic IMCI (eIMCI) via handheld PDAs	Perceived improvement in clinical workflow and adherence to IMCI. Caretaker satisfaction, perceived provider competence, thoroughness of examination	Providers and caregivers viewed eIMCI positively; providers found it faster, easier and helpful for IMCI adherence, while caregivers noted better service, thorough examination of their child and more knowledgeable providers
Policymaker Studies (n=2)						
Jones et al, 2025 [156]	Nepal	1 urban and 1 peri-urban community in Bhaktapur and	Participatory qualitative case study with 20 diverse community members lacking prior AMR or video experience	Participatory video (PV) production workshops with AMR education and	Community engagement, knowledge-sharing, empowerment and advocacy reach in addressing AMR in	PV empowered communities to advocate against AMR while policymakers found the videos effective for AMR education,

		Chandragiri municipalities		community showcasing events	addition to policymaker attitudes	highlighting PV's potential as a grassroots AMS tool in LMICs
Sawant et al, 2024 [153]	India	Rural households in two blocks (Junnar – tribal/distant, and Mulshi – rural/urban-adjacent) in Pune District	Cross-sectional study of 443 rural households	Machine Learning algorithms (stepwise logistic, lasso, random forest, XGBoost and Boruta)	XGBoost+Boruta with 7 predictors was the top model for predicting OTC antibiotic use, identifying key factors like perceived usefulness, eye-related use, high dose and long duration	OTC antibiotic use prevalence: 35.9% (95% CI: 31.6–40.5). XGBTree+Boruta with AUROC: 0.934 (95% CI: 0.891–0.978), log-loss: 0.279

Table 3: Risk of Bias assessment summary table

Author/ Year	Study Type	Bias Assessment Tool	Overall Risk of Bias	Bias Appraisal Summary
Patient + Provider Studies (n=1)				
Mekuria et al, 2019 [148]	Explanatory sequential mixed-methods study	ROBINS-1/CASP		ROBINS-1: Serious risk due to limited causal control CASP: High-quality qualitative component offering valuable context for digital health implementation in low-resource settings
Provider Studies (n=21)				

Author/ Year	Study Type	Bias Assessment Tool	Overall Risk of Bias	Bias Appraisal Summary
Langet et al, 2025 [149]	Quasi-experimental pre-post study	ROBINS-1		Moderate risk of bias due to use of a historical control. However, secular trends were adjusted for. Other potential confounders such as demographics, clinical features and healthcare access were also addressed
Hürlimann et al, 2024 [152]	Pre-post observational study	ROBINS-1		Serious risk of bias due to use of historical control and no adjustment for time-related confounders , although all other domains had a low to moderate risk
Tan et al, 2024 [147]	Parallel group cross-sectional cluster RCT	RoB-2		Low as all domains were judged low risk, indicating overall low risk of bias for the trial
Peiffer-Smadja et al, 2024 [157]	Qualitative implementation research (semi structured interviews)	CASP		Well-aligned methodology, sampling and analysis. Limited reflexivity but overall offers valuable insights for AI implementation in clinical practice
Tan et al, 2023 [139]	Cluster RCT	RoB-2		Some concerns mainly from potential bias in outcome measurement. All other domains showed low risk
Schmitz T et al, 2022 [154]	Observational study (quasi-experimental, non-randomized controlled)	ROBINS-1		Serious risk of bias from confounding due to contextual differences in epidemiology, health-seeking behaviour and health system factors. Potentially, Hawthorne effect may also have influenced outcomes
Ellington et al, 2021 [159]	Exploratory qualitative study (semi structured interviews)	CASP		Methodologically strong across most criteria with minor limitation in reflexivity reporting
Peiffer-Smadja et al, 2020 [162]	Qualitative pre-implementation study	CASP		Strong methodology with clear focus on CDSS acceptability. Minor limitation in reflexivity reporting
Tan et al, 2020 [144]	Post hoc subgroup analysis from RCT	RoB-2		Some concerns. The inherent characteristics of subgroup analyses introduce the potential for confounding to bias the results
Bernasconi et al, 2019 [150]	Implementation research (pre-post comparison using two cross-sectional surveys)	ROBINS-1		Serious risk. Lack of confounder adjustment in pre-post design leads to serious overall bias risk
Keitel et al, 2019 [145]	Randomized controlled noninferiority trial (subgroup analysis)	RoB-2		Some concerns. Strong RCT basis but subgroup design raises issues of selective inference and generalizability
Bessat et al, 2019 [160]	Qualitative study (in-depth interviews and focus group discussions)	CASP		Methodologically sound with robust qualitative methods. A minor limitation is the limited reporting on researcher reflexivity
Steinhardt et al, 2019 [143]	Cluster RCT	RoB-2		Low risk. All domains show low risk, indicating a well-conducted cluster RCT with strong internal validity
Bernasconi et al, 2018 [151]	Pre-post implementation study	ROBINS-1		Serious risk from. Confounding from secular trends and population differences across survey rounds limits causal inference

Author/ Year	Study Type	Bias Assessment Tool	Overall Risk of Bias	Bias Appraisal Summary
O'Donovan et al, 2018 [140]	Pilot randomised controlled trial	RoB-2	🟡	Some concerns. Small pilot RCT with limited reporting and potential of reactivity bias raises transparency and validity concerns
Rambaud-Althaus et, 2017 [141]	Pilot cluster-randomized implementation study	RoB-2	🟡	Some concerns. Well-conducted pilot cluster RCT but outcome assessment may be affected by observer bias
Keitel et al, 2017 [146]	Randomized controlled non-inferiority trial	RoB-2	🟢	Low risk. Rigorous non-inferiority RCT with low risk of bias across all domains
Shao et al, 2015 [155]	Controlled non-inferiority interventional study	ROBINS-1	🔴	Serious risk. Lack of randomization and potential facility-level confounding result in serious overall risk of bias
Shao et al, 2015 [158]	Qualitative study (in-depth interviews and focus group discussions)	CASP	🟢	Strong methodological quality with minor reflexivity limitations. Offers valuable insights into health worker views on mobile decision support tools
Perri-Moore et al, 2015 [142]	Cluster-randomized controlled trial	RoB-2	🟡	Some concerns. Well-conducted study with real-time outcome tracking and valid analysis but moderate concerns due to unclear allocation concealment and post-randomization recruitment
Mitchell et al, 2012 [161]	Qualitative pilot study nested within a quantitative implementation study	CASP	🟢	Clear aims, suitable qualitative methods and well-presented findings. Minor gaps in reflexivity, ethics and analysis detail but overall valuable and reliable for digital health implementation
Policymaker Studies (n=2)				
Jones et al, 2025 [156]	Participatory Research (Qualitative Case Study Evaluation)	CASP	🟢	Methodologically sound and ethically robust. The study offers valuable contextual insights, though deeper reflexivity on researcher-participant dynamics would strengthen it. Overall, it informs culturally grounded AMS interventions
Sawant et al, 2024 [153]	Cross-sectional descriptive study	ROBINS-1	🔴	Serious risk. Lack of a control group and residual confounding leads to serious bias risk despite strong design and implementation

🟢- Low risk of bias 🟡 - Moderate risk of bias 🔴 - Serious risk of bias

3.4 Study Outcomes

3.4.1 Effectiveness of Digital Interventions

The effectiveness of digital AMS interventions in LMIC community healthcare settings was most consistently demonstrated through measurable improvements in provider prescribing behaviour. Across 24 studies, interventions targeted predominantly healthcare providers particularly general practitioners, nurses and CHWs using digital tools designed to support rational antimicrobial decision-making. These tools achieved clinically meaningful improvements across several key prescribing outcomes, as synthesised below.

Change in Antibiotic Prescribing Rates

Thirteen studies evaluated changes in the proportion of patient encounters resulting in antibiotic prescriptions following the implementation of AMS interventions. Drawing from seven RCTs [139, 141, 143-147] and six non-randomised studies [149-152, 154, 155], the overall GRADE certainty of evidence was rated as moderate to high. Across these studies, consistent and substantial reductions in antibiotic prescribing were observed, though with notable variation in effect size. Reported reductions ranged from as little as 4% to over 80%, underscoring both the promise and the heterogeneity of intervention effectiveness. The most striking reductions were reported in RCTs evaluating the ePOCT clinical decision support algorithm, all conducted in Tanzania. Keitel et al. [146] demonstrated an impressive 83.4% decrease in antibiotic prescribing when comparing ePOCT to standard care. A subsequent trial by the same author revealed that integrating C-reactive protein (CRP) testing into the ePOCT protocol further enhanced prescribing performance, reducing antibiotic use from 40.4% to just 2.3%. This finding highlights the additive value of biomarker-informed decision-making when combined with digital support tools. Similarly, Tan et al. reported substantial reductions of 46.9% and 39.1% in separate evaluations conducted in 2023 and 2024, respectively, further affirming ePOCT's effectiveness across diverse settings within Tanzania [139, 147]

Evidence supporting the ALMANACH tool was also robust. In a pre-post evaluation, Shao et al. [155] observed a dramatic 68.9 percentage point decline from 84.3% to 15.4% marking the largest absolute reduction across all studies. Rambaud-Althaus et al. [141] reported a 45% reduction, even without digital augmentation, suggesting that standardised clinical protocols alone can influence prescribing behaviours. Non-randomised studies, including those by Hürlimann et al. [152] and Bernasconi et al. [151], while subject to greater risk of confounding, corroborated these findings with prescribing reductions frequently exceeding 40% following ALMANACH implementation. Conversely, a quasi-experimental study from Nigeria reported only a modest 4% decline in oral antibiotic use with ALMANACH, accompanied by an increase in parenteral antibiotic prescriptions (from 9.4% to 17%) [154]. This finding raises concerns about therapeutic substitution rather than true prescribing reduction.

Finally, a study from Malawi examining a short SMS-based intervention recorded a non-significant 4.1% reduction in prescribing, likely limited by a small sample size (n = 39) [143]. Taken together, these findings demonstrate the considerable potential of digital tools particularly ePOCT and ALMANACH to reduce unnecessary antibiotic prescribing in community settings across LMICs. However, their impact remains highly context-dependent, influenced by factors such as implementation fidelity, integration into routine clinical workflows and the availability of complementary diagnostic inputs.

Reduction in Inappropriate Prescribing

Twelve studies assessed the impact of digital AMS interventions on inappropriate antibiotic prescribing, either directly by evaluating prescriptions issued for viral or clinically unjustified cases or indirectly, using overall reductions as a proxy indicator. This outcome was supported by high-certainty evidence from seven RCTs [139, 141, 143-147] and moderate-certainty evidence from five non-randomised studies [149-152, 155], collectively demonstrating consistent improvements in prescribing quality following digital AMS implementation.

In Somalia, Hürlimann et al. [152] reported a striking decline in inappropriate antibiotic use of over 30 times for upper respiratory tract infections, from 96.6% pre-intervention to just 3.1% post-ALMANACH deployment. Additionally, the study documented a 22.1% reduction in incorrect diagnoses of intestinal parasitosis, highlighting the broader diagnostic improvements enabled by the tool. Similarly, in Afghanistan in 2018, Bernasconi et al. [151] found that prior to intervention, 87.1% of children were prescribed antibiotics unnecessarily. Post-intervention, the appropriateness of prescribing markedly improved, dropping by over 50%, underscoring the transformative potential of ALMANACH. Tanzanian studies provided further robust evidence. Shao et al. [155] demonstrated that inappropriate antibiotic prescribing was significantly reduced in the ALMANACH intervention arm, with only 15.4% of children receiving antibiotics compared to 38.7% in the control group despite clinical criteria supporting few of these prescriptions. Furthermore, in Nigeria in 2019, Bernasconi et al. [150] demonstrated an improvement in correct treatment rates from 29.5% to 48.4% following the adoption of ALMANACH. Rambaud-Althaus et al. [141] also confirmed the tool's utility, noting that while both digital and paper-based versions of ALMANACH enhanced viral diagnosis and supported more appropriate management, the digital format yielding slightly superior diagnostic accuracy.

Studies evaluating ePOCT echoed these findings. In a 2024 study, Tan et al. [147] reported a 30.5% increase in appropriate prescribing, rising from 51.4% to 81.9%. In an earlier study conducted in 2020, the same author observed an increase in appropriate Day 0 prescribing from 47.9% to 98.2% [144]. These improvements were largely attributed to algorithm-based decision support embedded in ePOCT, which guided clinicians through context-appropriate prescribing pathways. Together, these findings underscore the considerable potential of digital AMS interventions particularly algorithm-driven clinical decision support systems to substantially reduce inappropriate antibiotic prescribing in low-resource settings. However, the persistence of systemic and diagnostic barriers, including limited access to point-of-care testing and entrenched prescribing habits, suggests that digital tools must be complemented by broader health system reforms to ensure the sustainability of antimicrobial stewardship gains.

Use of Broad- vs. Narrow-Spectrum Antibiotics

Only four studies addressed antibiotic class selection, a critical yet underexplored proxy indicator for AMR. The GRADE certainty of evidence for this outcome ranged from moderate (1 RCT) [143] to low (two observational studies [148, 151] and one qualitative study [157]), reflecting the limited dataset, methodological variability and confounding contextual factors. In Malawi, Steinhardt et al. [143] conducted a RCT that evaluated the impact of SMS-based reminders on antibiotic prescribing practices. Beginning on Day 4 of illness, health workers received messages such as, "For pneumonia, 1st line Rx is amoxicillin and 2nd line is erythromycin. For SEVERE pneumonia, treat with IM Xpen." Despite the intervention's alignment with guideline-concordant care, it yielded no significant improvement in pneumonia management. The study noted that prescribing behaviours were predominantly shaped by entrenched clinical routines and the common practice of initiating antibiotic treatment during the initial patient encounter. Furthermore, local supply chain limitations impeded the appropriate selection of antibiotic classes.

In Kenya, a mixed-methods study by Mekuria et al. [148] investigated the drivers of antibiotic class selection through M-TIBA, a digital health exchange platform. Providers reported frequent overuse of broad-spectrum antibiotics driven by drug stockouts, sociocultural expectations and habitual prescribing practices. One clinician remarked:

"If you don't have a broad-spectrum antibiotic, maybe you combine two antibiotics together if you think they can offer wide coverage."

Another reflected on normative perceptions:

"Many clinicians believe that prescribing Amoxicillin or Augmentin means they've treated the patient."

Caregivers, too, influenced decisions, with one mother stating:

"I would have looked for another place to be given drugs because of the way my baby is feeling."

Evidence from Bernasconi et al. (151) further underscored the challenges in aligning antibiotic class selection with IMCI guidelines. Analysis of prescriptions following ALMANACH implementation revealed substantial deviations. 50.9% of Augmentin, Cefixime and Cephradine were dosed incorrectly. Alarmingly, despite being contraindicated in young children, Cephradine and Cefixime were prescribed to 24 patients. These findings exposed not only diagnostic and prescribing gaps but also the risks posed by algorithm non-adherence. Peiffer-Smadja et al. (157) added further qualitative nuance through a 2024 CDSS pre-implementation interview exploring the reasons for misuse of Watch and Reserve class of antibiotics in West Africa. This study highlighted how economic and structural barriers significantly shaped prescriber choices. One clinician noted:

"Ceftriaxone, a second- or third-line antibiotic, costs less than first-line amoxicillin, so it's what we use."

Another lamented the absence of local epidemiological data:

"We don't have data based on local resistance patterns. In Europe, you could justify third-generation cephalosporins but here, it's a guess."

Collectively, these findings suggest that while digital tools and guideline-based reminders may encourage appropriate class selection, their success remains heavily contingent on broader systemic enablers, particularly reliable medicine supply, cost parity between first line and higher-tier antibiotics and the availability of locally relevant microbiological data. Addressing these structural constraints is essential to optimise antibiotic class selection and ensure that digital stewardship tools can fulfil their potential in LMIC settings.

Clinical Outcomes

Nine studies (five RCTs (139, 144-147) and four observational studies (149, 150, 154, 155) reported on patient-level clinical outcomes, offering valuable insights into the safety and effectiveness of digital AMS interventions in community healthcare settings across LMICs. The overall quality of evidence was rated moderate. Collectively, the findings suggest that reductions in antibiotic use facilitated by digital decision-support systems did not compromise and in some instances enhanced patient outcomes. All RCTs were from Tanzania and consistently demonstrated superior clinical outcomes with ePOCT compared to ALMANACH or standard care. Keitel et al. (146) reported a 43% relative risk reduction in clinical failure when using ePOCT versus ALMANACH, alongside a notable decrease in severe adverse events (0.6% vs. 1.5%). Interestingly, referral rates were higher with ePOCT (6.6%) than ALMANACH (2.9%). A subsequent study by the same author reaffirmed these findings, with lower clinical failure by Day 7 (2.9% vs. 4.8%) and rates of hospitalization and death reducing by half in the CRP-informed ePOCT arm compared to standard algorithms (0.5% vs. 1.5%) (145). Similarly, Tan et al.

[139] demonstrated non-inferiority in clinical failure rates between ePOCT (3.7%) and routine care (3.8%), reinforcing its safety. In an earlier study, the same author found lower failure rates with ePOCT (1.8%) than ALMANACH (16.7%) and striking differences in hospital admission rates among referred patients, 20% for ePOCT versus 71% for ALMANACH [144]. In Kenya and Senegal, Langet et al. [149] showed stable Day 7 caregiver-reported recovery rates among infants (89.8% vs. 91.6%) and slight improvements of 2.2% among children aged 2–59 months compared to the CDSS pre-intervention period. Comparable benefits were also observed with ALMANACH. Schmitz et al. [154] documented improved Day 7 recovery of 85.4% versus 71.4% with standard care. Shao et al. [155] confirmed non-inferiority in clinical cure rates (97.3% ALMANACH vs. 92.0% IMCI paper guidelines), while Bernasconi et al. [150] highlighted improvements in danger sign screening (60% vs. 37.1%). While some studies observed increased referral rates for ePOCT (1.2% vs. 1.0%) [139] and ALMANACH (9.5% vs. 3%) [154], these may reflect improved risk stratification. Collectively, the evidence affirms the clinical safety and potential of digital AMS tools, supporting their broader integration into LMIC community health systems.

Trends in AMR

Although none of the included studies directly assessed changes in AMR prevalence at the facility or community level, three studies investigated indirect indicators. The certainty of evidence was rated as low, primarily due to reliance on surrogate measures and the absence of longitudinal microbial surveillance systems. Sawant et al. [153] employed machine learning algorithms to model predictors of OTC antibiotic use as a behavioural proxy for AMR risk in rural communities. The Boruta algorithm identified key behavioural predictors, including the belief in the usefulness of purchasing medicines directly from pharmacies, antibiotic use for minor conditions such as eye complaints, higher household-level antibiotic consumption and prolonged or high-dose antibiotic use, particularly among the socioeconomically marginalised in Pune, India. The prevalence of OTC antibiotic use here was 35.9% (95% CI: 31.6–40.5). These patterns, while indirect, provide early warning signs of population-level behaviours that may accelerate AMR emergence and underscore the need for targeted community interventions. In a pre-implementation study, Peiffer-Smadja et al. [157] examined stakeholder perceptions of digital tools in shaping AMR policy ecosystems. Participants recognised the potential of CDSS such as *Antibioclic Afrique* to catalyse policy reform and support regional governance. One clinician remarked:

"We must not stop only at our scientific level but go precisely to the level of decision-makers… to formalize the algorithms, the recommendations… and ensure that they are applied at the national level by each of the countries."

Further, Jones et al. [156] highlighted the use of participatory video as a strategy to disseminate AMR awareness beyond local communities. Participants noted that the visual and contextually relevant nature of the videos enhanced engagement and reflection. As one participant in Chandragiri remarked:

"People might get bored when they are informed about it (AMR) in person, but they would think about it ten times if they could see it visually."

These studies suggest that while the current evidence base remains limited by the absence of microbial data, digital tools can contribute meaningfully to AMR awareness, policy engagement and behavioural surveillance. Strengthening these indirect pathways through integrated digital strategies, particularly those embedded within national health systems will be essential for advancing sustainable AMR mitigation efforts in LMICs.

3.4.2 Pathways of Effective Digital Interventions

Knowledge, Attitude and Behavioural Changes Among Healthcare Providers and Patients

Digital AMS interventions demonstrated significant potential to influence provider and patient knowledge, attitudes and behaviours related to antibiotic use through multifaceted behavioural mechanisms. This was supported by high-certainty GRADE evidence from three RCTs [140, 142, 143], moderate- certainty evidence from seven qualitative studies [156-162] and two low-certainty evidence from two observational studies [148, 150], yielding an overall rating of moderate certainty. O'Donovan et al. [140] found that tablet-based video training significantly improved CHWs understanding of antibiotic use and AMR, offering a feasible alternative to conventional in-person sessions. Similarly, Jones et al. [156] reported that participatory video production in Nepal fostered both community engagement and knowledge enhancement. Audiences described feeling empowered, with one participant observing:

"They now know that they are not supposed to simply buy the medicines that they want and consume it carelessly."

The authenticity of community-led content, as opposed to professionally produced media was also seen to resonate more powerfully with local viewers.

The impact of eIMCI tools on provider communication and patient engagement was consistently positive. Perri-Moore et al. [142] documented that providers using eIMCI verbalised clinical problems more effectively (98.8% vs. 77.8%) and offered significantly more counselling, leading to improved caregiver recall of treatment and follow-up advice compared to paper-based protocols. These benefits were echoed by Mitchell et al. [161], who reported that 82% of providers found PDAs with eIMCI faster than traditional forms, affirming that the devices systematically guided clinical assessment and reminded them of key procedural steps. Caregiver engagement also improved. 55% reported feeling more involved during consultations, while 62% believed the PDAs enhanced diagnostic and treatment accuracy. However, some caregivers developed an overly inflated trust in the devices, with one remarking:

"With the instrument the truth can be seen."

High satisfaction with eIMCI was also reported by Bessat et al. [160], who highlighted its value for clinical decision-making and provider learning. Similarly, Shao et al. [158] noted that ALMANACH enhanced prescribing accuracy and clinician confidence. One provider reflected:

"Before, I was just prescribing antibiotics... now I know many diseases are febrile and don't need antibiotics."

Peiffer-Smadja et al. [162] found unanimous agreement among providers that digital tools improved care quality, guideline adherence and reduced errors. However, concerns were raised regarding the potential for 'blind obedience' to algorithmic outputs and mixed effects on clinician-patient relationships. Despite this optimism, Bernasconi et al. [150] observed that in Nigeria, many providers continued habitual prescribing patterns with providers frequently disregarding CDSS recommendations, signalling behavioural inertia. Finally, in the case of SMS-based reminders, Steinhardt et al. [143] found that they were insufficient to improve provider knowledge, underscoring the limitations of passive digital prompts in the absence of comprehensive training or supportive system infrastructure. Collectively, these findings suggest that digital AMS tools can meaningfully influence antimicrobial-related behaviours among both providers and patients. However, their success depends on contextual adaptability, user-centred design, digital literacy and sustained stakeholder engagement.

3.4.3 Facilitators and barriers of implementing Digital AMS Interventions

Feasibility and Acceptability

The successful implementation of these tools in LMIC community settings is mediated by an intricate interplay of technical, behavioural, systemic and contextual factors. This section critically synthesises the key barriers and enablers to implementation across multiple levels of the health system, drawing on studies with varying methodological strengths. According to GRADE assessments, evidence certainty ranged from high in one RCT [140], to moderate in six qualitative studies [157-162], and low in two observational studies [149, 152], yielding an overall moderate rating. Technical design emerged as a foundational enabler of feasibility. Langet et al. [149] found that tools such as ePOCT were well-suited to resource-constrained environments due to their modular architecture, mobile compatibility and offline functionality. Yet, implementation was complicated by referral barriers, as health worker and caregiver decisions were influenced by illness severity, perceived costs, logistical challenges and power dynamics.

Hürlimann et al. [152] identified concerns among healthcare workers and supervisors related to longer consultation times, caregiver mistrust in digital technologies and unreliable electricity supply in facilities. Despite these challenges, caregivers responded favourably post-implementation:

"Since ALMANACH started, my child improved with the medications prescribed by the health worker." (Mother #1) and *"I read directly from the tablet and understood the messages."* (Mother #2)

Peiffer-Smadja et al. [157] mapped challenges at the individual, system and national levels in the 2024 study. At the individual level, key issues included patient self-medication and poor adherence to prescribing guidelines. System-level barriers involved stock-driven prescribing, regulatory weaknesses and heterogeneity in prescriber training. Participants stressed the importance of designing CDSS for a broader range of prescribers:

"The CDSS should not only target physicians... but also general practitioners, nurses, midwives... who are the main prescribers in rural areas."

Recommendations included phased implementation, early adopter mobilisation and co-designing tools responsive to national AMR priorities. Ellington et al. [159] reported strong provider acceptability for the ALRITE app. Health workers praised its utility in guiding clinical assessments, dosage calculation and health education. Nevertheless, some expressed concern about perceptions of professionalism:

"Clients might think you're not knowledgeable... But I can start by engaging the patients and informing them... I'm improving diagnosis for your child."

The 2020 study by Peiffer-Smadja et al. [162] reported that while most providers owned smartphones, few had access to computers or utilised CDSS. Common barriers included concerns over exacerbating self-medication and a mismatch between CDSS recommendations and local AMR epidemiology. The authors advocated co-design approaches, tailored content and iterative rollouts. Bessat et al. [160] reported high acceptance of eIMCI but noted 'slowness' of the device as a key constraint, exacerbated during high-attendance periods. Double workload due to parallel manual registers and misaligned diagnostic classifications further dampened uptake. O'Donovan et al. [140] found tablet-based video training feasible and well-received, with 98% (n=58) of CHWs describing the experience positively, using expressions such as "It made me happy" and "It was good." Navigation difficulties were common but mitigated through peer support.

This was echoed by Shao et al. [158] with favourable provider responses to ALMANACH, noting improved clinical decision-making and reductions in inappropriate antibiotic use. However, challenges such as prolonged consultation time and typing difficulties were noted. Finally, Mitchell et al. [161] revealed high provider satisfaction with PDA-based eIMCI with enhanced adherence to protocols, greater patient engagement and improved diagnostic confidence frequently cited as benefits. Collectively, these findings affirm that the success of digital health tools hinges on early stakeholder engagement, contextual adaptation, robust system integration and sustained technical support. Addressing digital illiteracy, improving infrastructure and embedding digital tools into routine clinical practice and national reporting systems will be critical to their scale and sustainability.

Cost and Cost-Effectiveness

The economic dimensions of digital AMS interventions were not the primary focus of any included study, resulting in a low GRADE certainty rating for this outcome. Although no formal cost-effectiveness analyses were undertaken, several studies provided valuable qualitative insights into affordability, perceived cost savings and implementation feasibility in resource-constrained settings. The 2024 Peiffer-Smadja study [157] illustrated how patient-level economic constraints can inadvertently shape antibiotic prescribing decisions, even when CDSS are available. One healthcare provider highlighted this dilemma:

> *"There is no Social Security, so it's the patients who pay. A very illustrative example: when you take an antibiotic like Ceftriaxone which should be the second- or third-line antibiotic, it costs less than one euro compared to the antibiotic like amoxicillin which should be the first line. These are quite a few reasons that can impact on the quality of antibiotic prescribing."*

The 2020 study by Peiffer-Smadja et al. [162] further noted that CDSS tools designed as user-friendly mobile applications with free access may substantially lower implementation costs and facilitate broader uptake. Ellington et al. [159] reinforced this theme, finding that while the ALRITE app was available free of charge, feasibility was nonetheless impacted by indirect costs and equipment limitations.

Steinhardt et al. [143] explored the use of low-cost SMS-based behavioural interventions, where the average cost per message was USD 0.035. Despite the affordability, the study concluded that text messages alone may be insufficient to significantly alter healthcare worker behaviour. Similarly, O'Donovan et al. [140] evaluated tablet-based training videos and identified cost-related usability issues such as poor battery life and an inability to pause videos, underscoring the need to balance hardware affordability with functional reliability in resource constrained environments. Crucially, none of the studies reported quantified implementation or maintenance costs, nor did any conduct comparative cost-effectiveness analyses against standard care or alternative AMS strategies. This represents a critical gap in the evidence base, particularly given the pressing need to ensure financial sustainability of digital AMS interventions in LMIC contexts. Future research must integrate robust economic evaluations, including cost-effectiveness and cost-benefit analyses, to inform scalable and long-term deployment strategies.

Table 4: Summary of Findings Table with certainty of evidence assessment using GRADE/GRADE-CERQual for the primary and secondary outcomes

Outcomes	No of Studies	Certainty of Evidence (GRADE/GRADE-CERQual)	Impact
Primary Outcomes			
1) Change in antibiotic prescribing rates	(7 RCTs [139, 141, 143-147])	⊕⊕⊕⊕ High	Studies showed that digital AMS interventions consistently reduced antibiotic prescribing rates across LMIC primary care settings. Reductions ranged as low as 4% [154] to as high as 83% [146], demonstrating a meaningful impact on antibiotic use patterns.
	(6 Observational Studies [149-152, 154, 155])	⊕⊕⊕◯ Moderate	
2) Reduction in inappropriate antibiotic prescribing	(7 RCTs [139, 141, 143-147])	⊕⊕⊕⊕ High	Several high-quality studies showed that digital tools significantly reduced inappropriate antibiotic prescriptions, such as those for viral infections or against guidelines. The effect was consistent across settings, ranging from around 20% [150] to over 90% [152].
	(5 Observational Studies [149-152, 155])	⊕⊕⊕◯ Moderate	
3) Use of broad-spectrum vs. narrow-spectrum antibiotics	(1 RCT [143])	⊕⊕⊕◯ Moderate	Only 4 studies assessed shifts in antibiotic class selection and methods for measuring spectrum use varied. However, the magnitude and consistency of effect varied with some studies reporting modest improvements while others found no significant change.
	(2 Observational Studies [148, 151])	⊕⊕◯◯ Low	
	(1 Qualitative Study [157])	⊕⊕◯◯ Low	
Secondary Outcomes			
4) Clinical outcomes: infection resolution, adverse events and hospital referrals	(5 RCTs [139, 144-147])	⊕⊕⊕◯ Moderate	Most studies reported that clinical outcomes were similar or slightly improved with digital AMS tools with no significant increase in adverse events or hospital referrals.
	(4 Observational Studies [149, 150, 154, 155])	⊕⊕◯◯ Low	
5) Trends in antimicrobial resistance at the community or facility level	(1 Observational Study [153])	⊕⊕◯◯ Low	Only 3 studies addressed AMR trends and that too indirectly or through proxy indicators or stakeholder perceptions with limited microbiological
	(2 Qualitative Studies [156, 157])	⊕⊕◯◯ Low	

			surveillance data, making the strength and direction of effect uncertain.
6) Knowledge, attitudes or behaviour toward antibiotic use among healthcare providers and/or patients	(3 RCTs [140, 142, 143])	⊕⊕⊕⊕ High	Studies showed that digital AMS interventions improved knowledge, attitudes and prescribing behaviours among providers and patients. Reported changes included increased awareness of antibiotic resistance, greater adherence to clinical guidelines and reduced intent to prescribe inappropriately.
	(2 Observational Studies [148, 151])	⊕⊕◯◯ Low	
	(7 Qualitative Studies [156-162])	⊕⊕⊕◯ Moderate	
7) Feasibility and acceptability of digital AMS interventions in routine practice	(1 RCT [140])	⊕⊕⊕⊕ High	Most users found the digital AMS tools acceptable and feasible in practice particularly when integrated with existing workflows. However, challenges such as digital literacy, infrastructure and contextual adaptation were frequently noted.
	(2 Observational Studies [149, 152])	⊕⊕◯◯ Low	
	(6 Qualitative Studies [157-162])	⊕⊕⊕◯ Moderate	
8) Cost or cost-effectiveness of digital AMS interventions	(2 RCTs [140, 143])	⊕⊕◯◯ Low	No studies conducted formal economic evaluations. While some suggested potential cost savings, conclusions remain tentative due to limited data, absence of cost-effectiveness analyses and reliance on perceived rather than measured value.
	(3 Qualitative Studies [157, 159, 162])	⊕⊕◯◯ Low	

GRADE/ GRADE-CERQual Working Group grades of evidence. **High certainty**: Very confident that the true effect lies close to that of the estimate of the effect. **Moderate certainty**: Moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different. **Low certainty**: Confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect. **Very low certainty**: Very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

4. Discussion

4.1 Summary of Key Findings

This systematic review synthesised findings from 24 studies across 18 LMICs evaluating diverse digital AMS interventions in community settings. The interventions were predominantly provider-facing. Moderate- to high-certainty evidence consistently demonstrated that digital tools, particularly CDSS such as ePOCT, ALMANACH and eIMCI substantially reduced antibiotic prescribing rates, with reductions ranging from under 5% to over 80% across different settings in Africa and Asia. The integration of biomarker data, as in ePOCT with CRP testing, further enhanced prescribing accuracy and clinical outcomes. Digital interventions also improved the appropriateness of antibiotic use. Studies reported marked declines in incorrect prescriptions for conditions such as upper respiratory tract and gastrointestinal infections. Provider-directed digital interventions that included built-in training modules, structured clinical algorithms or guideline-based prompts not only improved prescribing accuracy but also boosted confidence among lower-cadre health workers.

Behavioural pathways, evaluated through video education and mHealth apps also highlighted gains in provider knowledge, caregiver engagement and reductions in self-medication. However, despite their impact, tools targeting antibiotic class switching (broad-to narrow-spectrum) were scarce and revealed challenges, such as stock-driven prescribing and economic barriers influencing broad-spectrum antibiotic use. Patient-level outcomes, although secondary in most studies were favourable. Digital AMS tools demonstrated clinical safety and in some cases improved recovery rates and reduced hospitalisations. Nevertheless, patient- and policymaker-directed strategies remain markedly underrepresented. Only one study jointly targeted patients and providers and two others involved policy-level tools, including AI-based surveillance algorithms. Overall, digital AMS interventions demonstrated considerable promise in improving the quality of care and antibiotic stewardship in these settings, albeit within a landscape shaped by significant heterogeneity in design, implementation and outcome measurement.

4.2 Interpretation in the Context of Existing Literature

This review corroborates and extends the existing global evidence on the effectiveness of digital AMS interventions, offering a critical LMIC-specific lens often absent from prior syntheses dominated by developed countries. While CDSS and mHealth tools are well-established in HICs for enhancing prescribing accuracy and guideline adherence, the findings here demonstrate that significant clinical and behavioural gains can also be realised in LMICs, even amid infrastructural fragility, workforce shortages and limited diagnostic capacity. Unlike digital AMS interventions embedded within advanced electronic health record ecosystems typical of HICs, the LMIC-based tools examined in this review such as ePOCT, ALMANACH and M-TIBA were often offline-compatible, mobile-based and explicitly designed for low-resource, high-burden settings. Their effectiveness, even in facilities without consistent electricity or internet connectivity, doesn't just reflect their thoughtful contextual adaptation but aligns closely with the WHO's Global Action Plan on AMR [(57)] and the Global Strategy on Digital Health 2020–2025 [(93)].

Furthermore, this review adds unique value by showcasing the potential of emerging tools such AI-driven dashboards that draw on behavioural science and implementation research principles [(153)]. These findings align with emerging frameworks that emphasise human-centred design, digital literacy and health system integration. Nonetheless, the broader evidence base remains constrained by a lack of longitudinal follow-up, economic evaluations and scalability data. The dominance of small-scale or pilot studies, limited inclusion of patients and policymakers as primary users and the absence of AMR surveillance data continue to hamper the transferability and long-term policy relevance of these interventions across diverse LMIC settings. Addressing these limitations is critical for transitioning digital AMS tools from innovation to system-wide impact.

4.3 Mechanisms of Change and Contextual Influences

The effectiveness of these interventions was driven by a set of interconnected mechanisms that shaped adoption, fidelity and sustainability. Four key drivers emerged from this review namely, supportive health systems, cultural and contextual relevance, user-centred behavioural design and technological integration into clinical workflows (see Figure 3). These drivers interacted across the spectrum of digital intervention inputs and implementation processes, while being shaped by contextual enablers and barriers. Collectively they influenced key outcomes such as prescribing behaviour, clinical effectiveness and stakeholder engagement.

Systemic support emerged as the foundational determinant of the feasibility and longevity of digital AMS initiatives. Countries with coherent digital health strategies, regulatory alignment and formal institutional partnerships such as Kenya [(148)] and India [(153)] demonstrated stronger implementation performance. These health systems enabled the integration of tools into reporting workflows, supported interoperability and provided the policy infrastructure needed to scale interventions beyond pilot stages.

Cultural and contextual relevance influenced both design and process. Interventions that were co-created with local stakeholders, adapted to end-user needs and sensitive to prevailing norms reported higher engagement. In Nepal, participatory video approaches fostered trust and improved knowledge uptake [(156)], while in West Africa, tailoring CDSS interfaces to include diverse prescriber types and aligning with regional treatment practices facilitated better provider acceptance [(157)]. Tools lacking contextual fit, by contrast, risked low engagement and diminished impact.

Behavioural design played a critical role in facilitating adoption and sustained use. Successful tools featured intuitive user interfaces, embedded decision support and prompt-based reinforcement mechanisms that aligned with clinical routines. Training modules and ongoing support helped mitigate low digital literacy, while perceived clinical benefits such as improved recovery rates and prescribing confidence also strengthened trust and engagement. Barriers such as clinician scepticism towards algorithmic recommendations [(162)], perceived workload and inadequate infrastructure often impeded fidelity and adherence.

Technological integration functioned as an enabling layer. Tools embedded into facility-level systems and linked with existing protocols such as IMCI were associated with improved prescribing and patient outcomes [(139, 146)]. Conversely, stand-alone digital tools such as eIMCI and basic mHealth apps that operated outside routine workflows encountered challenges including limited uptake, redundancy and provider disengagement [(160, 161)]. These findings underscore that the success of digital AMS interventions was contingent not on individual components alone but on their alignment with broader system structures, local realities, behavioural processes and infrastructure. Future implementation must consider this interplay holistically to embed interventions into national stewardship efforts and drive sustainable impact.

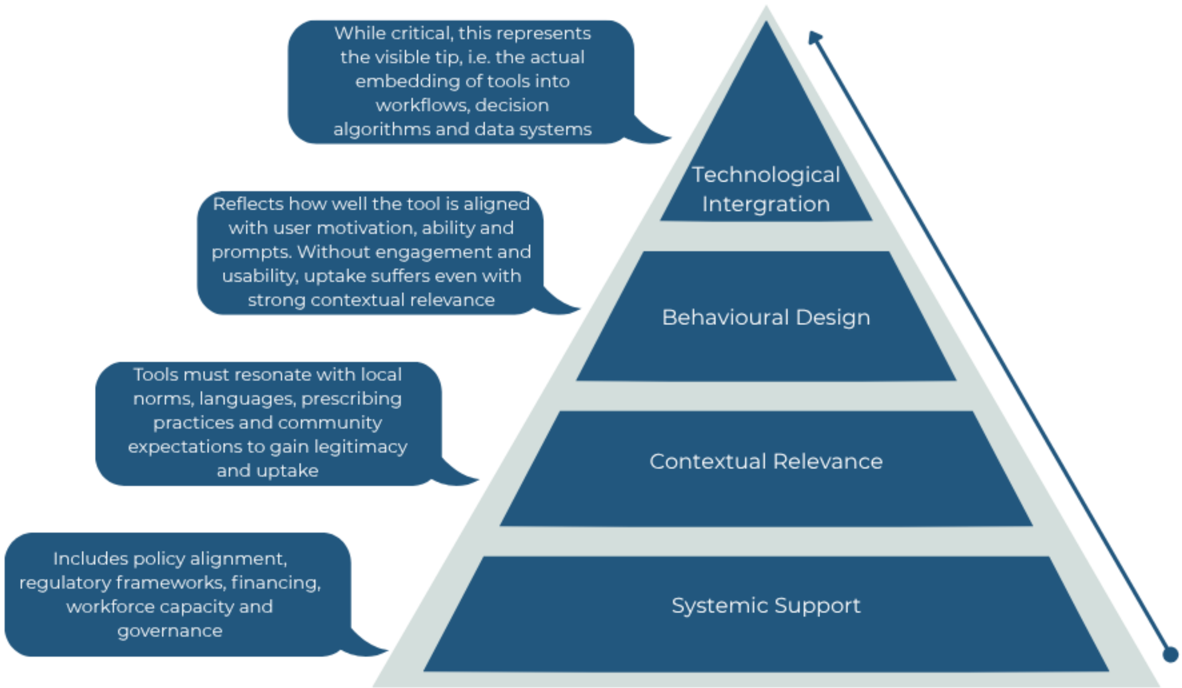


Figure 3: This figure illustrates the factors behind the successful adaptation of digital health interventions in LMIC community settings

4.4 Strengths and Limitations

This systematic review possesses several strengths. First, it employed a comprehensive multi-database and grey literature search, ensuring robust coverage of peer-reviewed and implementation-focused studies. Second, data extraction was rigorously standardised and independently double-reviewed, enhancing reliability and reducing the risk of selection or interpretation bias. Third, the inclusion of RCTs, observational, qualitative and mixed-methods studies enabled a comprehensive synthesis of both outcome and implementation data, allowing for a nuanced understanding of intervention effectiveness and process-level mechanisms. Finally, the use of established critical appraisal tools (RoB 2, ROBINS-I and CASP) along with evidence certainty frameworks (GRADE and GRADE-CERQual) further strengthened the review's internal validity by enabling tailored quality assessments and transparent evaluation of confidence in findings across heterogeneous methodologies.

However, several limitations must be acknowledged. The number of studies included was relatively small (n=24), which, while reflective of the nascent state of digital AMS research in LMICs, limits the breadth of evidence. The methodological heterogeneity particularly differences in intervention types, outcome measures and study designs hampered meta-analytic pooling and restricted cross-study comparability. Furthermore, many studies lacked long-term follow-up, limiting insights into sustainability and resistance trend evolution. Potential publication bias is also a concern, as language restrictions and underrepresentation of grey literature may have excluded relevant non-English studies or unpublished programmatic evaluations. The geographic concentration in Sub-Saharan Africa (n=21 studies) further limits generalisability to other LMIC regions such as Latin America, East Asia or the Middle East. Lastly, limited reporting of intervention cost and resource inputs constrains the ability to assess scalability and economic feasibility, key concerns for LMIC policymakers.

4.5 Implications for Practice and Policy

This review presents critical implications and actionable priorities for enhancing AMS through digital means. Foremost, Ministries of Health should prioritise the integration of digital tools, particularly CDSS platforms such as ePOCT and ALMANACH into national health information systems. Interventions embedded within existing workflows and aligned with WHO's IMCI protocols clearly demonstrated greater uptake, fidelity and sustainability. Conversely, stand-alone tools that operate within siloed platforms or donor-driven projects often struggled with limited adoption and redundancy post-funding. Additionally, investment in digital infrastructure remains an urgent necessity. Many interventions relied on mobile devices and offline functionality to circumvent infrastructural gaps. However, scaling and enhancing these tools may require improved internet connectivity, reliable electricity supply and access to appropriate digital hardware at the primary care level. Equally critical is digital literacy training, especially for lower-level providers who frequently deliver frontline care.

Behavioural interventions such as structured prompts, participatory education and algorithm-guided triage should be co-designed with end-users to enhance contextual fit, uptake and system-wide impact. Robust regulatory frameworks must also accompany the deployment of AI-driven tools. While studies showed potential for AI and predictive analytics, their safe and effective use demands ethical oversight, data governance mechanisms and local validation to mitigate misuse and algorithmic bias. Finally, AMS efforts must expand its scope to include patients and policymakers. Mobile platforms offering health education, prescription tracking and behaviour change communication alongside stronger policymaker engagement in shaping surveillance and response are vital to fostering stewardship accountability across all system levels.

4.6 Recommendations for Future Research

This review identifies several critical avenues to strengthen the evidence base on digital AMS interventions in LMIC community settings. First, future research should prioritise well-powered, multi-centre trials that employ harmonised outcome measures. Current evidence, while promising, is heavily concentrated in Sub-Saharan Africa and largely comprises single-site studies, limiting external validity and regional transferability. Comparative trials across diverse LMIC settings particularly in Southeast Asia, Latin America and the Middle East are essential to elucidate contextual determinants of effectiveness. Second, there is a notable lack of robust economic evaluations. While some studies offer qualitative insights into cost and resource constraints [157, 159], none conducted formal cost-effectiveness or budget impact analyses. Such evaluations are critical for engaging global funders like the Gates Foundation [163] and the Fleming Fund [164], as they provide essential evidence on the value of investing in digital AMS interventions. Future studies should therefore incorporate economic modelling and equity-sensitive evaluations to inform policymaker decisions on resource allocation, particularly given the financial constraints of LMIC health systems.

Third, mixed-methods research should be further leveraged to better understand the factors influencing adoption and fidelity. Qualitative inquiry like Jones et al. [156] and the two Peiffer-Smadja studies [157, 162] are good examples that demonstrated provider perceptions, patient experiences and systemic barriers, facilitating the design of contextually adaptive and user-centred tools, factors often overlooked in purely quantitative research. Fourth, longitudinal research is needed to assess the sustained impact of digital AMS tools on prescribing behaviours and antimicrobial resistance trends. Integrating prescribing data with microbiological surveillance platforms can help evaluate intervention effectiveness over time and support One Health approaches to AMR control. Lastly, implementation research grounded in systems thinking is imperative. Future studies should examine how digital AMS tools interact with governance, financing, digital health infrastructure and cross-sectoral policies. Such approaches can inform scalable, sustainable strategies to institutionalise digital stewardship across LMIC community healthcare settings.

5. Conclusion

This systematic review demonstrates the growing potential of digital interventions to enhance AMS in community healthcare settings across LMICs. The evidence suggests that digital tools can contribute meaningfully to improving prescribing practices, supporting behaviour change among healthcare providers and facilitating more rational use of antibiotics without compromising clinical outcomes. The review found that digital interventions are most effective when designed with contextual relevance, aligned with existing clinical workflows and supported by strong governance and institutional integration. Interventions that are easy to use, provide timely support to decision-making and promote user trust have shown promising results in both improving prescribing accuracy and reducing inappropriate antibiotic use. However, the implementation and scale-up of digital AMS tools remain challenged by infrastructural limitations, variable digital literacy, insufficient workforce capacity and fragmented health information systems. There is also a noticeable lack of robust economic evaluations and limited inclusion of patient or policymaker perspectives in intervention design and assessment. Looking forward, successful and sustainable digital AMS initiatives in LMICs will depend on greater investment in digital infrastructure, stronger multisectoral collaboration and policy alignment at national levels. Co-designing interventions with local stakeholders, embedding them within broader health systems and ensuring flexibility for local adaptation are critical to maximising their impact. As AMR continues to threaten global health security, digital health interventions represent a vital and underutilised weapon in our arsenal to strengthen community healthcare delivery and promote the responsible use of antibiotics in resource-limited settings.

6. References

1. Naghavi M, Vollset SE, Ikuta KS, Swetschinski LR, Gray AP, Wool EE, et al. Global burden of bacterial antimicrobial resistance 1990–2021: a systematic analysis with forecasts to 2050. The Lancet. 2024;404(10459):1199-226.
2. Ahmed SK, Hussein S, Qurbani K, Ibrahim RH, Fareeq A, Mahmood KA, et al. Antimicrobial resistance: Impacts, challenges, and future prospects. Journal of Medicine, Surgery, and Public Health. 2024;2:100081.
3. Tang KWK, Millar BC, Moore JE. Antimicrobial Resistance (AMR). Br J Biomed Sci. 2023;80:11387.
4. Oliveira M, Antunes W, Mota S, Madureira-Carvalho Á, Dinis-Oliveira RJ, Dias da Silva D. An Overview of the Recent Advances in Antimicrobial Resistance. Microorganisms [Internet]. 2024; 12(9).
5. Chan A. Institute For Health Metrics And Evaluation. 2022. [cited 2025 1/7/2025]. Available from: https://www.healthdata.org/news-events/insights-blog/acting-data/among-superbugs-mrsa-forefront-antimicrobial-resistance.
6. Aguilar GR, Swetschinski LR, Weaver ND, Ikuta KS, Mestrovic T, Gray AP, et al. The burden of antimicrobial resistance in the Americas in 2019: a cross-country systematic analysis. The Lancet Regional Health – Americas. 2023;25.
7. O'Neill J. TACKLING DRUG-RESISTANT INFECTIONS GLOBALLY: FINAL REPORT AND RECOMMENDATIONS. 2016 May 2016.
8. Rupasinghe NM, C.; Muthee, T.; Mazimba, A. Stopping the Grand Pandemic: A Framework for Action - Addressing Antimicrobial Resistance through World Bank Operations. World Bank; 2024 2024-05-09.
9. Anthony McDonnell AC, Tim Laurence, Sophie Gulliver, Tom Drake, Suzanne Edwards, Charles Kenny, Olimpia Lamberti, Alec Morton, Asti Shafira, Robert Smith, Javier Guzman. Forecasting the Fallout from AMR: Economic Impacts of Antimicrobial Resistance in Humans. 2024.
10. Spellberg B, Blaser M, Guidos RJ, Boucher HW, Bradley JS, Eisenstein BI, et al. Combating antimicrobial resistance: policy recommendations to save lives. Clin Infect Dis. 2011;52 Suppl 5(Suppl 5):S397-428.

11. Oliver M. Counting the Cost of TB in Europe [Internet]: RESULTS UK. 2013. [cited 2025]. Available from: https://old.results.org.uk/blog/counting-cost-tb-europe#:~:text=On%20August%2015th%20the,(disability%20adjusted%20life%20years).
12. OECD. Stemming the Superbug Tide: JUST A FEW DOLLARS MORE. 2018.
13. Naylor NR, Hasso-Agopsowicz M, Kim C, Ma Y, Frost I, Abbas K, et al. The global economic burden of antibiotic-resistant infections and the potential impact of bacterial vaccines: a modelling study. BMJ Glob Health. 2025;10(6).
14. Anderson DJ, Pyatt DG, Weber DJ, Rutala WA. Statewide costs of health care-associated infections: estimates for acute care hospitals in North Carolina. Am J Infect Control. 2013;41(9):764-8.
15. Massimo Sartelli FC, Fausto Catena and Leonardo Pagani. GLOBAL INFECTION PREVENTION AND MANAGEMENT IN HEALTHCARE: Antimicrobial resistance and One Health: Global Alliance for Infections in Surgery; 2024. Available from: https://infectionsinsurgery.org/wp-content/uploads/2024/11/volume-1-published-18-november-2.pdf.
16. Gashegu M, Gahamanyi N, Ndayambaje FX, Munyemana JB, Ndahindwa V, Lukwago F, et al. Exploring Prescription Practices: Insights from an Antimicrobial Stewardship Program at a Tertiary Healthcare Facility, Rwanda. Antibiotics [Internet]. 2024; 13(6).
17. Salam MA, Al-Amin MY, Salam MT, Pawar JS, Akhter N, Rabaan AA, et al. Antimicrobial Resistance: A Growing Serious Threat for Global Public Health. Healthcare (Basel). 2023;11(13).
18. Charani E, McKee M, Ahmad R, Balasegaram M, Bonaconsa C, Merrett GB, et al. Optimising antimicrobial use in humans – review of current evidence and an interdisciplinary consensus on key priorities for research. The Lancet Regional Health - Europe. 2021;7:100161.
19. IFPMA. From resistance to resilience: What could the future antibiotic pipeline look like? ; 2024.
20. WHO. Global Antimicrobial Resistance and Use Surveillance System (GLASS) report Antibiotic use data for 2022. 2022.
21. Aslam B, Asghar R, Muzammil S, Shafique M, Siddique AB, Khurshid M, et al. AMR and Sustainable Development Goals: at a crossroads. Globalization and Health. 2024;20(1):73.
22. Luong Nguyen T, Didier W, Mats M, Peter Søgaard J. 'When global health meets global goals': assessing the alignment between antimicrobial resistance and sustainable development policies in 10 African and Asian countries. BMJ Global Health. 2025;10(3):e017837.
23. Lewnard JA, Charani E, Gleason A, Hsu LY, Khan WA, Karkey A, et al. Burden of bacterial antimicrobial resistance in low-income and middle-income countries avertible by existing interventions: an evidence review and modelling analysis. The Lancet. 2024;403(10442):2439-54.
24. de Kraker MEA. Understanding the impact of antimicrobial resistance on outcomes of bloodstream infections in low- and middle-income countries. PLoS Med. 2023;20(7):e1004262.
25. Sartorius B, Gray AP, Davis Weaver N, Robles Aguilar G, Swetschinski LR, Ikuta KS, et al. The burden of bacterial antimicrobial resistance in the WHO African region in 2019: a cross-country systematic analysis. The Lancet Global Health. 2024;12(2):15.
26. Boltena MT, Wolde M, Hailu B, El-Khatib Z, Steck V, Woldegerima S, et al. Point prevalence of evidence-based antimicrobial use among hospitalized patients in sub-Saharan Africa: a systematic review and meta-analysis. Scientific Reports. 2024;14(1):12652.
27. Sulis G, Sayood S, Gandra S. How can we tackle the overuse of antibiotics in low- and middle-income countries? Expert Rev Anti Infect Ther. 2023;21(11):1189-201.
28. Otaigbe, II, Elikwu CJ. Drivers of inappropriate antibiotic use in low- and middle-income countries. JAC Antimicrob Resist. 2023;5(3):dlad062.
29. Pokharel S, Raut S, Adhikari B. Tackling antimicrobial resistance in low-income and middle-income countries. BMJ Glob Health. 2019;4(6):e002104.
30. Sihombing B, Bhatia R, Srivastava R, Aditama TY, Laxminarayan R, Rijal S. Response to antimicrobial resistance in South-East Asia Region. The Lancet Regional Health - Southeast Asia. 2023;18.
31. Otaigbe II. Achieving universal health coverage in low- and middle-income countries through digital antimicrobial stewardship2023.

32. Zewdie S, Kassa AA, Yayehrad AT, Bizuneh MM, Ayenew W, Zewudie M, et al. Non-prescription antibiotic use and its predictors among children in low- and middle-income countries: a systematic review and meta-analysis. Ital J Pediatr. 2024;50(1):260.
33. Torres NF, Chibi B, Kuupiel D, Solomon VP, Mashamba-Thompson TP, Middleton LE. The use of non-prescribed antibiotics; prevalence estimates in low-and-middle-income countries. A systematic review and meta-analysis. Arch Public Health. 2021;79(1):2.
34. Auta A, Hadi MA, Oga E, Adewuyi EO, Abdu-Aguye SN, Adeloye D, et al. Global access to antibiotics without prescription in community pharmacies: A systematic review and meta-analysis. J Infect. 2019;78(1):8-18.
35. Ventola CL. The antibiotic resistance crisis: part 1: causes and threats. P t. 2015;40(4):277-83.
36. Arshad AR, Ijaz F, Siddiqui MS, Khalid S, Fatima A, Aftab RK. COVID-19 pandemic and antimicrobial resistance in developing countries. Discoveries (Craiova). 2021;9(2):e127.
37. IHME. GBD Foresight Visualization. University of Washington, Seattle, WA: Institute for Health Metrics and Evaluation (IHME); 2024.
38. Charani E, Mendelson M, Pallett SJC, Ahmad R, Mpundu M, Mbamalu O, et al. An analysis of existing national action plans for antimicrobial resistance—gaps and opportunities in strategies optimising antibiotic use in human populations. The Lancet Global Health. 2023;11(3):e466-e74.
39. Ehsan H. Antibiotic Resistance in Developing Countries: Emerging Threats and Policy Responses. Public Health Challenges. 2025;4(1):e70034.
40. Cox JA, Vlieghe E, Mendelson M, Wertheim H, Ndegwa L, Villegas MV, et al. Antibiotic stewardship in low- and middle-income countries: the same but different? Clin Microbiol Infect. 2017;23(11):812-8.
41. Iskandar K, Molinier L, Hallit S, Sartelli M, Hardcastle TC, Haque M, et al. Surveillance of antimicrobial resistance in low- and middle-income countries: a scattered picture. Antimicrob Resist Infect Control. 2021;10(1):63.
42. Gandra S, Alvarez-Uria G, Turner P, Joshi J, Limmathurotsakul D, van Doorn HR. Antimicrobial Resistance Surveillance in Low- and Middle-Income Countries: Progress and Challenges in Eight South Asian and Southeast Asian Countries. Clin Microbiol Rev. 2020;33(3).
43. Ritchie H. Three-quarters of antibiotics are used on animals. Here's why that's a major problem2017. Available from: https://www.weforum.org/stories/2017/11/three-quarters-of-antibiotics-are-used-on-animals-heres-why-thats-a-major-problem/#:~:text=It's%20expected%20that%20as%20global,important%20antibiotics%20in%20livestock.12.
44. Kusi J, Ojewole CO, Ojewole AE, Nwi-Mozu I. Antimicrobial Resistance Development Pathways in Surface Waters and Public Health Implications. Antibiotics (Basel). 2022;11(6).
45. Almakki A, Jumas-Bilak E, Marchandin H, Licznar-Fajardo P. Antibiotic resistance in urban runoff. Sci Total Environ. 2019;667:64-76.
46. Otaigbe, II. Mitigating inequitable access to appropriate antibiotics in low- and middle-income countries. JAC Antimicrob Resist. 2025;7(2):dlaf061.
47. Unicomb LE, Nizame FA, Uddin MR, Nahar P, Lucas PJ, Khisa N, et al. Motivating antibiotic stewardship in Bangladesh: identifying audiences and target behaviours using the behaviour change wheel. BMC Public Health. 2021;21(1):968.
48. Huong VTL, Ngan TTD, Thao HP, Quang LM, Hanh TTT, Hien NT, et al. Assessing feasibility of establishing antimicrobial stewardship programmes in two provincial-level hospitals in Vietnam: an implementation research study. BMJ Open. 2021;11(10):e053343.
49. Zavaleta-Monestel E, Hasselmyr Hasselmyr S, García-Montero J, Arguedas-Chacón S, Rojas-Chinchilla C, Díaz-Madriz JP. The Impact of Vaccination as a Strategy to Combat Bacterial Antimicrobial Resistance. Cureus. 2024;16(7):e65840.
50. Frost I, Sati H, Garcia-Vello P, Hasso-Agopsowicz M, Lienhardt C, Gigante V, et al. The role of bacterial vaccines in the fight against antimicrobial resistance: an analysis of the preclinical and clinical development pipeline. Lancet Microbe. 2023;4(2):e113-e25.

51. Seale A, Gordon N, Islam J, Peacock S, Scott J. AMR Surveillance in low and middle-income settings - A roadmap for participation in the Global Antimicrobial Surveillance System (GLASS) [version 1; peer review: 3 approved]. Wellcome Open Research. 2017;2(92).
52. Kalanxhi SSE. Highlights from the 79th United Nations General Assembly Week – A critical time for global action to tackle AMR2024. Available from: https://onehealthtrust.org/news-media/blog/highlights-from-the-79th-united-nations-general-assembly-week-a-critical-time-for-global-action-to-tackle-amr/.
53. Russell Dacombe JP, Selina Wallis, Minakshi Bhardwaj and Imelda Bates. Fleming Fund: supporting surveillance capacity for antimicrobial resistance. U.K.: Wellcome Trust; 2016.
54. NICE. Antimicrobial stewardship: systems and processes for effective antimicrobial medicine use. National Institute For Health And Care Excellence; 2015. p. 27.
55. Dellit TH, Owens RC, McGowan JE, Gerding DN, Weinstein RA, Burke JP, et al. Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America Guidelines for Developing an Institutional Program to Enhance Antimicrobial Stewardship. Clin Infect Dis. 2007;44(2):159-77.
56. Hibbard R, Mendelson M, Page SW, Ferreira JP, Pulcini C, Paul MC, et al. Antimicrobial stewardship: a definition with a One Health perspective. npj Antimicrobials and Resistance. 2024;2(1):15.
57. WHO. GLOBAL ACTION PLAN ON ANTIMICROBIAL RESISTANCE. 2015.
58. Villanueva P, Coffin SE, Mekasha A, McMullan B, Cotton MF, Bryant PA. Comparison of Antimicrobial Stewardship and Infection Prevention and Control Activities and Resources Between Low-/Middle- and High-income Countries. Pediatr Infect Dis J. 2022;41(3s):S3-s9.
59. PAR. The Foundation to Prevent Antibiotic Resistance Sweden 2017.
60. Turner P, Ashley EA, Celhay OJ, Douangnouvong A, Hamers RL, Ling CL, et al. ACORN (A Clinically-Oriented Antimicrobial Resistance Surveillance Network): a pilot protocol for case based antimicrobial resistance surveillance. Wellcome Open Res. 2020;5:13.
61. Wade T, Roberts N, Ban JW, Waweru-Siika W, Winston H, Williams V, et al. Utility of healthcare-worker-targeted antimicrobial stewardship interventions in hospitals of low- and lower-middle-income countries: a scoping review of systematic reviews. Journal of Hospital Infection. 2023;131:43-53.
62. Al-Omari A, Al Mutair A, Alhumaid S, Salih S, Alanazi A, Albarsan H, et al. The impact of antimicrobial stewardship program implementation at four tertiary private hospitals: results of a five-years pre-post analysis. Antimicrob Resist Infect Control. 2020;9(1):95.
63. Nathwani D, Varghese D, Stephens J, Ansari W, Martin S, Charbonneau C. Value of hospital antimicrobial stewardship programs [ASPs]: a systematic review. Antimicrobial Resistance & Infection Control. 2019;8(1):35.
64. Principi N, Esposito S. Antimicrobial stewardship in paediatrics. BMC Infect Dis. 2016;16(1):424.
65. Brigadoi G, Rossin S, Chiusaroli L, Demarin GC, Maestri L, Tesser F, et al. Impact of Antibiotic Stewardship on Treatment of Hospitalized Children with Skin and Soft-Tissue Infections. Children (Basel). 2024;11(11).
66. Buehrle DJ, Shively NR, Wagener MM, Clancy CJ, Decker BK. Sustained Reductions in Overall and Unnecessary Antibiotic Prescribing at Primary Care Clinics in a Veterans Affairs Healthcare System Following a Multifaceted Stewardship Intervention. Clin Infect Dis. 2019;71(8):e316-e22.
67. Nace DA, Hanlon JT, Crnich CJ, Drinka PJ, Schweon SJ, Anderson G, et al. A Multifaceted Antimicrobial Stewardship Program for the Treatment of Uncomplicated Cystitis in Nursing Home Residents. JAMA Intern Med. 2020;180(7):944-51.
68. Zimmerman S, Sloane PD, Bertrand R, Olsho LEW, Beeber A, Kistler C, et al. Successfully Reducing Antibiotic Prescribing in Nursing Homes. Journal of the American Geriatrics Society. 2014;62(5):907-12.
69. Sallam M, Snygg J. Improving Antimicrobial Stewardship Program Using the Lean Six Sigma Methodology: A Descriptive Study from Mediclinic Welcare Hospital in Dubai, the UAE. Healthcare (Basel). 2023;11(23).

70. Honda H, Ohmagari N, Tokuda Y, Mattar C, Warren DK. Antimicrobial Stewardship in Inpatient Settings in the Asia Pacific Region: A Systematic Review and Meta-analysis. Clin Infect Dis. 2017;64(suppl_2):S119-S26.
71. Taggart LR, Leung E, Muller MP, Matukas LM, Daneman N. Differential outcome of an antimicrobial stewardship audit and feedback program in two intensive care units: a controlled interrupted time series study. BMC Infect Dis. 2015;15:480.
72. Álvarez-Lerma F, Grau S, Echeverría-Esnal D, Martínez-Alonso M, Gracia-Arnillas MP, Horcajada JP, et al. A Before-and-After Study of the Effectiveness of an Antimicrobial Stewardship Program in Critical Care. Antimicrob Agents Chemother. 2018;62(4).
73. Mary Helen Ribero Pombo SG, Didi Thompson, Anjana Sankhil Lamkang, Celine Pulcini, Ramanan Laxminarayan. GLOBAL CORE STANDARDS FOR HOSPITAL ANTIMICROBIAL STEWARDSHIP PROGRAMS INTERNATIONAL PERSPECTIVES AND FUTURE DIRECTIONS. 2018.
74. CDC. Core Elements of Hospital Antibiotic Stewardship Programs. Centre For Disease Control and Prevention; 2019. p. 40.
75. Okonkwo RI, Ndukwe H, Grant G, Khan S. Antimicrobial stewardship in the community setting: a qualitative exploratory study. Antimicrob Resist Infect Control. 2025;14(1):9.
76. Physiopedia. Levels of Healthcare2025. Available from: https://www.physio-pedia.com/Levels_of_Healthcare.
77. Jeffries Mazhar R, Willows TM, Bhattarai S, Tinn C-S, Misago N, English M. First referral hospitals in low- and middle-income countries: the need for a renewed focus. Health Policy and Planning. 2024;39(2):224-32.
78. Belachew SA, Hall L, Selvey LA. Non-prescription dispensing of antibiotic agents among community drug retail outlets in Sub-Saharan African countries: a systematic review and meta-analysis. Antimicrobial Resistance & Infection Control. 2021;10(1):13.
79. NuffliedTrust. Antibiotic prescribing: We look at prescribing patterns for antibiotics, both in England and internationally2025. Available from: https://www.nuffieldtrust.org.uk/resource/antibiotic-prescribing#:~:text=Antibiotic%20consumption%20by%20provider&text=This%20overall%20decrease%20will%20contribute,have%20the%20same%20clinical%20impact.
80. Piednoir E, Thibon P, Messidor L, Launay L, Verdon R, Tattevin P. Holistic analysis of the determinants of antibiotic prescription in primary care in France: a cross-sectional study with nationwide panel data. J Antimicrob Chemother. 2025;80(6):1568-72.
81. Saleem Z, Moore CE, Kalungia AC, Schellack N, Ogunleye O, Chigome A, et al. Status and implications of the knowledge, attitudes and practices towards AWaRe antibiotic use, resistance and stewardship among low- and middle-income countries. JAC-Antimicr Res. 2025;7(2).
82. Chandra Deb L, McGrath BM, Schlosser L, Hewitt A, Schweitzer C, Rotar J, et al. Antibiotic Prescribing Practices for Upper Respiratory Tract Infections Among Primary Care Providers: A Descriptive Study. Open Forum Infect Dis. 2022;9(7).
83. Dolk FCK, Pouwels KB, Smith DRM, Robotham JV, Smieszek T. Antibiotics in primary care in England: which antibiotics are prescribed and for which conditions? J Antimicrob Chemother. 2018;73(suppl_2):ii2-ii10.
84. Palmer NOA. Antimicrobial resistance and antibiotic prescribing in dental practice. Dental Update. 2016;43(10):954-60.
85. Cassettari VC, da Silveira IR, Dropa M, Lincopan N, Mamizuka EM, Matté MH, et al. Risk factors for colonisation of newborn infants during an outbreak of extended-spectrum β-lactamase-producing Klebsiella pneumoniae in an intermediate-risk neonatal unit. Journal of Hospital Infection. 2009;71(4):340-7.
86. Karanika S, Karantanos T, Arvanitis M, Grigoras C, Mylonakis E. Fecal Colonization With Extended-spectrum Beta-lactamase–Producing Enterobacteriaceae and Risk Factors Among Healthy Individuals: A Systematic Review and Metaanalysis. Clin Infect Dis. 2016;63(3):310-8.
87. Sanchez GV, Baird AMG, Karlowsky JA, Master RN, Bordon JM. Nitrofurantoin retains antimicrobial activity against multidrug-resistant urinary Escherichia coli from US outpatients. J Antimicrob Chemother. 2014;69(12):3259-62.

88. Spurling GKP, Dooley L, Clark J, Askew DA. Immediate versus delayed versus no antibiotics for respiratory infections. Cochrane Database of Systematic Reviews. 2023(10).
89. Rognstad S, Brekke M, Fetveit A, Dalen I, Straand J. Prescription peer academic detailing to reduce inappropriate prescribing for older patients: a cluster randomised controlled trial. British Journal of General Practice. 2013;63(613):e554.
90. Cross EL, Tolfree R, Kipping R. Systematic review of public-targeted communication interventions to improve antibiotic use. J Antimicrob Chemother. 2017;72(4):975-87.
91. Maduko W, Olamijuwon E, Kesby M, Hale JM. Public-targeted interventions addressing antimicrobial resistance and antibiotic use in Sub-Saharan Africa: a scoping review. BMJ Glob Health. 2025;10(3).
92. WHO. WHO AWaRe (access, watch, reserve) classification of antibiotics for evaluation and monitoring of use. World Health Organization; 2023.
93. WHO. Global strategy on digital health 2020-2025. Geneva: World Health Organization; 2021.
94. Curtis CE, Al Bahar F, Marriott JF. The effectiveness of computerised decision support on antibiotic use in hospitals: A systematic review. PLOS ONE. 2017;12(8):e0183062.
95. Vento TJ, Veillette JJ, Gelman SS, Adams A, Jones P, Repko K, et al. Implementation of an Infectious Diseases Telehealth Consultation and Antibiotic Stewardship Program for 16 Small Community Hospitals. Open Forum Infect Dis. 2021;8(6):ofab168.
96. SuperCharge. 2024. Available from: https://supercharge.io/us/blog/digital-health-solutions-transforming-patient-care.
97. Parzen-Johnson S, Kronforst KD, Shah RM, Whitmer GR, Scardina T, Chandarraju M, et al. Use of the Electronic Health Record to Optimize Antimicrobial Prescribing. Clinical Therapeutics. 2021;43(10):1681-8.
98. Forrest GN, Van Schooneveld TC, Kullar R, Schulz LT, Duong P, Postelnick M. Use of Electronic Health Records and Clinical Decision Support Systems for Antimicrobial Stewardship. Clin Infect Dis. 2014;59(suppl_3):S122-S33.
99. Thursky KA, Buising KL, Bak N, Macgregor L, Street AC, Macintyre CR, et al. Reduction of broad-spectrum antibiotic use with computerized decision support in an intensive care unit. International Journal for Quality in Health Care. 2006;18(3):224-31.
100. Beaulac K, Corcione S, Epstein L, Davidson LE, Doron S. Antimicrobial Stewardship in a Long-Term Acute Care Hospital Using Offsite Electronic Medical Record Audit. Infection Control & Hospital Epidemiology. 2016;37(4):433-9.
101. Hermsen ED, VanSchooneveld TC, Sayles H, Rupp ME. Implementation of a Clinical Decision Support System for Antimicrobial Stewardship. INFECTION CONTROL AND HOSPITAL EPIDEMIOLOGY. 2012;33(4).
102. Arnold A, McLellan S, Stokes JM. How AI can help us beat AMR. npj Antimicrobials and Resistance. 2025;3(1):18.
103. Leighton S. How we made an app for GP antibiotic prescribing2013. Available from: https://www.pulsetoday.co.uk/resource/clinical-areas/long-term-conditions-prescribing/how-we-made-an-app-for-gp-antibiotic-prescribing/.
104. Haque F, Ball RL, Khatun S, Ahmed M, Kache S, Chisti MJ, et al. Evaluation of a Smartphone Decision-Support Tool for Diarrheal Disease Management in a Resource-Limited Setting. PLoS neglected tropical diseases. 2017;11(1):e0005290.
105. Ogunnigbo O, Nabiryo M, Atteh M, Muringu E, Olaitan OJ, Rutter V, et al. Exploring the Antimicrobial Stewardship Educational Needs of Healthcare Students and the Potential of an Antimicrobial Prescribing App as an Educational Tool in Selected African Countries. Antibiotics (Basel). 2022;11(5).
106. Elshenawy RA. REPORT ON ANTIMICROBIAL STEWARDSHIP AND AMR SURVEILLANCE: INSIGHTS FROM THE SOUTH CENTRE WAAW 2024 WEBINAR. The South Centre; 2025.
107. Laight K. Latest ESPAUR report shows sustained decline in antibiotic consumption in England2022. Available from: https://wchh.onlinelibrary.wiley.com/do/10.1002/psb.0010084.

108. ECDC. ECDC Digital Roadmap 2022−2027. European Centre for Disease Prevention and Control; 2022. p. 18.
109. WHO. Digital Health Atlas. 2019.
110. Mutai D, Mwakala M, Njuguna C. Fighting malaria with digital health: How Kenya is transforming its community health sector2024. Available from: https://www.path.org/our-impact/articles/fighting-malaria-with-digital-health-how-kenya-is-transforming-its-community-health-sector/.
111. Lepere P, Babington-Ashaye A, Martínez-Pérez GZ, Ekouevi DK, Labrique AB, Calmy A. How mHealth Can Contribute to Improving the Continuum of Care: A Scoping Review Approach to the Case of Human Immunodeficiency Virus in Sub-Saharan Africa. Public Health Rev. 2022;43:1604557.
112. Hamainza B, Killeen GF, Kamuliwo M, Bennett A, Yukich JO. Comparison of a mobile phone-based malaria reporting system with source participant register data for capturing spatial and temporal trends in epidemiological indicators of malaria transmission collected by community health workers in rural Zambia. Malaria Journal. 2014;13(1):489.
113. Githinji S, Kigen S, Memusi D, Nyandigisi A, Wamari A, Muturi A, et al. Using mobile phone text messaging for malaria surveillance in rural Kenya. Malaria Journal. 2014;13(1):107.
114. Kiyasseh D, Zhu T, Clifton D. The Promise of Clinical Decision Support Systems Targetting Low-Resource Settings. IEEE Reviews in Biomedical Engineering. 2022;15:354-71.
115. Coulborn RM, Panunzi I, Spijker S, Brant WE, Duran LT, Kosack CS, et al. Feasibility of using teleradiology to improve tuberculosis screening and case management in a district hospital in Malawi. Bulletin of the World Health Organization. 2012;90(9):705.
116. Frangoudes F, Hadjiaros M, Schiza EC, Matsangidou M, Tsivitanidou O, Neokleous K, editors. An Overview of the Use of Chatbots in Medical and Healthcare Education. Learning and Collaboration Technologies: Games and Virtual Environments for Learning; 2021 2021//; Cham: Springer International Publishing.
117. Acharya KP, Subedi D. Use of Social Media as a Tool to Reduce Antibiotic Usage: A Neglected Approach to Combat Antimicrobial Resistance in Low and Middle Income Countries. Front Public Health. 2020;8:558576.
118. Tarín-Pelló A, Marco-Crespo E, Suay-García B, Galiana-Roselló C, Bueso-Bordils JI, Pérez-Gracia MT. Innovative gamification and outreach tools to raise awareness about antimicrobial resistance. Front Microbiol. 2022;13:977319.
119. MeriexFoundation. Africa CDC Antimicrobial Resistance Surveillance Network Launched during a Special Edition of ACDx Course2017. Available from: https://www.fondation-merieux.org/en/news/38-students-from-20-countries-took-our-advanced-course-on-diagnostics-acdx/#:~:text=Event-,Africa%20CDC%20Antimicrobial%20Resistance%20Surveillance%20Network%20Launched,Special%20Edition%20of%20ACDx%20Course&text=The%20Advanced%20Course%20on%20Diagnostics,this%20area%20were%20also%20presented.
120. Yadav SK, Shrestha L, Acharya J, Gompo TR, Chapagain S, Jha R. Integrative Digital Tools to Strengthen Data Management for Antimicrobial Resistance Surveillance in the “One Health” Domain in Nepal. Trop Med Infect Dis [Internet]. 2023; 8(6).
121. RuralServicesNetwork. Empowering Rural Communities with Digital Connectivity2024. Available from: https://www.rsnonline.org.uk/empowering-rural-communities-with-digital-connectivity#:~:text=Without%20adequate%20digital%20connectivity%2C%20rural%20residents%20face,digital%20marketplace%2C%20hindering%20economic%20growth%20and%20innovation.
122. WHO. Energizing health: accelerating electricity access in health-care facilities. World Health Organization; 2023.
123. Kaboré SS, Ngangue P, Soubeiga D, Barro A, Pilabré AH, Bationo N, et al. Barriers and facilitators for the sustainability of digital health interventions in low and middle-income countries: A systematic review. Front Digit Health. 2022;4:1014375.
124. Iyanna S, Kaur P, Ractham P, Talwar S, Najmul Islam AKM. Digital transformation of healthcare sector. What is impeding adoption and continued usage of technology-driven innovations by end-users? Journal of Business Research. 2022;153:150-61.

125. Ackerhans S, Huynh T, Kaiser C, Schultz C. Exploring the role of professional identity in the implementation of clinical decision support systems—a narrative review. Implementation Science. 2024;19(1):11.
126. Ramsey A, Lord S, Torrey J, Marsch L, Lardiere M. Paving the Way to Successful Implementation: Identifying Key Barriers to Use of Technology-Based Therapeutic Tools for Behavioral Health Care. J Behav Health Serv Res. 2016;43(1):54-70.
127. Botes M. Regulatory challenges of digital health: the case of mental health applications and personal data in South Africa. Front Pharmacol. 2025;16:1498600.
128. Postigo A. Regulation of digital health and health data in the Asia Pacific region. Bangkok: Asia-Pacific Research and Training Network on Trade (ARTNeT); 2023.
129. McGowan J, Sampson M, Salzwedel DM, Cogo E, Foerster V, Lefebvre C. PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. J Clin Epidemiol. 2016;75:40-6.
130. Richardson WS, Wilson MC, Nishikawa J, Hayward RS. The well-built clinical question: a key to evidence-based decisions. ACP J Club. 1995;123(3):A12-3.
131. Johnson N, Phillips M. Rayyan for systematic reviews. Journal of Electronic Resources Librarianship. 2018;30(1):46-8.
132. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Bmj. 2021;372:n71.
133. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:l4898.
134. Sterne JAC; Higgins JPT ea. The Risk of Bias in Non-randomized Studies of Interventions, Version 2 (ROBINS-I V2); launched 22 November 20242024 18 June 2025]. Available from: https://www.riskofbias.info/welcome/robins-i-v2.
135. CASP. Critical Appraisal Skills Programme (Qualitative Studies Checklist). 2025.
136. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924.
137. Lewin S, Glenton C, Munthe-Kaas H, Carlsen B, Colvin CJ, Gülmezoglu M, et al. Using qualitative evidence in decision making for health and social interventions: an approach to assess confidence in findings from qualitative evidence syntheses (GRADE-CERQual). PLoS Med. 2015;12(10):e1001895.
138. Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. Am J Public Health. 1999;89(9):1322-7.
139. Tan R, Kavishe G, Luwanda LB, Kulinkina AV, Renggli S, Mangu C, et al. A digital health algorithm to guide antibiotic prescription in pediatric outpatient care: a cluster randomized controlled trial. NATURE MEDICINE. 2023;30(1):76-+.
140. O'Donovan J, Kabali K, Taylor C, Chukhina M, Kading JC, Fuld J, et al. The use of low-cost Android tablets to train community health workers in Mukono, Uganda, in the recognition, treatment and prevention of pneumonia in children under five: A pilot randomised controlled trial. Human Resources for Health. 2018;16(1).
141. Rambaud-Althaus C, Shao A, Samaka J, Swai N, Perri S, Kahama-Maro J, et al. Performance of Health Workers Using an Electronic Algorithm for the Management of Childhood Illness in Tanzania: A Pilot Implementation Study. Am J Trop Med Hyg. 2017;96(1):249-57.
142. Perri-Moore S, Routen T, Shao AF, Rambaud-Althaus C, Swai N, Kahama-Maro J, et al. Using an eIMCI-Derived Decision Support Protocol to Improve Provider-Caretaker Communication for Treatment of Children Under 5 in Tanzania. Glob Health Commun. 2015;1(1):41-7.
143. Steinhardt LC, Mathanga DP, Mwandama D, Nsona H, Moyo D, Gumbo A, et al. The Effect of Text Message Reminders to Health Workers on Quality of Care for Malaria, Pneumonia, and Diarrhea in Malawi: a Cluster-Randomized, Controlled Trial. American journal of tropical medicine and hygiene. 2019;100(2):460-9.
144. Tan R, Kagoro F, Levine GA, Masimba J, Samaka J, Sangu W, et al. Clinical Outcome of Febrile Tanzanian Children with Severe Malnutrition Using Anthropometry in Comparison to Clinical Signs. AMERICAN JOURNAL OF TROPICAL MEDICINE AND HYGIENE. 2020;102(2):427-35.

145. Keitel K, Samaka J, Masimba J, Temba H, Said Z, Kagoro F, et al. Safety and Efficacy of C-reactive Protein-guided Antibiotic Use to Treat Acute Respiratory Infections in Tanzanian Children: A Planned Subgroup Analysis of a Randomized Controlled Noninferiority Trial Evaluating a Novel Electronic Clinical Decision Algorithm (ePOCT). Clin Infect Dis. 2019;69(11):1926-34.
146. Keitel K, Kagoro F, Samaka J, Masimba J, Said Z, Temba H, et al. A novel electronic algorithm using host biomarker point-of-care tests for the management of febrile illnesses in Tanzanian children (e-POCT): A randomized, controlled non-inferiority trial. PLoS Med. 2017;14(10):e1002411.
147. Tan R, Kavishe G, Kulinkina AV, Renggli S, Luwanda LB, Mangu C, et al. Quality of care when using a digital clinical decision support algorithm to manage sick children at primary care health facilities in Tanzania: a cross-sectional cluster randomized controlled trial (DYNAMIC study). medRxiv: the preprint server for health sciences. 2024.
148. Mekuria LA, de Wit TF, Spieker N, Koech R, Nyarango R, Ndwiga S, et al. Analyzing data from the digital healthcare exchange platform for surveillance of antibiotic prescriptions in primary care in urban Kenya: A mixed-methods study. PLoS One. 2019;14(9):e0222651.
149. Langet H, Faye PM, Njiri F, Cicconi S, Levine GA, Glass TR, et al. Effectiveness of introducing pulse oximetry and clinical decision support algorithms for the management of sick children in primary care in Kenya and Senegal on referral and antibiotic prescription: the TIMCI quasi-experimental pre-post study. EClinicalMedicine. 2025;83:103196.
150. Bernasconi A, Crabbé F, Adedeji AM, Bello A, Schmitz T, Landi M, et al. Results from one-year use of an electronic Clinical Decision Support System in a post-conflict context: An implementation research. PLoS One. 2019;14(12):e0225634.
151. Bernasconi A, Crabbé F, Rossi R, Qani I, Vanobberghen A, Raab M, et al. The ALMANACH Project: Preliminary results and potentiality from Afghanistan. Int J Med Informatics. 2018;114:130-5.
152. Hürlimann E, Landi M, Miikkulainen A, Renner C, Musard C, Mohamed HH, et al. Impact of digital clinical decision support on quality of care and antibiotic stewardship for children under five in South-Central Somalia. Oxf Open Digit Health. 2024;2(Suppl 2):ii32-ii44.
153. Pravin-Arun S, Sakshi-Shantanu H, Yogita-Purushottam H, Mugdha-Sharad P, Uma-Satish M, Abhay-Machindra K. Predicting over-the-counter antibiotic use in rural Pune, India, using machine learning methods. Epidemiology and Health. 2024:e2024044-e.
154. Schmitz T, Beynon F, Musard C, Kwiatkowski M, Landi M, Ishaya D, et al. Effectiveness of an electronic clinical decision support system in improving the management of childhood illness in primary care in rural Nigeria: an observational study. BMJ Open. 2022;12(7):e055315.
155. Shao AF, Rambaud-Althaus C, Samaka J, Faustine AF, Perri-Moore S, Swai N, et al. New Algorithm for Managing Childhood Illness Using Mobile Technology (ALMANACH): A Controlled Non-Inferiority Study on Clinical Outcome and Antibiotic Use in Tanzania. PLoS One. 2015;10(7):e0132316.
156. Jones N, Arjyal A, King R, Mitchell J, Soria-Donlan I, Baral S, et al. Using participatory video to generate active agents of change at community level to address the drivers of antimicrobial resistance in two settings in Nepal. BMC Public Health. 2025;25(1):1137.
157. Peiffer-Smadja N, Descousse S, Courrèges E, Nganbou A, Jeanmougin P, Birgand G, et al. Implementation of a Clinical Decision Support System for Antimicrobial Prescribing in Sub-Saharan Africa: Multisectoral Qualitative Study. J Med Internet Res. 2024;26.
158. Shao AF, Rambaud-Althaus C, Swai N, Kahama-Maro J, Genton B, D'Acremont V, et al. Can smartphones and tablets improve the management of childhood illness in Tanzania? A qualitative study from a primary health care worker's perspective. BMC Health Services Research. 2015;15(1).
159. Ellington LE, Najjingo I, Rosenfeld M, Stout JW, Farquhar SA, Vashistha A, et al. Health workers' perspectives of a mobile health tool to improve diagnosis and management of paediatric acute respiratory illnesses in Uganda: A qualitative study. BMJ Open. 2021;11(7).
160. Bessat C, Zonon NA, D'Acremont V. Large-scale implementation of electronic Integrated Management of Childhood Illness (eIMCI) at the primary care level in Burkina Faso: A qualitative study on health worker perception of its medical content, usability and impact on antibiotic prescription and resistance. BMC Public Health. 2019;19(1).

161. Mitchell M, Maya G, Melania N, Daniel M, Jan VE, and Hedt-Gauthier B. Perceived Improvement in Integrated Management of Childhood Illness Implementation through Use of Mobile Technology: Qualitative Evidence From a Pilot Study in Tanzania. Journal of Health Communication. 2012;17(sup1):118-27.
162. Peiffer-Smadja N, Poda A, Ouedraogo AS, Guiard-Schmid JB, Delory T, Le Bel J, et al. Paving the way for the implementation of a decision support system for antibiotic prescribing in primary care in west Africa: Preimplementation and co-design workshop with physicians. J Med Internet Res. 2020;22(7).
163. TheGatesFoundation. Philanthropic Partnership Launches New Initiative Tackling Antimicrobial Resistance, the Third-Leading Cause of Death Globally, By Fast-Tracking Discovery of New Treatments2025. Available from: https://www.gatesfoundation.org/ideas/media-center/press-releases/2025/02/amr-bacteria-treatment-discovery.
164. TheFlemingFund. Fleming Fund Annual Review. Department of Health & Social Care; 2023.

7. Appendices

Appendix 1: Response to Feedback

	Marker 1 feedback comments	Response to Marker 1	Marker 2 feedback comments	Response to Marker 2
Introduction	The topic and its importance are clearly described in a well-structured introduction, along with the limitations of existing evidence. The introduction does make reference to effectiveness, mechanism and facilitators/barriers and hence is consistent with the aims. There is scope to make some minor improvements to the writing, including punctuation. Some of the sentences are quite long. The word ‘efficacy’ is used when the author probably means ‘effectiveness’, as I doubt that the studies are explanatory trials. At the end of the first paragraph I was not clear what ‘dual challenges needed to be balanced’ as there were a number of challenges listed in the preceding sentences with some description of their potential determinants.	Thank you. Thank you. Punctuations were improved to be more in line with academic writing. Long sentences were shortened. The term “efficacy” was replaced with “effectiveness” reflecting the real-world context of antibiotic stewardship. Challenges were more clearly articulated under a dedicated subsection in the Introduction (1.3.1 Opportunities and Challenges for Digital AMS in LMICs).	Clear and structured introduction including relevant points to make the case for study. Did the candidate identify any previous reviews/systematic review for LMIC or HIC in this area? If so, it needs to be mentioned and briefly discussed. Candidate mentions that most research in this area is done in HIC or hospital settings (two citations given), more details/references would be important to include to provide the context and clearly show the gap in understanding and what this review adds.	Thank you. Yes, I identified several relevant systematic reviews: Auta et al. (34) in Section 1.1.1 on global antibiotic use in community pharmacies, Nathwani et al. (63) in Section 1.2 on hospital AMS, Cross et al. (90) in Section 1.2.1 on communication strategies to improve antibiotic use, Curtis et al. (94) in Section 1.3 on CDSS effectiveness and Kaboré et al. (123) in Section 1.3.1 on digital implementation enablers/barriers in LMICs. Importantly, there was no systematic reviews found that looked at digital AMS reviews in the community settings of LMICs that adopted a multi-stakeholder approach. A more comprehensive citation list of HIC and hospital settings studies were given in the Introduction under Section 1.1, 1.2, 1.2.1 and 1.3.
Research Aims/ Questions	The aims are clearly stated addressing effectiveness, mechanisms and facilitators/barriers, but there is some inconsistency between different sections of the protocol in terms of the apparent focus of the aims, in particular what specific outcomes will be assessed. What data will be assessed to determine if interventions have been effective in guiding policymakers?	The Aims of the study has been more clearly delineated under Section 1.5 through one primary and two secondary research questions. The specific outcomes (3 primary outcomes and 5 secondary outcomes) of the study have been listed under Section 2.6. Data that will be assessed to determine intervention effectiveness are change in antibiotic prescription rates and inappropriate prescription, changes in antibiotic class used, clinical outcomes as well as	Clear and appropriate aims/questions stated and divided into primary and secondary. Please define ‘community care’ in the context of LMIC as you have defined other key terms (AMR/AMU & Digital interventions). `	Thank you. The term ‘community care’ in the context of LMICs was defined early on in the Introduction under Section 1.2.1 to encompass some level of secondary care including district and sub-district hospitals. This was reiterated in Section 2.4 under the Inclusion/Exclusion Criteria and Rationale.

	Marker 1 feedback comments	Response to Marker 1	Marker 2 feedback comments	Response to Marker 2
		behavioural changes factors, all of which are based on the primary and secondary research outcomes. These are relevant to decision-making and policy recommendation.		
Methods	The methods are well organised, justified and broadly consistent with the aims. I would recommend getting used to writing in the active rather than passive voice and avoid the word 'methodology' when you mean method(s). It was not clear what you would do if an intervention targeted both the community and secondary care. If it was excluded then potentially informative data might be overlooked. As above, what data will be extracted concerning mechanism and facilitators/barriers? There could have been greater specificity in the description of the outcomes. Is the primary outcome change (ie a difference between baseline and follow-up) or between-group differences or simply antimicrobial use/prescribing? Given that you intend to include all study designs you will probably need to accept any assessment/analytic approach in the original studies.	Thank you. The text has been written in the active voice and reviewed by the thesis supervisor to ensure it meets academic publication standards. The word 'Methodology' has been replaced with 'Methods'. Studies that targeted both the community and secondary care was included to ensure potentially informative data were not overlooked. This was mentioned in Section 2.4 under the Inclusion/Exclusion Criteria and Rationale. Data on systemic factors, contextual relevance, patient/ provider knowledge and behaviours towards antibiotic use as well as the feasibility and acceptability of digital AMS interventions were extracted. These were elaborated in Section 3.4.2 and 3.4.3 in the Results and in Section 4.3 in the Discussion. The outcomes were described in greater specificity under Section 3 of the Results as well as in the data extraction table (Table 2). All assessment/analytical approach were accepted from the primary studies and the data was consolidated and narratively synthesised accordingly under Section 3.4.	Qualitative narrative synthesis is an appropriate analytic approach. Consider quantitative data analysis for a subset of studies for example if there are a few RCTs you could do a meta-analysis.	Thank you. A meta-analysis was not able to be done as the included RCTs were heterogenous in terms of study settings, target population, disease studied, intervention used and outcomes measured. However, a detailed narrative synthesis and subgroup analysis was done to ensure robustness of the findings.
Discussion	Good reflection on the strengths, limitations, likely challenges and contingency planning. The tools used to assess risk of bias of individual studies will not address overall risk of publication bias.	Thank you. The tools used to assess individual risk of bias (RoB2, ROBINS-1 and CASP) were specific to the study design of each study. The risk of publication bias was	Strengths and limitations discussed appropriately, and table of contingency plan included	Thank you.

	Marker 1 feedback comments	Response to Marker 1	Marker 2 feedback comments	Response to Marker 2
		assessed using GRADE/GRADE-CERQual when assessing for the certainty of the evidence.		
Timeline and References	Timeline looks feasible assuming that timely support from the medical student(s) will be forthcoming. Consistent formatting of references, with the exception of 'Organization WH'.	Thank you. References have all been formatted to ensure they are consistent and follow the Vancouver referencing style.	Relevant references included.	Thank you.
Overall impression	Clearly written, well presented, coherent protocol with a logical flow and appropriate acknowledgement of uncertainty.	Thank you.	The protocol contains key sections with clear, relevant aims and methods.	Thank you.
Up to three key things done well	1. Clear presentation including use of tables, figures and appendices. 2. Well organised and justified methods that are broadly coherent with the stated aims. 3.	Thank you.	1. Logical structure throughout and inclusion of clear and relevant points for each section 2. Clear presentation using bullet points, tables and Gantt chart 3. Appropriate terminology used throughout	Thank you.
Up to three key areas for improvement	1. Greater specificity in outcome description 2. Scope for minor improvements to writing style. 3.	The 3 primary and 5 secondary outcome have been described in greater detail under Section 2.6 in the Methods and elaborated further under Section 3.4 under the Results section. Writing style has been improved to have a more consistent tone in line with academic writing.	1. Please define 'community settings' 2. Include more existing literature and briefly discuss any previous reviews in LMIC or HIC in any setting 3. In some places the sentences need to be clearer for example, 1 million lives annually due to AMR. Is this global or only in LIMC?	Community settings/community care has been defined under Section 1.2.1 in the Introduction. This was reiterated in Section 2.4 under the Inclusion/Exclusion Criteria and Rationale. More literature done in HICs were included. There were not many systematic reviews in LMICs looking at the similar scope and breadth of this review. However more individual studies have been elaborated on in the Introduction section as mentioned above. The review was proofread to ensure clarity of facts and figures. The 1 million lives lost due to AMR annually was made clearer to reflect the global nature of the issue.

Appendix 2: Research Protocol

Submitted JAN 24, 2025

Effectiveness of Digital Antimicrobial Stewardship Initiatives in Community Healthcare Settings Across Low- and Middle-Income Countries: A Systematic Review

Introduction

Widely recognised as one of the most pressing global health threats of our time, antimicrobial resistance (AMR), claims over a million lives annually (1). AMR, which occurs when bacteria and other pathogens evolve to withstand the effects of antimicrobial agents (2), especially antibiotics is projected to cause approximately 39 million deaths by 2050 if left unaddressed (1). The World Health Organization (WHO) acknowledges AMR as a critical conundrum (2), for low-and middle-income countries (LMICs) (3), where high burdens of infectious diseases and improper use of antibiotics (4) intersect with limited resources and poor healthcare infrastructure to exacerbate the issue (5). Furthermore, another unique problem LMICs face is the "access versus excess" dilemma (6), where expanding appropriate access to essential antimicrobials and simultaneously restricting its inappropriate use remain a challenge (7), mainly due to factors such weak and inadequate health systems, as unregulated drug markets (8) and poor public awareness (9, 10). The consequences of these are dire, ranging from prolonged illness and increased preventable deaths (11) to significant economic losses and productivity (12). Balancing these dual challenges therefore requires stewardship interventions that ensure equitable access to antimicrobials while curbing their misuse.

Defined as *"an organisation or health-care-system-wide approach to promoting and monitoring judicious use of antimicrobials to preserve their future effectiveness through the use of a coordinated programme"(13)*, antimicrobial stewardship (AMS) activities are intended to optimise appropriate use of antimicrobials. These initiatives have demonstrated considerable success in hospital settings with hand hygiene, formulary restrictions, pre-authorisation requirements and accountable audit mechanisms, in-line with the WHO's five pillars of integrated AMS interventions (14). Nevertheless, replicating this in community healthcare settings in LMICs can be particularly challenging since prescribing practices are influenced by limited diagnostic tools, leading to empirical treatments that do not usually align with best practices (15, 16). Healthcare providers who often lack training (17), may prescribe antimicrobials based on patient demand or misconception about efficacy. Moreover, informal sourcing methods through unregulated pharmacies and street vendors (18) that are prevalent in many LMICs also worsen the issue by facilitating easy access of these medications. These compounded by consumption practices among patients (19) including self-medication without professional advice and not completing the antimicrobial course, fuel resistance further, undermining existing AMS efforts.

The emergence and use of digital health interventions including Artificial Intelligence (AI) within AMS programs offer a promising avenue to tackle these challenge (20, 21). Via the use of advanced computational algorithms and machine learning techniques (22, 23), these tools can help to analyse complex medical data, assist in diagnosis, personalise treatments and improve operational efficiency (24). An example of this is the utilisation of mobile health (mHealth) applications (25) and AI-based chatbots to provide education on proper antibiotic use and behaviour change interventions for patients. At the provider level, clinical decision support systems (CDSS) (26, 27), electronic prescribing systems and telemedicine platforms can assist in guiding prescribing practices and improving diagnostic accuracy. Policymakers on the other hand, could benefit from digital surveillance systems (28, 29) and electronic health records (EHRs), that enable them to monitor real-time resistance trends and facilitate the development of data-driven policies. Collectively, these stakeholder-specific interventions provide a structured approach for integrating digital AMS strategies across multiple levels of healthcare.

However, despite their potential, the effectiveness of digital AMS interventions in community healthcare settings across LMICs remains underexplored and fragmented. Available studies often focus on high-income countries (30) or hospital-based settings (31), leaving critical shortcomings in understanding how these tools perform in resource-limited, community-oriented environments. Additionally, the contextual challenges of implementing digital AMS interventions in LMICs, such as infrastructural limitations, varying levels of digital literacy and cultural differences have not been thoroughly explored thus far to provide actionable insights into what needs to be done next. This study is designed to bridge these gaps by summarising the existing data to evaluate the efficacy of different digital AMS interventions in community settings in LMICs.

Aims & Research Questions

This study aims to synthesise the findings from available literature and add to the evidence base by providing a more comprehensive and nuanced understanding of the effectiveness of digital AMS initiatives in community healthcare settings in LMICs. By evaluating their impact on antimicrobial prescribing patterns, resistance trends and patient outcomes, this review seeks to provide actionable insights for policymakers, healthcare providers and researchers working to combat AMR in resource-constrained settings, ultimately contributing to the development of scalable and contextually appropriate digital AMS strategies to improve global health outcomes.

The principal research questions identified after conducting a pilot search are:

1. How effective are digital interventions in improving antimicrobial use (AMU) among patients, influencing providers' prescribing/dispensing practices and guiding policymakers in community healthcare settings in LMICs?

2. What are the pathways through which effective digital interventions influence patient and provider behaviours and antimicrobial resistance trends in community settings?

3. What are the facilitators and barriers of implementing digital AMS initiatives in LMICs and how can these be optimised?

Methods

Study Approach

The protocol for this systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) to ensure transparency.

Information Sources

PubMed, Embase, Scopus, Cochrane Library, WHO Global Index Medicus, TRIP Database and Web of Science were pilot searched for relevant studies in addition to Google advanced search to identify grey literature from inception till January 2025 and will be rerun at the end of February 2025 to identify updated publications.

Search Strategy

The search strategy will cover four domains, namely: a) antimicrobial stewardship b) digital interventions c) low- and middle-income countries and d) community healthcare settings, including patients, providers and policymakers as key subdomains. Keywords and MeSH terms were refined with the help of Ms. Veronica Philips, a medical librarian at the University of Cambridge during the initial search, following the Peer Review of Electronic Search Strategies (PRESS) checklist (32) (see Appendix 2 for the full PubMed search list). Forward and backward citation screening will also be done to identify relevant articles and provide insights into the evolution of digital tools in AMS.

Eligibility Criteria

The full eligibility criteria (Appendix 1) for this review were developed based on the Population, Intervention, Comparison and Outcome (PICO) framework (33) as shown in the non-exhaustive list in Figure 1. Only full text peer-reviewed articles and grey literature published in English and are open access will be included for the data synthesis due to resource limitations of translating studies from other languages. The following studies will be excluded:

- Not conducted in LMICs as defined by the World Bank
- Hospital or other tertiary care-based AMS interventions
- Studies that lack relevant outcome data such as changes in antimicrobial use, AMR trends or patient-related outcomes

Population	Intervention	Comparison	Outcome
• Patients, healthcare providers and policymakers in community healthcare settings in LMICs	• mHealth applications AI chatbots, telemedicine platforms, electronic prescription systems, CDSS, blockchain based supply chain monitoring	• Usual care, non-digital AMS interventions or no AMS interventions	• **Primary:** Improved antimicrobial prescribing practice, reduction in improper antimicrobial use • **Secondary:** trends in AMR, patient-related outcomes, cost-effectiveness, feasibility of interventions

Figure 1: Eligibility Criteria based on the PICO framework.

Selection Process

Two reviewers (myself and a medical student) will independently review and filter the titles, abstracts and full texts based on the eligibility criteria after deduplication in EndNote. This process will be aided by Rayyan (34), a web-based screening tool and documented according to the PRISMA Flow Diagram (35) in Figure 2. Any conflicts between the first two reviewers will be resolved with the help of an independent third reviewer.

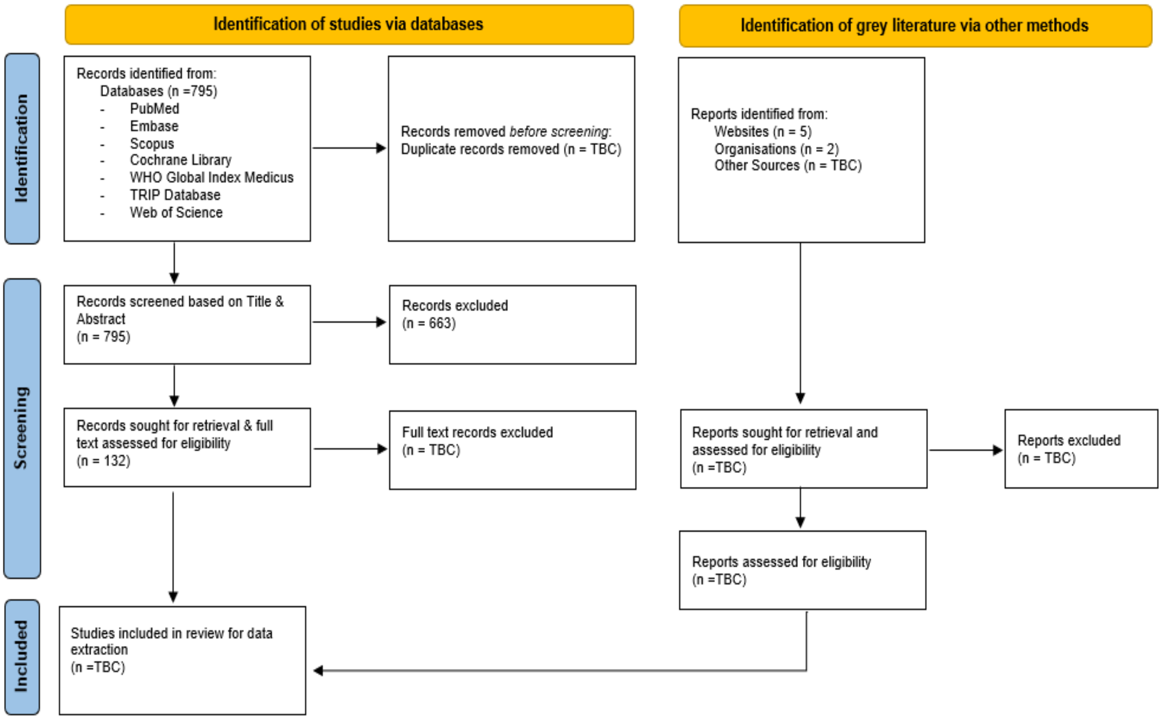


Figure 2: PRISMA 2020 Flow Diagram for study selection including searches from databases and other sources based on pilot search

Data Extraction

The data extraction process will be conducted by both reviewers using a standardised data extraction template (Microsoft Excel®; Microsoft Corporation, Redmond, WA, 2024) created specifically for this study. We will extract data from each study to include: 1) authors 2) publication year 3) study type 4) study population (including age group and type of community healthcare facility) 5) types of digital intervention 6) any comparisons/existing interventions and 7) study outcomes. Data will also be collected for all reported measures, time points and analyses relevant to each outcome domain. In cases where multiple measures or time points are reported, the most comprehensive and effective data will be prioritised, effectiveness being defined based on their ability to achieve measurable improvements in the primary and secondary outcomes listed below:

Primary Outcomes:

- Changes in antimicrobial prescribing practices
- Reductions in inappropriate antimicrobial use (including broad spectrum antibiotics)
- Frequency of antibiotic prescription without clinical justification

Secondary Outcomes:

- Trends in antimicrobial resistance rates
- Patient-related outcomes such as infection resolution and adverse drug reactions
- Patient/ Healthcare provider knowledge and attitudes toward AMS
- Cost-effectiveness of digital AMS interventions
- Implementation outcomes including feasibility, acceptability and scalability of digital AMS tools

Risk of Bias Assessment

Risk of bias (RoB) will be independently assessed by both reviewers using the Cochrane Risk of Bias (36) for randomised controlled trials and the Risk Of Bias In Non-randomized Studies - of Interventions (ROBINS-I) version 2 for non-randomised studies. Focus will be on biases related to incomplete or selective reporting of outcomes and the heterogeneity of digital AMS interventions across LMICs. The findings will be summarised in a risk-of-bias table, allowing for a transparent evaluation of the credibility of the included evidence.

Certainty of Evidence Assessment

C**ertainty assessment** will be done using the **Grading of Recommendations, Assessment, Development, and Evaluations (GRADE)** framework (37) to evaluate confidence in the evidence, categorising outcomes as "high," "moderate," "low," or "very low". Two independent reviewers will perform these assessments and disagreements will be resolved through discussion or consultation with a third reviewer. If the data limited, the scope may be supplemented by expanding to include evidence from high-income countries (HICs).

Data Synthesis/Analytical Framework

The data analysis for this systematic review will employ qualitative methods, guided by a conceptual framework that examines patient-level, provider-level and policymaker-level issues and the effectiveness of digital AMS interventions for each group. Narrative synthesis will be used to summarise and interpret findings, organising data into thematic categories such as knowledge-related interventions, upskilling courses, job aids and digital supply chain optimisation. At the patient level, the framework will consider education and behaviour change strategies to improve awareness and adherence. At the provider level, it will analyse decision-support tools, training programs and virtual mentorship initiatives to enhance prescribing practices. At the policymaker level, the focus will be on using big data analytics to evaluate the development and implementation of guidelines and surveillance systems. Studies will be grouped and analysed by intervention type and target population to identify patterns, trends and commonalities in effectiveness as well as explore implementation barriers and facilitators.

To address heterogeneity, **subgroup analyses** will be conducted to explore variations in outcomes across different study characteristics. Subgroups will include geographical region, type of community healthcare setting and the specific digital AMS tools used. For example, studies in rural versus urban LMIC settings or those targeting patients versus healthcare providers will be compared to identify differential effects. The synthesis will also consider contextual factors such as healthcare infrastructure, digital literacy and cultural influences that may affect the success of digital AMS initiatives. The results of the subgroup analyses will be integrated into the narrative synthesis to provide nuanced insights and inform recommendations for practice and policy.

Choice of Methodology

A systematic review is considered the most suitable method for this study as it enables comprehensive identification of literature while minimising bias to answer the research questions. Given the diversity of digital antimicrobial stewardship initiatives and the complexity of community healthcare settings in LMICs, subgroup analyses and narrative synthesis will explore heterogeneity across studies. Pilot searches have ensured sufficient literature volume, however meaningful conclusions can only be made once the full search and has been completed and data analysed.

Discussion

Strengths & Limitations

This review offers significant value by addressing an important gap in the literature on the effectiveness of digital AMS initiatives in LMICs. Its comprehensive search protocol, encompassing multiple databases and grey literature sources, designed with the expert input of a medical librarian to capture as many relevant studies as possible, ensures a thorough exploration of available evidence. This was back tested through pilot searches, confirming that sufficient publications were available for a meaningful synthesis. Another strength of this study is the inclusion of rigorous quality appraisal processes by two reviewers and the use of risk-of-bias tools further enhances the validity of the findings, providing confidence in the study's conclusions. Additionally, the data synthesis approach, which combines different qualitative methods, allows for a nuanced understanding of the interventions' effectiveness across diverse settings.

Limitations include the incorporation of studies with different designs, methodologies, interventions and outcomes that would introduce variability, complicating the comparability of findings. This anticipated heterogeneity may preclude a meta-analysis, necessitating reliance on subgroup analysis and narrative synthesis alone. The potential scarcity of high-quality data from LMICs and the English language requirement can cause publication bias, skewing the results and limiting its generalisability. These limitations and other risks that may arise underscore the importance of appropriate contingency measures as shown in Table 1.

Table 1: Risk Assessment & Contingency Plans

Risk Assessment	**Likelihood**	**Impact**	**Contingency Plans**
Difficulty accessing full-text articles for inclusion in the review	Low	High	Utilise the University of Cambridge's institutional access to request articles or contact authors directly for full texts.
Inconsistent reporting of outcomes across studies	Moderate	Moderate	Develop a standardised data extraction template using Microsoft Excel and conduct a narrative synthesis for diverse outcomes.
Limited availability of studies specific to LMIC community settings	Moderate	High	Expand search to include grey literature and consider studies from high income countries to draw relevant lessons.
Risk of bias in included studies as studies with non-significant results may not have been published	High	Moderate	Validated risk-of-bias tools (Cochrane RoB or ROBINS-I) will be used to assess this.
Low quality studies	Low	Moderate	Apply strict inclusion & exclusion criteria and use the GRADE Framework to assess evidence certainty for key outcomes to ensure only high-quality studies are selected.
Potential for large heterogeneity	Moderate	High	Perform subgroup analysis based on key variables (e.g. region, intervention type & population characteristics) and do a narrative synthesis to categorise studies and explore patterns.
Time constraints for screening studies	Moderate	Moderate	Create weekly screening targets and adhering to them by sharing access to data extraction sheet with supervisor for better accountability.

Ethics and Dissemination

Ethics approval is not required for this study as it involves secondary data analysis. Findings will be disseminated through peer-reviewed publications, conference presentations and stakeholder meetings to inform policy and practice in LMICs.

Timeline

Figure 3: Gantt Chart showing the tentative time frames for key project phases during the Lent and Easter Terms: Protocol Development, Literature Screening, Data Synthesis and Writing & Editing together with some contingency time

References

1. Naghavi M, Vollset SE, Ikuta KS, Swetschinski LR, Gray AP, Wool EE, et al. Global burden of bacterial antimicrobial resistance 1990–2021: a systematic analysis with forecasts to 2050. The Lancet. 2024;404(10459):1199-226.
2. (WHO) WHO. Antimicrobial resistance2023. Available from: https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.

3. Sartorius B, Gray AP, Davis Weaver N, Robles Aguilar G, Swetschinski LR, Ikuta KS, et al. The burden of bacterial antimicrobial resistance in the WHO African region in 2019: a cross-country systematic analysis. The Lancet Global Health. 2024;12(2):e201-e16.
4. Boltena MT, Wolde M, Hailu B, El-Khatib Z, Steck V, Woldegerima S, et al. Point prevalence of evidence-based antimicrobial use among hospitalized patients in sub-Saharan Africa: a systematic review and meta-analysis. Sci Rep. 2024;14(1):12652.
5. Sulis G, Sayood S, Gandra S. How can we tackle the overuse of antibiotics in low- and middle-income countries? Expert Review of Anti-infective Therapy. 2023;21(11):1189-201.
6. Heyman G, Cars O, Bejarano M-T, Peterson S. Access, excess, and ethics—towards a sustainable distribution model for antibiotics. Upsala Journal of Medical Sciences. 2014;119(2):134–41.
7. Laxminarayan R, Matsoso P, Pant S, Brower C, Røttingen JA, Klugman K, et al. Access to effective antimicrobials: a worldwide challenge. Lancet. 2016;387(10014):168-75.
8. Mendelson M, Røttingen J-A, Gopinathan U, Hamer DH, Wertheim H, Basnyat B, et al. Maximising access to achieve appropriate human antimicrobial use in low-income and middle-income countries. The Lancet. 2016;387(10014):188-98.
9. Chukwu EE, Oladele DA, Awoderu OB, Afocha EE, Lawal RG, Abdus-Salam I, et al. A national survey of public awareness of antimicrobial resistance in Nigeria. Antimicrob Resist Infect Control. 2020;9(1):72.
10. Kosiyaporn H, Chanvatik S, Issaramalai T, Kaewkhankhaeng W, Kulthanmanusorn A, Saengruang N, et al. Surveys of knowledge and awareness of antibiotic use and antimicrobial resistance in general population: A systematic review. PLoS One. 2020;15(1):e0227973.
11. Murray CJL, Ikuta KS, Sharara F, Swetschinski L, Robles Aguilar G, Gray A, et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. The Lancet. 2022;399(10325):629-55.
12. Poudel AN, Zhu S, Cooper N, Little P, Tarrant C, Hickman M, et al. The economic burden of antibiotic resistance: A systematic review and meta-analysis. PLOS ONE. 2023;18(5):e0285170.
13. Excellence NIfHaC. Antimicrobial stewardship: systems and processes for effective antimicrobial medicine use Antimicrobial Stewardship: NICE; 2015. p. 1.
14. Organization WH. WHO POLICY GUIDANCE ON INTEGRATED ANTIMICROBIAL STEWARDSHIP ACTIVITIES. 2021. p. 45.
15. Organization WH. The WHO AWaRe (Access, Watch, Reserve) antibiotic book. Switzerland: WHO; 2022.
16. van Houten CB, Cohen A, Engelhard D, Hays JP, Karlsson R, Moore E, et al. Antibiotic misuse in respiratory tract infections in children and adults—a prospective, multicentre study (TAILORED Treatment). European Journal of Clinical Microbiology & Infectious Diseases. 2019;38(3):505-14.
17. Baraka MA, Alsultan H, Alsalman T, Alaithan H, Islam MA, Alasseri AA. Health care providers' perceptions regarding antimicrobial stewardship programs (AMS) implementation—facilitators and challenges: a cross-sectional study in the Eastern province of Saudi Arabia. Annals of Clinical Microbiology and Antimicrobials. 2019;18(1):26.
18. Belachew SA, Hall L, Selvey LA. Non-prescription dispensing of antibiotic agents among community drug retail outlets in Sub-Saharan African countries: a systematic review and meta-analysis. Antimicrobial Resistance & Infection Control. 2021;10(1):13.
19. Mukherjee A, Surial R, Sahay S, Thakral Y, Gondara A. Social and cultural determinants of antibiotics prescriptions: analysis from a public community health centre in North India. Front Pharmacol. 2024;15.
20. Marra AR, Langford BJ, Nori P, Bearman G. Revolutionizing antimicrobial stewardship, infection prevention, and public health with artificial intelligence: the middle path. Antimicrob Steward Healthc Epidemiol. 2023;3(1):e219.
21. Wong F, de la Fuente-Nunez C, Collins JJ. Leveraging artificial intelligence in the fight against infectious diseases. Science. 2023;381(6654):164-70.

22. de la Lastra JMP, Wardell SJT, Pal T, de la Fuente-Nunez C, Pletzer D. From Data to Decisions: Leveraging Artificial Intelligence and Machine Learning in Combating Antimicrobial Resistance - a Comprehensive Review. J Med Syst. 2024;48(1):71.
23. Rabaan AA, Alhumaid S, Mutair AA, Garout M, Abulhamayel Y, Halwani MA, et al. Application of Artificial Intelligence in Combating High Antimicrobial Resistance Rates. Antibiotics (Basel). 2022;11(6).
24. Alowais SA, Alghamdi SS, Alsuhebany N, Alqahtani T, Alshaya AI, Almohareb SN, et al. Revolutionizing healthcare: the role of artificial intelligence in clinical practice. BMC Medical Education. 2023;23(1):689.
25. Charani E, Gharbi M, Moore LSP, Castro-Sanchéz E, Lawson W, Gilchrist M, et al. Effect of adding a mobile health intervention to a multimodal antimicrobial stewardship programme across three teaching hospitals: an interrupted time series study. J Antimicrob Chemother. 2017;72(6):1825-31.
26. Akhloufi H, Verhaegh SJC, Jaspers MWM, Melles DC, van der Sijs H, Verbon A. A usability study to improve a clinical decision support system for the prescription of antibiotic drugs. PLoS One. 2019;14(9):e0223073.
27. Peiffer-Smadja N, Rawson TM, Ahmad R, Buchard A, Georgiou P, Lescure FX, et al. Machine learning for clinical decision support in infectious diseases: a narrative review of current applications. Clin Microbiol Infect. 2020;26(5):584-95.
28. Chuchu VM, Njung'e J, Muasa B, Gathira M, Olela G, Bubi KS, et al. Progress made in digitalizing antimicrobial resistance surveillance in a One Health approach in Kenya. Front Public Health. 2024;12:1411962.
29. Sakagianni A, Koufopoulou C, Feretzakis G, Kalles D, Verykios VS, Myrianthefs P, et al. Using Machine Learning to Predict Antimicrobial Resistance-A Literature Review. Antibiotics (Basel). 2023;12(3).
30. Eisenmann M, Spreckelsen C, Rauschenberger V, Krone M, Kampmeier S. A qualitative, multi-centre approach to the current state of digitalisation and automation of surveillance in infection prevention and control in German hospitals. Antimicrob Resist Infect Control. 2024;13(1):78.
31. Van Dort BA, Ritchie A, Penm J, Gray TJ, Ronnachit A, Baysari MT. A tale of 2 digital hospitals: A qualitative study of antimicrobial stewardship teams. Br J Clin Pharmacol. 2024;90(4):1152-61.
32. McGowan J, Sampson M, Salzwedel DM, Cogo E, Foerster V, Lefebvre C. PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. J Clin Epidemiol. 2016;75:40-6.
33. Richardson WS, Wilson MC, Nishikawa J, Hayward RS. The well-built clinical question: a key to evidence-based decisions. ACP J Club. 1995;123(3):A12-3.
34. Johnson N, Phillips M. Rayyan for systematic reviews. Journal of Electronic Resources Librarianship. 2018;30(1):46-8.
35. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Bmj. 2021;372:n71.
36. Higgins JPT, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, et al. The Cochrane Collaboration’s tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928.
37. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924-6.

Appendix 3: Search Strategy

Searches were conducted on 23 May 2025 in English, with no restrictions on publication date. All databases were searched from inception.

Pubmed	Results
"antimicrobial stewardship"[tw] OR "antibiotic stewardship"[tw] “anti-bacterial agent*”[MeSH] OR "responsible antibiotic use"[tw] OR "rational antibiotic use"[tw] OR "judicious antibiotic use"[tw] OR "infection control program*"[tw] OR "antimicrobial management"[tw] OR "antibiotic use"[tw] OR "antimicrobial use"[tw] OR “antibiotic”[tw] OR "antiviral"[tw] OR "antifungal"[tw] OR "antiparasitic"[tw] OR "antibiotic resistance management"[tw] OR “antibiotic resistance” OR "antimicrobial resistance control"[tw] OR "antibiotic prescribing"[tw] OR "antimicrobial prescribing"[tw] OR "antimicrobial therapy optimi*"[tw] OR "antimicrobial drug use"[tw] OR "appropriate antimicrobial prescribing"[tw] OR "appropriate antibiotic prescribing"[tw] OR "rational antimicrobial therapy"[tw] OR "antibiotic consumption monitoring"[tw] OR "antimicrobial consumption monitoring"[tw] OR "antibiotic rationalization"[tw] OR "antibiotic treatment guide*"[tw] OR "appropriate antimicrobial therapy"[tw] OR "antimicrobial resistance strateg*"[tw] OR "antimicrobial resistance"[tw] OR "multi-drug resistant"[tw] OR "MDR organism*"[tw] OR "resistant bacteria"[tw] OR "superbug*"[tw] OR "ESKAPE pathogen*"[tw] OR "resistance gene*"[tw] OR "extended-spectrum beta-lactamase"[tw] OR "AMR surveillance"[tw] OR "resistance pattern*"[tw] OR "emerging resistance"[tw] OR "antimicrobial surveillance"[tw] OR "nosocomial infection*"[tw] OR "healthcare-associated infection*"[tw] OR "drug resistance, microbial"[MeSH] OR "antimicrobial stewardship"[MeSH] OR "drug utilization"[MeSH]	846,624
"digital health"[tw] OR "eHealth"[tw] OR "mHealth"[tw] OR "telemedicine"[tw] OR "telehealth"[tw] OR "mobile health application*"[tw] OR "digital healthcare"[tw] OR "health technology"[tw] OR "digital solution*"[tw] OR "digital tool*"[tw] OR "health informatic*"[tw] OR "electronic health record*"[tw] OR "EHR"[tw] OR "electronic medical record*"[tw] OR "EMR"[tw] OR "clinical decision support system*"[tw] OR "CDSS"[tw] OR "health information technology"[tw] OR "HIT"[tw] OR "healthcare technology"[tw] OR "technology-enabled healthcare"[tw] OR “blockchain” [tw] OR "health apps"[tw] OR "smartphone health application*"[tw] OR "wearable health technology"[tw] OR "remote patient monitoring"[tw] OR "RPM"[tw] OR "virtual health"[tw] OR "virtual consultation*"[tw] OR "online health service*"[tw]IT OR "e-prescribing"[tw] OR "electronic prescribing system*"[tw] OR "healthcare innovation"[tw] OR "digital intervention*"[tw] OR "digital health intervention*"[tw] OR "artificial intelligence in health"[tw] OR "AI in healthcare"[tw] OR "machine learning in health"[tw] OR "healthcare data analytic*"[tw] OR "health monitoring app*"[tw] OR "teleconsultation"[tw] OR "health chatbot*"[tw] OR "digital health platform*"[tw] OR "internet-based healthcare"[tw] OR "healthcare digitization"[tw] OR "remote health service*"[tw] OR "virtual care platform*"[tw] OR "connected health"[tw] OR "artificial intelligence"[MeSH] OR "machine learning"[MeSH] OR "natural language processing"[MeSH] OR "algorithms"[MeSH] OR "decision support systems, clinical"[MeSH] OR "artificial intelligence"[tw] OR "machine learning"[tw] OR "deep learning"[tw] OR "natural language processing"[tw] OR "neural network*"[tw] OR "convolutional neural network*"[tw] OR "recurrent neural network*"[tw] OR "large language model"[tw] OR "generative AI"[tw] OR "decision support system"[tw] OR "clinical decision support"[tw] OR "predictive analytic*"[tw] OR "data-driven model"[tw] OR "intelligent system"[tw] OR "computer-aided diagnosis"[tw] OR "automated detection"[tw] OR "algorithmic prediction"[tw] OR "AI in healthcare"[tw] OR "AI-based tool"[tw] OR "chatbot"[tw] OR "clinical NLP"[tw] OR "health informatic*"[tw] OR "pattern recognition"[tw] OR "Bayesian network"[tw]	789,588
"community healthcare"[tw] OR "primary healthcare"[tw] OR "primary care"[tw] OR “community setting*” OR "primary health care"[MeSH] OR "primary health care"[tw] OR "outpatient care"[tw] OR "ambulatory care"[tw] OR "ambulatory health service*"[tw] OR "outpatient service*"[tw] OR "outpatient clinic*"[tw] OR "general outpatient care"[tw] OR "non-hospital healthcare"[tw] OR "family medicine"[tw] OR "family practice"[tw] OR "family practice"[MeSH] OR "general practice"[tw] OR "general practitioner*"[tw] OR “GP” OR "GP clinic*"[tw] OR "primary care provider*"[tw] OR "community health center*"[tw] OR "community health service*"[tw] OR "community health service*"[MeSH] OR "community health worker*"[tw] OR "village health worker*"[tw] OR "health extension service*"[tw] OR "health post*"[tw] OR "district hospital*"[tw] OR "district health center*"[tw] OR "regional health center*"[tw] OR "rural clinic*"[tw] OR "urban health services"[tw] OR "rural health services"[tw] OR "rural health services"[MeSH] OR "local health clinic*"[tw] OR "neighborhood clinic*"[tw] OR "local healthcare facilit*"[tw] OR "local outpatient clinic*"[tw] OR "essential health service*"[tw] OR "secondary healthcare"[tw] OR "secondary care"[tw] OR "referral hospital*"[tw] OR "district hospital*"[tw] OR "community-based care"[tw] OR "community health program*"[tw] OR "community health initiative*"[tw] OR "health dispensar*"[tw] OR "local healthcare provider*"[tw] OR "community-based medical care"[tw] OR "frontline health service*"[tw] OR "local health service*"[tw] OR "health policy planning"[tw] OR "community health policy"[tw] OR "local healthcare polic*"[tw] OR "healthcare policymaker*"[tw]	985,047
"low- and middle-income countr*"[tw] OR "LMIC*"[tw] OR "developing countr*"[tw] OR "developing nation*"[tw] OR "developing econom*"[tw] OR "developing region*"[tw] OR "developing world"[tw] OR "emerging econom*"[tw] OR "emerging market econom*"[tw] OR "emerging market*"[tw] OR "transitional econom*"[tw] OR "underdeveloped countr*"[tw] OR "least developed countr*"[tw] OR	1,088,605

"LDC"[tw] OR "third world countr*"[tw] OR "global south"[tw] OR "resource-limited setting*"[tw] OR "resource-constrained setting*"[tw] OR "resource-poor setting*"[tw] OR "low-resource setting*"[tw] OR "low-income countr*"[tw] OR "middle-income countr*"[tw] OR "lower-middle-income countr*"[tw] OR "low-income setting*"[tw] OR "middle-income setting*"[tw] OR "low and lower-middle income countr*"[tw] OR "low and middle-income region*"[tw] OR "economically developing countr*"[tw] OR "economically developing nation*"[tw] OR "economically disadvantaged region*"[tw] OR "financially constrained countr*"[tw] OR "poverty-stricken region*"[tw] OR "low socioeconomic region*"[tw] OR "sub-Saharan Africa"[tw] OR "South Asia"[tw] OR "Latin America"[tw] OR "Southeast Asia"[tw] OR "Caribbean nation*"[tw] OR "Pacific Island nation*"[tw] OR "Afghanistan"[tw] OR “Angola”[tw] OR "Bangladesh"[tw] OR "Benin"[tw] OR "Bhutan"[tw] OR "Burkina Faso"[tw] OR "Burundi"[tw] OR “Bolivia”[tw] OR “Cabo Verde”[tw] OR "Cambodia"[tw] OR "Cameroon"[tw] OR "Central African Republic"[tw] OR "Chad"[tw] OR "Comoros"[tw] OR "Congo"[tw] OR "Côte d'Ivoire"[tw] OR "Djibouti"[tw] OR "Egypt"[tw] OR "El Salvador"[tw] OR "Eritrea"[tw] OR "Eswatini"[tw] OR "Ethiopia"[tw] OR "Gambia, The"[tw] OR "Ghana"[tw] OR "Guinea"[tw] OR "Guinea-Bissau"[tw] OR "Haiti"[tw] OR "Honduras"[tw] OR "India"[tw] OR "Indonesia"[tw] OR “Jordan”[tw] OR "Kenya"[tw] OR “Kiribati”[tw] "Kyrgyz Republic"[tw] OR “Korea” OR "Lao PDR"[tw] OR “Lebanon”[tw] OR "Lesotho"[tw] OR "Liberia"[tw] OR "Madagascar"[tw] OR "Malawi"[tw] OR "Mali"[tw] OR "Mauritania"[tw] OR "Mozambique"[tw] OR "Myanmar"[tw] OR “Micronesia”[tw] OR “Morocco”[tw] OR "Nepal"[tw] OR "Nicaragua"[tw] OR "Niger"[tw] OR "Nigeria"[tw] OR "Pakistan"[tw] OR "Papua New Guinea"[tw] OR “Philippines”[tw] OR “Peru”[tw] OR "Rwanda"[tw] OR “Samoa”[tw] OR “São Tomé and Principe”[tw] OR "Senegal"[tw] OR "Sierra Leone"[tw] OR "Somalia"[tw] OR "South Sudan"[tw] OR "Sudan"[tw] OR “Syria”[tw] OR “Solomon Islands”[tw] OR “Sri Lanka”[tw] OR "Tanzania"[tw] OR “Tajikistan”[tw] OR "Togo"[tw] OR “Timor-Leste”[tw] OR “Tunisia”[tw] OR "Uganda"[tw] OR “Uzbekistan”[tw] OR “Vanuatu”[tw] OR “Vietnam”[tw] OR “West Bank and Gaza” OR "Yemen"[tw] OR "Zambia"[tw] OR "Zimbabwe"[tw] OR "Developing Countries"[MeSH] OR "Poverty Areas"[MeSH]	
Combined with AND	21

Embase	**Results**
exp 'antimicrobial stewardship'/ OR exp 'antibiotic stewardship'/ OR 'responsible antibiotic use' OR 'rational antibiotic use' OR 'judicious antibiotic use' OR 'infection control program*' OR 'antimicrobial management' OR 'antibiotic use' OR 'antimicrobial use' OR exp 'antibiotic'/ OR exp 'antiviral agent'/ OR exp 'antifungal agent'/ OR exp 'antiprotozoal agent'/ OR 'antibiotic resistance management' OR exp 'antibiotic resistance'/ OR 'antimicrobial resistance control' OR 'antibiotic prescribing' OR 'antimicrobial prescribing' OR 'antimicrobial therapy optimi*' OR 'antimicrobial drug use' OR 'appropriate antimicrobial prescribing' OR 'appropriate antibiotic prescribing' OR 'rational antimicrobial therapy' OR 'antibiotic consumption monitoring' OR 'antimicrobial consumption monitoring' OR 'antibiotic rationalization' OR 'antibiotic treatment guide*' OR 'appropriate antimicrobial therapy' OR 'antimicrobial resistance strateg*' OR exp 'antimicrobial resistance'/ OR exp 'multiple drug resistance'/ OR 'MDR organism*' OR 'resistant bacteria' OR 'superbug*' OR 'ESKAPE pathogen*' OR 'resistance gene*' OR exp 'beta lactamase'/ OR 'AMR surveillance' OR 'resistance pattern*' OR 'emerging resistance' OR 'antimicrobial surveillance' OR exp 'hospital infection'/ OR exp 'healthcare associated infection'/ OR exp 'drug resistance microbial'/ OR exp 'drug utilization'/ OR exp 'antiinfective agent'/	5561871
'digital health' OR 'eHealth' OR 'mHealth' OR 'telemedicine' OR 'telehealth' OR 'mobile health application*' OR 'digital healthcare' OR 'health technology' OR 'digital solution*' OR 'digital tool*' OR 'health informatic*' OR 'electronic health record*' OR 'EHR' OR 'electronic medical record*' OR 'EMR' OR 'clinical decision support system*' OR 'CDSS' OR 'health information technology' OR 'HIT' OR 'healthcare technology' OR 'technology-enabled healthcare' OR 'blockchain' OR 'health apps' OR 'smartphone health application*' OR 'wearable health technology' OR 'remote patient monitoring' OR 'RPM' OR 'virtual health' OR 'virtual consultation*' OR 'online health service*' OR 'e-prescribing' OR 'electronic prescribing system*' OR 'healthcare innovation' OR 'digital intervention*' OR 'digital health intervention*' OR 'artificial intelligence in health' OR 'AI in healthcare' OR 'machine learning in health' OR 'healthcare data analytic*' OR 'health monitoring app*' OR 'teleconsultation' OR 'health chatbot*' OR 'digital health platform*' OR 'internet-based healthcare' OR 'healthcare digitization' OR 'remote health service*' OR 'virtual care platform*' OR 'connected health' OR exp 'artificial intelligence'/ OR exp 'machine learning'/ OR exp 'natural language processing'/ OR exp 'algorithm'/ OR exp 'decision support system'/ OR 'artificial intelligence' OR 'machine learning' OR 'deep learning' OR 'natural language processing' OR 'neural network*' OR 'convolutional neural network*' OR 'recurrent neural network*' OR 'large language model' OR 'generative AI' OR 'decision support system' OR 'clinical decision support' OR 'predictive analytic*' OR 'data-driven model' OR 'intelligent system' OR 'computer-aided diagnosis' OR 'automated detection' OR 'algorithmic prediction' OR 'AI in healthcare' OR 'AI-based tool' OR 'chatbot' OR 'clinical NLP' OR 'pattern recognition' OR 'Bayesian network'	1631059

'community healthcare' OR 'primary healthcare' OR 'primary care' OR ‘community setting*’ OR exp 'primary health care'/ OR 'primary health care' OR 'outpatient care' OR 'ambulatory care' OR 'ambulatory health service*' OR 'outpatient service*' OR 'outpatient clinic*' OR 'general outpatient care' OR 'non-hospital healthcare' OR 'family medicine' OR 'family practice' OR exp 'family practice'/ OR 'general practice' OR 'general practitioner*' OR 'GP' OR 'GP clinic*' OR 'primary care provider*' OR 'community health center*' OR 'community health service*' OR exp 'community health service'/ OR 'community health worker*' OR 'village health worker*' OR 'health extension service*' OR 'health post*' OR 'district hospital*' OR 'district health center*' OR 'regional health center*' OR 'rural clinic*' OR 'exp rural health service'/ OR 'rural health services' OR 'urban health services' OR 'local health clinic*' OR 'neighborhood clinic*' OR 'local healthcare facilit*' OR 'local outpatient clinic*' OR 'essential health service*' OR 'secondary healthcare' OR 'secondary care' OR 'referral hospital*' OR 'community-based care' OR 'community health program*' OR 'community health initiative*' OR 'health dispensar*' OR 'local healthcare provider*' OR 'community-based medical care' OR 'frontline health service*' OR 'local health service*' OR 'health policy planning' OR 'community health policy' OR 'local healthcare polic*' OR 'healthcare policymaker*'	930724
'low and middle income countr*' OR 'LMIC*' OR 'developing countr*' OR 'developing nation*' OR 'developing econom*' OR 'developing region*' OR 'developing world' OR 'emerging econom*' OR 'emerging market econom*' OR 'emerging market*' OR 'transitional econom*' OR 'underdeveloped countr*' OR 'least developed countr*' OR 'LDC' OR 'third world countr*' OR 'global south' OR 'resource limited setting*' OR 'resource constrained setting*' OR 'resource poor setting*' OR 'low resource setting*' OR 'low income countr*' OR 'middle income countr*' OR 'lower middle income countr*' OR 'low income setting*' OR 'middle income setting*' OR 'low and lower middle income countr*' OR 'low and middle income region*' OR 'economically developing countr*' OR 'economically developing nation*' OR 'economically disadvantaged region*' OR 'financially constrained countr*' OR 'poverty stricken region*' OR 'low socioeconomic region*' OR 'sub Saharan Africa' OR 'South Asia' OR 'Latin America' OR 'Southeast Asia' OR 'Caribbean nation*' OR 'Pacific Island nation*' OR 'Afghanistan' OR 'Angola' OR 'Bangladesh' OR 'Benin' OR 'Bhutan' OR 'Burkina Faso' OR 'Burundi' OR 'Bolivia' OR 'Cabo Verde' OR 'Cambodia' OR 'Cameroon' OR 'Central African Republic' OR 'Chad' OR 'Comoros' OR 'Congo' OR 'Cote d Ivoire' OR 'Djibouti' OR 'Egypt' OR 'El Salvador' OR 'Eritrea' OR 'Eswatini' OR 'Ethiopia' OR 'Gambia' OR 'Ghana' OR 'Guinea' OR 'Guinea Bissau' OR 'Haiti' OR 'Honduras' OR 'India' OR 'Indonesia' OR 'Jordan' OR 'Kenya' OR 'Kiribati' OR 'Kyrgyz Republic' OR 'Korea' OR 'Lao PDR' OR 'Lebanon' OR 'Lesotho' OR 'Liberia' OR 'Madagascar' OR 'Malawi' OR 'Mali' OR 'Mauritania' OR 'Mozambique' OR 'Myanmar' OR 'Micronesia' OR 'Morocco' OR 'Nepal' OR 'Nicaragua' OR 'Niger' OR 'Nigeria' OR 'Pakistan' OR 'Papua New Guinea' OR 'Philippines' OR 'Peru' OR 'Rwanda' OR 'Samoa' OR 'Sao Tome and Principe' OR 'Senegal' OR 'Sierra Leone' OR 'Somalia' OR 'South Sudan' OR 'Sudan' OR 'Syria' OR 'Solomon Islands' OR 'Sri Lanka' OR 'Tanzania' OR 'Tajikistan' OR 'Togo' OR 'Timor Leste' OR 'Tunisia' OR 'Uganda' OR 'Uzbekistan' OR 'Vanuatu' OR 'Vietnam' OR 'West Bank and Gaza' OR 'Yemen' OR 'Zambia' OR 'Zimbabwe' OR exp 'developing country'/ OR exp 'poverty area'/	182047
Combined with AND	16

Scopus	**Results**
TITLE-ABS-KEY ("antimicrobial stewardship" OR "antibiotic stewardship" OR "anti-bacterial agent*" OR "responsible antibiotic use" OR "rational antibiotic use" OR "judicious antibiotic use" OR "infection control program*" OR "antimicrobial management" OR "antibiotic use" OR "antimicrobial use" OR "antibiotic" OR "antiviral" OR "antifungal" OR "antiparasitic" OR "antibiotic resistance management" OR "antibiotic resistance" OR "antimicrobial resistance control" OR "antibiotic prescribing" OR "antimicrobial prescribing" OR "antimicrobial therapy optimi*" OR "antimicrobial drug use" OR "appropriate antimicrobial prescribing" OR "appropriate antibiotic prescribing" OR "rational antimicrobial therapy" OR "antibiotic consumption monitoring" OR "antimicrobial consumption monitoring" OR "antibiotic rationalization" OR "antibiotic treatment guide*" OR "appropriate antimicrobial therapy" OR "antimicrobial resistance strateg*" OR "antimicrobial resistance" OR "multi-drug resistant" OR "MDR organism*" OR "resistant bacteria" OR "superbug*" OR "ESKAPE pathogen*" OR "resistance gene*" OR "extended-spectrum beta-lactamase" OR "AMR surveillance" OR "resistance pattern*" OR "emerging resistance" OR "antimicrobial surveillance" OR "nosocomial infection*" OR "healthcare-associated infection*" OR "drug resistance microbial" OR "drug utilization")	1,716,499
TITLE-ABS-KEY ("digital health" OR "eHealth" OR "mHealth" OR "telemedicine" OR "telehealth" OR "mobile health application*" OR "digital healthcare" OR "health technology" OR "digital solution*" OR "digital tool*" OR "health informatic*" OR "electronic health record*" OR "EHR" OR "electronic medical record*" OR "EMR" OR "clinical decision support system*" OR "CDSS" OR "health information technology" OR "HIT" OR "healthcare technology" OR "technology-enabled healthcare" OR "blockchain" OR "health apps" OR "smartphone health application*" OR "wearable health technology" OR "remote patient monitoring" OR "RPM" OR "virtual health" OR "virtual consultation*" OR "online health service*"	7,118,107

OR "e-prescribing" OR "electronic prescribing system*" OR "healthcare innovation" OR "digital intervention*" OR "digital health intervention*" OR "artificial intelligence in health" OR "AI in healthcare" OR "machine learning in health" OR "healthcare data analytic*" OR "health monitoring app*" OR "teleconsultation" OR "health chatbot*" OR "digital health platform*" OR "internet-based healthcare" OR "healthcare digitization" OR "remote health service*" OR "virtual care platform*" OR "connected health" OR "artificial intelligence" OR "machine learning" OR "natural language processing" OR "algorithms" OR "decision support systems, clinical" OR "deep learning" OR "neural network*" OR "convolutional neural network*" OR "recurrent neural network*" OR "large language model" OR "generative AI" OR "decision support system" OR "clinical decision support" OR "predictive analytic*" OR "data-driven model" OR "intelligent system" OR "computer-aided diagnosis" OR "automated detection" OR "algorithmic prediction" OR "AI in healthcare" OR "AI-based tool" OR "chatbot" OR "clinical NLP" OR "pattern recognition" OR "Bayesian network")	
TITLE-ABS-KEY ("community healthcare" OR "primary healthcare" OR "primary care" OR "primary health care" OR "community setting*" OR "outpatient care" OR "ambulatory care" OR "ambulatory health service*" OR "outpatient service*" OR "outpatient clinic*" OR "general outpatient care" OR "non-hospital healthcare" OR "family medicine" OR "family practice" OR "general practice" OR "general practitioner*" OR "GP" OR "GP clinic*" OR "primary care provider*" OR "community health center*" OR "community health service*" OR "community health worker*" OR "village health worker*" OR "health extension service*" OR "health post*" OR "district hospital*" OR "district health center*" OR "regional health center*" OR "rural clinic*" OR "urban health services" OR "rural health services" OR "local health clinic*" OR "neighborhood clinic*" OR "local healthcare facilit*" OR "local outpatient clinic*" OR "essential health service*" OR "secondary healthcare" OR "secondary care" OR "referral hospital*" OR "community-based care" OR "community health program*" OR "community health initiative*" OR "health dispensar*" OR "local healthcare provider*" OR "community-based medical care" OR "frontline health service*" OR "local health service*" OR "health policy planning" OR "community health policy" OR "local healthcare polic*" OR "healthcare policymaker*")	822,879
TITLE-ABS-KEY("low- and middle-income countr*" OR "LMIC*" OR "developing countr*" OR "developing nation*" OR "developing econom*" OR "developing region*" OR "developing world" OR "emerging econom*" OR "emerging market econom*" OR "emerging market*" OR "transitional econom*" OR "underdeveloped countr*" OR "least developed countr*" OR "LDC" OR "third world countr*" OR "global south" OR "resource-limited setting*" OR "resource-constrained setting*" OR "resource-poor setting*" OR "low-resource setting*" OR "low-income countr*" OR "middle-income countr*" OR "lower-middle-income countr*" OR "low-income setting*" OR "middle-income setting*" OR "low and lower-middle income countr*" OR "low and middle-income region*" OR "economically developing countr*" OR "economically developing nation*" OR "economically disadvantaged region*" OR "financially constrained countr*" OR "poverty-stricken region*" OR "low socioeconomic region*" OR "sub-Saharan Africa" OR "South Asia" OR "Latin America" OR "Southeast Asia" OR "Caribbean nation*" OR "Pacific Island nation*" OR "Afghanistan" OR "Angola" OR "Bangladesh" OR "Benin" OR "Bhutan" OR "Burkina Faso" OR "Burundi" OR "Bolivia" OR "Cabo Verde" OR "Cambodia" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Comoros" OR "Congo" OR "Cote d' Ivoire" OR "Djibouti" OR "Egypt" OR "El Salvador" OR "Eritrea" OR "Eswatini" OR "Ethiopia" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Haiti" OR "Honduras" OR "India" OR "Indonesia" OR "Jordan" OR "Kenya" OR "Kiribati" OR "Kyrgyz Republic" OR "Korea" OR "Lao PDR" OR "Lebanon" OR "Lesotho" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritania" OR "Mozambique" OR "Myanmar" OR "Micronesia" OR "Morocco" OR "Nepal" OR "Nicaragua" OR "Niger" OR "Nigeria" OR "Pakistan" OR "Papua New Guinea" OR "Philippines" OR "Peru" OR "Rwanda" OR "Samoa" OR "Sao Tome and Principe" OR "Senegal" OR "Sierra Leone" OR "Somalia" OR "South Sudan" OR "Sudan" OR "Syria" OR "Solomon Islands" OR "Sri Lanka" OR "Tanzania" OR "Tajikistan" OR "Togo" OR "Timor-Leste" OR "Tunisia" OR "Uganda" OR "Uzbekistan" OR "Vanuatu" OR "Vietnam" OR "West Bank and Gaza" OR "Yemen" OR "Zambia" OR "Zimbabwe")	3,322,265
Combined with AND	262

Cochrane Library	**Results**
"antimicrobial stewardship" OR "antibiotic stewardship" OR "responsible antibiotic use" OR "rational antibiotic use" OR "judicious antibiotic use" OR (infection NEXT control NEXT program*) OR "antimicrobial management" OR "antibiotic use" OR "antimicrobial use" OR "antibiotic" OR "antiviral" OR "antifungal" OR "antiparasitic" OR "antibiotic resistance management" OR "antibiotic resistance" OR "antimicrobial resistance control" OR "antibiotic prescribing" OR "antimicrobial prescribing" OR (antimicrobial NEXT therapy NEXT optimi*) OR "antimicrobial drug use" OR "appropriate antimicrobial prescribing" OR "appropriate antibiotic prescribing" OR "rational antimicrobial therapy" OR (antibiotic	60696

NEXT consumption NEXT monitoring) OR (antimicrobial NEXT consumption NEXT monitoring) OR "antibiotic rationalization" OR (antibiotic NEXT treatment NEXT guide*) OR "appropriate antimicrobial therapy" OR (antimicrobial NEXT resistance NEXT strateg*) OR "antimicrobial resistance" OR "multi-drug resistant" OR (MDR NEXT organism*) OR "resistant bacteria" OR (ESKAPE NEXT pathogen*) OR (resistance NEXT gene*) OR "extended-spectrum beta-lactamase" OR (AMR NEXT surveillance) OR (resistance NEXT pattern*) OR "emerging resistance" OR (antimicrobial NEXT surveillance) OR (nosocomial NEXT infection*) OR (healthcare-associated NEXT infection*) OR "drug resistance, microbial" OR "drug utilization" MeSH descriptor: [Antimicrobial Stewardship] explode all trees, MeSH descriptor: [Drug Resistance, Microbial] explode all trees, MeSH descriptor: [Drug Resistance, Bacterial] explode all trees, MeSH descriptor: [Drug Resistance, Fungal] explode all trees, MeSH descriptor: [Drug Resistance, Viral] explode all trees, MeSH descriptor: [Anti-Bacterial Agents] explode all trees, MeSH descriptor: [Drug Utilization] explode all trees, MeSH descriptor: [Inappropriate Prescribing] explode all trees, MeSH descriptor: [Infection Control] explode all trees	
"digital health" OR "eHealth" OR "mHealth" OR "telemedicine" OR "telehealth" OR (mobile NEXT health NEXT application*) OR "digital healthcare" OR "health technology" OR (digital NEXT solution*) OR (digital NEXT tool*) OR (health NEXT informatic*) OR (electronic NEXT health NEXT record*) OR "EHR" OR (electronic NEXT medical NEXT record*) OR "EMR" OR (clinical NEXT decision NEXT support NEXT system*) OR "CDSS" OR "health information technology" OR "HIT" OR "healthcare technology" OR "technology-enabled healthcare" OR "blockchain" OR "health apps" OR (smartphone NEXT health NEXT application*) OR "wearable health technology" OR "remote patient monitoring" OR "RPM" OR "virtual health" OR (virtual NEXT consultation*) OR (online NEXT health NEXT service*) OR "e-prescribing" OR (electronic NEXT prescribing NEXT system*) OR "healthcare innovation" OR (digital NEXT intervention*) OR (digital NEXT health NEXT intervention*) OR "artificial intelligence in health" OR "AI in healthcare" OR "machine learning in health" OR (healthcare NEXT data NEXT analytic*) OR (health NEXT monitoring NEXT app*) OR "teleconsultation" OR (health NEXT chatbot*) OR (digital NEXT health NEXT platform*) OR "internet-based healthcare" OR "healthcare digitization" OR (remote NEXT health NEXT service*) OR (virtual NEXT care NEXT platform*) OR "connected health" OR "artificial intelligence" OR "machine learning" OR "natural language processing" OR "algorithms" OR "decision support systems, clinical" OR "deep learning" OR (neural NEXT network*) OR (convolutional NEXT neural NEXT network*) OR (recurrent NEXT neural NEXT network*) OR "large language model" OR "generative AI" OR (decision NEXT support NEXT system) OR (clinical NEXT decision NEXT support) OR (predictive NEXT analytic*) OR (data-driven NEXT model) OR "intelligent system" OR (computer-aided NEXT diagnosis) OR (automated NEXT detection) OR (algorithmic NEXT prediction) OR "AI in healthcare" OR "AI-based tool" OR "chatbot" OR "clinical NLP" OR (health NEXT informatic*) OR (pattern NEXT recognition) OR "Bayesian network" MeSH descriptor: [Artificial Intelligence] explode all trees, MeSH descriptor: [Machine Learning] explode all trees MeSH descriptor: [Natural Language Processing] explode all trees, MeSH descriptor: [Decision Support Systems, Clinical] explode all trees, MeSH descriptor: [Electronic Health Records] explode all trees, MeSH descriptor: [Remote Consultation] explode all trees, MeSH descriptor: [Telemedicine] explode all trees, MeSH descriptor: [Mobile Applications] explode all trees	61237
"community healthcare" OR "primary healthcare" OR "primary care" OR "primary health care" OR "outpatient care" OR (community NEXT setting*) OR "ambulatory care" OR (ambulatory NEXT health NEXT service*) OR (outpatient NEXT service*) OR (outpatient NEXT clinic*) OR "general outpatient care" OR "non-hospital healthcare" OR "family medicine" OR "family practice" OR "general practice" OR (general NEXT practitioner*) OR "GP" OR (GP NEXT clinic*) OR (primary NEXT care NEXT provider*) OR (community NEXT health NEXT center*) OR (community NEXT health NEXT service*) OR (community NEXT health NEXT worker*) OR (village NEXT health NEXT worker*) OR (health NEXT extension NEXT service*) OR (health NEXT post*) OR (district NEXT hospital*) OR (district NEXT health NEXT center*) OR (regional NEXT health NEXT center*) OR (rural NEXT clinic*) OR "urban health services" OR "rural health services" OR (local NEXT health NEXT clinic*) OR (neighborhood NEXT clinic*) OR (local NEXT healthcare NEXT facilit*) OR (local NEXT outpatient NEXT clinic*) OR (essential NEXT health NEXT service*) OR "secondary healthcare" OR "secondary care" OR (referral NEXT hospital*) OR "community-based care" OR (community NEXT health NEXT program*) OR (community NEXT health NEXT initiative*) OR (health NEXT dispensar*) OR (local NEXT healthcare NEXT provider*) OR "community-based medical care" OR (frontline NEXT health NEXT service*) OR (local NEXT health NEXT service*) OR (health NEXT policy NEXT planning) OR (community NEXT health NEXT policy) OR (local NEXT healthcare NEXT polic*) OR (healthcare NEXT policymaker*) MeSH descriptor: [Primary Health Care] explode all trees, MeSH descriptor: [Community Health Services] explode all trees, MeSH descriptor: [Community Health Workers] explode all trees, MeSH descriptor: [Family Practice] explode all trees, MeSH descriptor: [General Practice] explode all trees, MeSH descriptor: [Hospitals, District] explode all trees, MeSH descriptor: [Ambulatory Care] explode all trees	525453

"low income country" OR "middle income country" OR "low and middle income country" OR "low income setting" OR "middle income setting" OR "developing country" OR "developing countries" OR "developing nation" OR "developing nations" OR "emerging economy" OR "emerging economies" OR "resource limited setting" OR "resource constrained setting" OR "resource poor setting" OR "low resource setting" OR "underdeveloped country" OR "least developed country" OR "LDC" OR "third world country" OR "global south" OR "sub-Saharan Africa" OR "South Asia" OR "Latin America" OR "Southeast Asia" OR "Caribbean" OR "Pacific Islands" OR "Afghanistan" OR "Angola" OR "Bangladesh" OR "Benin" OR "Bhutan" OR "Burkina Faso" OR "Burundi" OR "Bolivia" OR "Cabo Verde" OR "Cambodia" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Comoros" OR "Congo" OR "Cote d'Ivoire" OR "Djibouti" OR "Egypt" OR "El Salvador" OR "Eritrea" OR "Eswatini" OR "Ethiopia" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Haiti" OR "Honduras" OR "India" OR "Indonesia" OR "Jordan" OR "Kenya" OR "Kiribati" OR "Kyrgyz Republic" OR "Korea" OR "Lao PDR" OR "Lebanon" OR "Lesotho" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritania" OR "Mozambique" OR "Myanmar" OR "Micronesia" OR "Morocco" OR "Nepal" OR "Nicaragua" OR "Niger" OR "Nigeria" OR "Pakistan" OR "Papua New Guinea" OR "Philippines" OR "Peru" OR "Rwanda" OR "Samoa" OR "Sao Tome and Principe" OR "Senegal" OR "Sierra Leone" OR "Somalia" OR "South Sudan" OR "Sudan" OR "Syria" OR "Solomon Islands" OR "Sri Lanka" OR "Tanzania" OR "Tajikistan" OR "Togo" OR "Timor-Leste" OR "Tunisia" OR "Uganda" OR "Uzbekistan" OR "Vanuatu" OR "Vietnam" OR "West Bank and Gaza" OR "Yemen" OR "Zambia" OR "Zimbabwe" MeSH descriptor: [Developing Countries] explode all trees, MeSH descriptor: [Poverty Areas] explode all trees	68127
Combined with AND	238

WHO Global Index Medicus	**Results**
"antimicrobial stewardship" OR "antibiotic stewardship" OR "responsible antibiotic use" OR "rational antibiotic use" OR "judicious antibiotic use" OR "infection control program*" OR "antimicrobial management" OR "antibiotic use" OR "antimicrobial use" OR "antibiotic" OR "antiviral" OR "antifungal" OR "antiparasitic" OR "antibiotic resistance management" OR "antibiotic resistance" OR "antimicrobial resistance control" OR "antibiotic prescribing" OR "antimicrobial prescribing" OR "antimicrobial therapy optimi*" OR "antimicrobial drug use" OR "appropriate antimicrobial prescribing" OR "appropriate antibiotic prescribing" OR "rational antimicrobial therapy" OR "antibiotic consumption monitoring" OR "antimicrobial consumption monitoring" OR "antibiotic rationalization" OR "antibiotic treatment guide*" OR "appropriate antimicrobial therapy" OR "antimicrobial resistance strateg*" OR "antimicrobial resistance" OR "multi-drug resistant" OR "MDR organism*" OR "resistant bacteria" OR "superbug*" OR "ESKAPE pathogen*" OR "resistance gene*" OR "extended-spectrum beta-lactamase" OR "AMR surveillance" OR "resistance pattern*" OR "emerging resistance" OR "antimicrobial surveillance" OR "nosocomial infection*" OR "healthcare-associated infection*"	50840
"digital health" OR "eHealth" OR "mHealth" OR "telemedicine" OR "telehealth" OR "mobile health application*" OR "digital healthcare" OR "health technology" OR "digital solution*" OR "digital tool*" OR "health informatic*" OR "electronic health record*" OR "EHR" OR "electronic medical record*" OR "EMR" OR "clinical decision support system*" OR "CDSS" OR "health information technology" OR "HIT" OR "healthcare technology" OR "technology-enabled healthcare" OR "blockchain" OR "health apps" OR "smartphone health application*" OR "wearable health technology" OR "remote patient monitoring" OR "RPM" OR "virtual health" OR "virtual consultation*" OR "online health service*" OR "e-prescribing" OR "electronic prescribing system*" OR "healthcare innovation" OR "digital intervention*" OR "digital health intervention*" OR "artificial intelligence in health" OR "AI in healthcare" OR "machine learning in health" OR "healthcare data analytic*" OR "health monitoring app*" OR "teleconsultation" OR "health chatbot*" OR "digital health platform*" OR "internet-based healthcare" OR "healthcare digitization" OR "remote health service*" OR "virtual care platform*" OR "connected health" OR "artificial intelligence" OR "machine learning" OR "natural language processing" OR "algorithms" OR "decision support systems, clinical" OR "deep learning" OR "neural network*" OR "convolutional neural network*" OR "recurrent neural network*" OR "large language model" OR "generative AI" OR "decision support system" OR "clinical decision support" OR "predictive analytic*" OR "data-driven model" OR "intelligent system" OR "computer-aided diagnosis" OR "automated detection" OR "algorithmic prediction" OR "AI in healthcare" OR "AI-based tool" OR "chatbot" OR "clinical NLP" OR "pattern recognition" OR "Bayesian network"	22431
"community healthcare" OR "primary healthcare" OR "primary care" OR "primary health care" OR "outpatient care" OR “community setting*” OR "ambulatory care" OR "ambulatory health service*" OR "outpatient service*" OR "outpatient clinic*" OR "general outpatient care" OR "non-hospital healthcare" OR "family medicine" OR "family practice" OR "general practice" OR "general practitioner*" OR "GP" OR "GP clinic*" OR "primary care provider*" OR "community health center*" OR "community health service*" OR "community health worker*" OR "village health worker*" OR "health extension service*" OR "health	43754

post*" OR "district hospital*" OR "district health center*" OR "regional health center*" OR "rural clinic*" OR "urban health services" OR "rural health services" OR "local health clinic*" OR "neighborhood clinic*" OR "local healthcare facilit*" OR "local outpatient clinic*" OR "essential health service*" OR "secondary healthcare" OR "secondary care" OR "referral hospital*" OR "community-based care" OR "community health program*" OR "community health initiative*" OR "health dispensar*" OR "local healthcare provider*" OR "community-based medical care" OR "frontline health service*" OR "local health service*" OR "health policy planning" OR "community health policy" OR "local healthcare polic*" OR "healthcare policymaker*"	
"low- and middle-income countr*" OR "LMIC*" OR "developing countr*" OR "developing nation*" OR "developing econom*" OR "developing region*" OR "developing world" OR "emerging econom*" OR "emerging market econom*" OR "emerging market*" OR "transitional econom*" OR "underdeveloped countr*" OR "least developed countr*" OR "LDC" OR "third world countr*" OR "global south" OR "resource-limited setting*" OR "resource-constrained setting*" OR "resource-poor setting*" OR "low-resource setting*" OR "low-income countr*" OR "middle-income countr*" OR "lower-middle-income countr*" OR "low-income setting*" OR "middle-income setting*" OR "low and lower-middle income countr*" OR "low and middle-income region*" OR "economically developing countr*" OR "economically developing nation*" OR "economically disadvantaged region*" OR "financially constrained countr*" OR "poverty-stricken region*" OR "low socioeconomic region*" OR "sub-Saharan Africa" OR "South Asia" OR "Latin America" OR "Southeast Asia" OR "Caribbean nation*" OR "Pacific Island nation*" OR "Afghanistan" OR "Angola" OR "Bangladesh" OR "Benin" OR "Bhutan" OR "Burkina Faso" OR "Burundi" OR "Bolivia" OR "Cabo Verde" OR "Cambodia" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Comoros" OR "Congo" OR "Cote d'Ivoire" OR "Djibouti" OR "Egypt" OR "El Salvador" OR "Eritrea" OR "Eswatini" OR "Ethiopia" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Haiti" OR "Honduras" OR "India" OR "Indonesia" OR "Jordan" OR "Kenya" OR "Kiribati" OR "Kyrgyz Republic" OR "Korea" OR "Lao PDR" OR "Lebanon" OR "Lesotho" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritania" OR "Mozambique" OR "Myanmar" OR "Micronesia" OR "Morocco" OR "Nepal" OR "Nicaragua" OR "Niger" OR "Nigeria" OR "Pakistan" OR "Papua New Guinea" OR "Philippines" OR "Peru" OR "Rwanda" OR "Samoa" OR "Sao Tome and Principe" OR "Senegal" OR "Sierra Leone" OR "Somalia" OR "South Sudan" OR "Sudan" OR "Syria" OR "Solomon Islands" OR "Sri Lanka" OR "Tanzania" OR "Tajikistan" OR "Togo" OR "Timor-Leste" OR "Tunisia" OR "Uganda" OR "Uzbekistan" OR "Vanuatu" OR "Vietnam" OR "West Bank and Gaza" OR "Yemen" OR "Zambia" OR "Zimbabwe"	140887
Combined with AND	13

TRIP Database	**Results**
"antimicrobial stewardship" OR "antibiotic stewardship" OR "responsible antibiotic use" OR "rational antibiotic use" OR "judicious antibiotic use" OR "infection control program*" OR "antimicrobial management" OR "antibiotic use" OR "antimicrobial use" OR "antibiotic" OR "antiviral" OR "antifungal" OR "antiparasitic" OR "antibiotic resistance management" OR "antibiotic resistance" OR "antimicrobial resistance control" OR "antibiotic prescribing" OR "antimicrobial prescribing" OR "antimicrobial therapy optimi*" OR "antimicrobial drug use" OR "appropriate antimicrobial prescribing" OR "appropriate antibiotic prescribing" OR "rational antimicrobial therapy" OR "antibiotic consumption monitoring" OR "antimicrobial consumption monitoring" OR "antibiotic rationalization" OR "antibiotic treatment guide*" OR "appropriate antimicrobial therapy" OR "antimicrobial resistance strateg*" OR "antimicrobial resistance" OR "multi-drug resistant" OR "MDR organism*" OR "resistant bacteria" OR "superbug*" OR "ESKAPE pathogen*" OR "resistance gene*" OR "extended-spectrum beta-lactamase" OR "AMR surveillance" OR "resistance pattern*" OR "emerging resistance" OR "antimicrobial surveillance" OR "nosocomial infection*" OR "healthcare-associated infection*"	Combined in PICO strategy
"digital health" OR "eHealth" OR "mHealth" OR "telemedicine" OR "telehealth" OR "mobile health application*" OR "digital healthcare" OR "health technology" OR "digital solution*" OR "digital tool*" OR "health informatic*" OR "electronic health record*" OR "EHR" OR "electronic medical record*" OR "EMR" OR "clinical decision support system*" OR "CDSS" OR "health information technology" OR "HIT" OR "healthcare technology" OR "technology-enabled healthcare" OR "blockchain" OR "health apps" OR "smartphone health application*" OR "wearable health technology" OR "remote patient monitoring" OR "RPM" OR "virtual health" OR "virtual consultation*" OR "online health service*" OR "e-prescribing" OR "electronic prescribing system*" OR "healthcare innovation" OR "digital intervention*" OR "digital health intervention*" OR "artificial intelligence in health" OR "AI in healthcare" OR "machine learning in health" OR "healthcare data analytic*" OR "health monitoring app*" OR "teleconsultation" OR "health chatbot*" OR "digital health platform*" OR "internet-based healthcare" OR "healthcare digitization" OR "remote health service*" OR "virtual care platform*" OR "connected health" OR "artificial intelligence" OR "machine learning" OR "natural language processing" OR "algorithms" OR "decision support systems,	Combined in PICO strategy

clinical" OR "deep learning" OR "neural network*" OR "convolutional neural network*" OR "recurrent neural network*" OR "large language model" OR "generative AI" OR "decision support system" OR "clinical decision support" OR "predictive analytic*" OR "data-driven model" OR "intelligent system" OR "computer-aided diagnosis" OR "automated detection" OR "algorithmic prediction" OR "AI in healthcare" OR "AI-based tool" OR "chatbot" OR "clinical NLP" OR "pattern recognition" OR "Bayesian network"	
"community healthcare" OR "primary healthcare" OR "primary care" OR "primary health care" OR "outpatient care" OR "community setting*" OR "ambulatory care" OR "ambulatory health service*" OR "outpatient service*" OR "outpatient clinic*" OR "general outpatient care" OR "non-hospital healthcare" OR "family medicine" OR "family practice" OR "general practice" OR "general practitioner*" OR "GP" OR "GP clinic*" OR "primary care provider*" OR "community health center*" OR "community health service*" OR "community health worker*" OR "village health worker*" OR "health extension service*" OR "health post*" OR "district hospital*" OR "district health center*" OR "regional health center*" OR "rural clinic*" OR "urban health services" OR "rural health services" OR "local health clinic*" OR "neighborhood clinic*" OR "local healthcare facilit*" OR "local outpatient clinic*" OR "essential health service*" OR "secondary healthcare" OR "secondary care" OR "referral hospital*" OR "community-based care" OR "community health program*" OR "community health initiative*" OR "health dispensar*" OR "local healthcare provider*" OR "community-based medical care" OR "frontline health service*" OR "local health service*" OR "health policy planning" OR "community health policy" OR "local healthcare polic*" OR "healthcare policymaker*"	Combined in PICO strategy
"low- and middle-income countr*" OR "LMIC*" OR "developing countr*" OR "developing nation*" OR "developing econom*" OR "developing region*" OR "developing world" OR "emerging econom*" OR "emerging market econom*" OR "emerging market*" OR "transitional econom*" OR "underdeveloped countr*" OR "least developed countr*" OR "LDC" OR "third world countr*" OR "global south" OR "resource-limited setting*" OR "resource-constrained setting*" OR "resource-poor setting*" OR "low-resource setting*" OR "low-income countr*" OR "middle-income countr*" OR "lower-middle-income countr*" OR "low-income setting*" OR "middle-income setting*" OR "low and lower-middle income countr*" OR "low and middle-income region*" OR "economically developing countr*" OR "economically developing nation*" OR "economically disadvantaged region*" OR "financially constrained countr*" OR "poverty-stricken region*" OR "low socioeconomic region*" OR "sub-Saharan Africa" OR "South Asia" OR "Latin America" OR "Southeast Asia" OR "Caribbean nation*" OR "Pacific Island nation*" OR "Afghanistan" OR "Angola" OR "Bangladesh" OR "Benin" OR "Bhutan" OR "Burkina Faso" OR "Burundi" OR "Bolivia" OR "Cabo Verde" OR "Cambodia" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Comoros" OR "Congo" OR "Côte d'Ivoire" OR "Djibouti" OR "Egypt" OR "El Salvador" OR "Eritrea" OR "Eswatini" OR "Ethiopia" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Haiti" OR "Honduras" OR "India" OR "Indonesia" OR "Jordan" OR "Kenya" OR "Kiribati" OR "Kyrgyz Republic" OR "Korea" OR "Lao PDR" OR "Lebanon" OR "Lesotho" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritania" OR "Mozambique" OR "Myanmar" OR "Micronesia" OR "Morocco" OR "Nepal" OR "Nicaragua" OR "Niger" OR "Nigeria" OR "Pakistan" OR "Papua New Guinea" OR "Philippines" OR "Peru" OR "Rwanda" OR "Samoa" OR "São Tomé and Principe" OR "Senegal" OR "Sierra Leone" OR "Somalia" OR "South Sudan" OR "Sudan" OR "Syria" OR "Solomon Islands" OR "Sri Lanka" OR "Tanzania" OR "Tajikistan" OR "Togo" OR "Timor-Leste" OR "Tunisia" OR "Uganda" OR "Uzbekistan" OR "Vanuatu" OR "Vietnam" OR "West Bank and Gaza" OR "Yemen" OR "Zambia" OR "Zimbabwe"	Combined in PICO strategy
Combined using PICO strategy	32

Web of Science	**Results**
TS = ("antimicrobial stewardship" OR "antibiotic stewardship" OR "responsible antibiotic use" OR "rational antibiotic use" OR "judicious antibiotic use" OR "infection control program*" OR "antimicrobial management" OR "antibiotic use" OR "antimicrobial use" OR "antibiotic" OR "antiviral" OR "antifungal" OR "antiparasitic" OR "antibiotic resistance management" OR "antibiotic resistance" OR "antimicrobial resistance control" OR "antibiotic prescribing" OR "antimicrobial prescribing" OR "antimicrobial therapy optimi*" OR "antimicrobial drug use" OR "appropriate antimicrobial prescribing" OR "appropriate antibiotic prescribing" OR "rational antimicrobial therapy" OR "antibiotic consumption monitoring" OR "antimicrobial consumption monitoring" OR "antibiotic rationalization" OR "antibiotic treatment guide*" OR "appropriate antimicrobial therapy" OR "antimicrobial resistance strateg*" OR "antimicrobial resistance" OR "multi-drug resistant" OR "MDR organism*" OR "resistant bacteria" OR "superbug*" OR "ESKAPE pathogen*" OR "resistance gene*" OR "extended-spectrum beta-lactamase" OR "AMR surveillance" OR "resistance pattern*" OR "emerging resistance" OR "antimicrobial surveillance" OR "nosocomial infection*" OR "healthcare-associated infection*")	726814

TS= ("digital health" OR eHealth OR mHealth OR telemedicine OR telehealth OR "mobile health application*" OR "digital healthcare" OR "health technology" OR "digital solution*" OR "digital tool*" OR "health informatic*" OR "electronic health record*" OR EHR OR "electronic medical record*" OR EMR OR "clinical decision support system*" OR CDSS OR "health information technology" OR HIT OR "healthcare technology" OR "technology-enabled healthcare" OR blockchain OR "health apps" OR "smartphone health application*" OR "wearable health technology" OR "remote patient monitoring" OR RPM OR "virtual health" OR "virtual consultation*" OR "online health service*" OR "e-prescribing" OR "electronic prescribing system*" OR "healthcare innovation" OR "digital intervention*" OR "digital health intervention*" OR "artificial intelligence in health" OR "AI in healthcare" OR "machine learning in health" OR "healthcare data analytic*" OR "health monitoring app*" OR teleconsultation OR "health chatbot*" OR "digital health platform*" OR "internet-based healthcare" OR "healthcare digitization" OR "remote health service*" OR "virtual care platform*" OR "connected health" OR "artificial intelligence" OR "machine learning" OR "natural language processing" OR algorithms OR "decision support systems, clinical" OR "deep learning" OR "neural network*" OR "convolutional neural network*" OR "recurrent neural network*" OR "large language model" OR "generative AI" OR "decision support system" OR "clinical decision support" OR "predictive analytic*" OR "data-driven model" OR "intelligent system" OR "computer-aided diagnosis" OR "automated detection" OR "algorithmic prediction" OR "AI-based tool" OR chatbot OR "clinical NLP" OR "pattern recognition" OR "Bayesian network")	4465963
TS=("community healthcare" OR "primary healthcare" OR "primary care" OR "primary health care" OR "outpatient care" OR "ambulatory care" OR "ambulatory health service*" OR "outpatient service*" OR "outpatient clinic*" OR "general outpatient care" OR "non-hospital healthcare" OR "family medicine" OR "family practice" OR "general practice" OR "general practitioner*" OR "GP" OR "GP clinic*" OR "primary care provider*" OR "community health center*" OR "community health service*" OR "community health worker*" OR "village health worker*" OR "health extension service*" OR "health post*" OR "district hospital*" OR "district health center*" OR "regional health center*" OR "rural clinic*" OR "urban health services" OR "rural health services" OR "local health clinic*" OR "neighborhood clinic*" OR "local healthcare facilit*" OR "local outpatient clinic*" OR "essential health service*" OR "secondary healthcare" OR "secondary care" OR "referral hospital*" OR "community-based care" OR "community health program*" OR "community health initiative*" OR "health dispensar*" OR "local healthcare provider*" OR "community-based medical care" OR "frontline health service*" OR "local health service*" OR "health policy planning" OR "community health policy" OR "local healthcare polic*" OR "healthcare policymaker*")	450955
TS=("low- and middle-income countr*" OR "LMIC*" OR "developing countr*" OR "developing nation*" OR "developing econom*" OR "developing region*" OR "developing world" OR "emerging econom*" OR "emerging market econom*" OR "emerging market*" OR "transitional econom*" OR "underdeveloped countr*" OR "least developed countr*" OR "LDC" OR "third world countr*" OR "global south" OR "resource-limited setting*" OR "resource-constrained setting*" OR "resource-poor setting*" OR "low-resource setting*" OR "low-income countr*" OR "middle-income countr*" OR "lower-middle-income countr*" OR "low-income setting*" OR "middle-income setting*" OR "low and lower-middle income countr*" OR "low and middle-income region*" OR "economically developing countr*" OR "economically developing nation*" OR "economically disadvantaged region*" OR "financially constrained countr*" OR "poverty-stricken region*" OR "low socioeconomic region*" OR "sub-Saharan Africa" OR "South Asia" OR "Latin America" OR "Southeast Asia" OR "Caribbean nation*" OR "Pacific Island nation*" OR "Afghanistan" OR "Angola" OR "Bangladesh" OR "Benin" OR "Bhutan" OR "Burkina Faso" OR "Burundi" OR "Bolivia" OR "Cabo Verde" OR "Cambodia" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Comoros" OR "Congo" OR "Côte d'Ivoire" OR "Djibouti" OR "Egypt" OR "El Salvador" OR "Eritrea" OR "Eswatini" OR "Ethiopia" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Haiti" OR "Honduras" OR "India" OR "Indonesia" OR "Jordan" OR "Kenya" OR "Kiribati" OR "Kyrgyz Republic" OR "Korea" OR "Lao PDR" OR "Lebanon" OR "Lesotho" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritania" OR "Mozambique" OR "Myanmar" OR "Micronesia" OR "Morocco" OR "Nepal" OR "Nicaragua" OR "Niger" OR "Nigeria" OR "Pakistan" OR "Papua New Guinea" OR "Philippines" OR "Peru" OR "Rwanda" OR "Samoa" OR "São Tomé and Principe" OR "Senegal" OR "Sierra Leone" OR "Somalia" OR "South Sudan" OR "Sudan" OR "Syria" OR "Solomon Islands" OR "Sri Lanka" OR "Tanzania" OR "Tajikistan" OR "Togo" OR "Timor-Leste" OR "Tunisia" OR "Uganda" OR "Uzbekistan" OR "Vanuatu" OR "Vietnam" OR "West Bank and Gaza" OR "Yemen" OR "Zambia" OR "Zimbabwe" OR "Developing Countries" OR "Poverty Areas")	2277367
Combined with AND	270

Appendix 4: Risk of Bias Full Assessment Tables

Author/ Year	1	2	3	4	5	Overall Risk of Bias
RCTs (n= 9)						
Tan et al, 2024 [147]	Low	Low	Low	Low	Low	Low as all domains were judged low risk, indicating overall low risk of bias for the trial
Tan et al, 2023 [139]	Low	Low	Low	Some Concerns	Low	Some concerns mainly from potential bias in outcome measurement. All other domains showed low risk
Tan et al, 2020 [144]	Low	Low	Low	Low	Some Concerns	Some concerns. The inherent characteristics of subgroup analyses introduce the potential for confounding to bias the results
Keitel et al, 2019 [145]	Low	Low	Low	Some Concerns	Some Concerns	Some concerns. Strong RCT basis but subgroup design raises issues of selective inference and generalizability
Steinhardt et al, 2019 [143]	Low	Low	Low	Low	Low	Low risk. All domains show low risk, indicating a well-conducted cluster RCT with strong internal validity
O'Donovan et al, 2018 [140]	Some Concerns	Low	Low	Low	Some Concerns	Some concerns. Small pilot RCT with limited reporting and potential of reactivity bias raises transparency and validity concerns
Rambaud-Althaus et, 2017 [141]	Low	Low	Low	Low	Some Concerns	Some concerns. Well-conducted pilot cluster RCT but outcome assessment may be affected by observer bias
Keitel et al, 2017 [146]	Low	Low	Low	Low	Low	Low risk. Rigorous non-inferiority RCT with low risk of bias across all domains
Perri-Moore et al, 2015 [142]	Some Concerns	Low	Low	Low	Some Concerns	Some concerns. Well-conducted study with real-time outcome tracking and valid analysis but moderate concerns due to unclear allocation concealment and post-randomization recruitment

Appendix 4.1: Risk of Bias Assessment for randomised controlled trials (RCTs) included in the systematic review using the Cochrane Risk of Bias 2 Tool. Each study was assessed based on 5 domains. 1) Risk of bias arising from the randomization process 2) Risk of bias due to deviations from the interventions 3) Missing outcome data 4) Risk of bias in measurement of the outcome 5) Risk of bias in selection of the reported result. Response options for the questions included Yes / Partially Yes / Partially No / No / No Information. The risk of bias judgement in each domain were then assigned Low, High or Some concerns. A majority of 'Low' responses overall indicate a positive methodological approach avoiding pitfalls for bias, whereas 'Some Concern' or 'High' suggests increased susceptibility to bias.

Author/ Year	1	2	3	4	5	6	7	Overall Risk of Bias
Observational Studies (n=8)								
Langet et al, 2025 (149)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate risk of bias due to use of a historical control. However, secular trends were adjusted for. Other potential confounders such as demographics, clinical features and healthcare access were also addressed
Hürlimann et al, 2024 (152)	Serious	Low	Low	Low	Low	Low	Low	Serious risk of bias due to use of historical control and no adjustment for time-related confounders , although all other domains had a low to moderate risk
Sawant et al, 2024 (153)	Serious	Low	Low	Low	Low	Low	Low	Serious risk. Lack of a control group and residual confounding leads to serious bias risk despite strong design and implementation
Schmitz T et al, 2022 (154)	Serious	Low	Low	Low	Low	Low	Low	Serious risk of bias from confounding due to contextual differences in epidemiology, health-seeking behaviour and health system factors. Potentially, Hawthorne effect may also have influenced outcomes
Bernasconi et al, 2019 (150)	Serious	Low	Moderate	Low	Moderate	Moderate	Low	Serious risk. Lack of confounder adjustment in pre-post design leads to serious overall bias risk
Mekuria et al, 2019 (148)	Serious	Low	Moderate	Low	Moderate	Moderate	Low	Serious risk due to limited causal control
Bernasconi et al, 2018 (151)	Serious	Low	Moderate	Low	Low	Moderate	Low	Serious risk. Confounding from secular trends and population differences across survey rounds limits causal inference
Shao et al, 2015 (155)	Serious	Moderate	Low	Low	Low	Moderate	Low	Serious risk. Lack of randomization and potential facility-level confounding result in serious overall risk of bias

Appendix 4.2: Risk of Bias Assessment for non-randomised controlled trials included in the systematic review using the ROBINS-1 V2 tool. Each study was assessed based on 7 domains. 1) Risk of bias due to confounding 2) Risk of bias in classification of interventions 3) Risk of bias in selection of participants into the study (or into the analysis) 4) Risk of bias due to deviations from intended interventions 5) Risk of bias due to missing data 6) Risk of bias arising from measurement of the outcome 7) Risk of bias in selection of the reported result. Response options for the questions included Not Applicable/ Yes/ Probably Yes/ No/Probably No/ No Information. The risk of bias judgement in each domain were then assigned Low, Moderate, Serious or Critical. A majority of 'Low' responses overall besides in Domain 1 indicate a positive methodological approach avoiding pitfalls for bias, whereas at least one domain with 'Moderate', 'Serious' or 'Critical' suggests increased susceptibility to bias.

Author/ Year	1	2	3	4	5	6	7	8	9	10	Appraisal Summary
Qualitative Studies (n= 8)											
Jones et al, 2025 [156]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Positive. Methodologically sound and ethically robust. The study offers valuable contextual insights, though deeper reflexivity on researcher-participant dynamics would strengthen it. Overall, it informs culturally grounded AMS interventions
Peiffer-Smadja et al, 2024 [157]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Positive. Well-aligned methodology, sampling and analysis. Limited reflexivity but overall offers valuable insights for AI implementation in clinical practice
Ellington et al, 2021 [159]	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Yes	Positive. Methodologically strong across most criteria with minor limitation in reflexivity reporting
Peiffer-Smadja et al, 2020 [162]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Strong methodology with clear focus on CDSS acceptability. Minor limitation in reflexivity reporting
Bessat et al, 2019 [160]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Positive. Methodologically sound with robust qualitative methods. A minor limitation is the limited reporting on researcher reflexivity
Mekuria et al, 2019 [148]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Positive. High-quality qualitative component offering valuable context for digital health implementation in low-resource settings
Shao et al, 2015 [158]	Yes	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Positive. Strong methodological quality with minor reflexivity limitations. Offers valuable insights into health worker views on mobile decision support tools
Mitchell et al, 2012 [161]	Yes	Yes	Yes	Can't tell	Yes	No	Can't tell	Can't tell	Yes	Yes	Positive. Clear aims, suitable qualitative methods and well-presented findings. Minor gaps in reflexivity, ethics and analysis detail but overall valuable and reliable for digital health implementation

Appendix 4.3: Risk of Bias Assessment for qualitative studies included in the systematic review using the CASP checklist. Each study was assessed based on 10 questions. 1) Was there a clear statement of the aims of the research? 2) Is a qualitative methodology appropriate? 3) Was the research design appropriate to address the aims of the research? 4) Was the recruitment strategy appropriate to the aims of the research? 5) Was the data collected in a way that addressed the research issue? 6) Has the relationship between researcher and participants been adequately considered? 7) Have ethical issues been taken into consideration? 8) Was the data analysis sufficiently rigorous? 9) Is there a clear statement of findings? 10) How valuable is the research? Response options for the questions included Yes, No and Can't Tell. A majority of 'Yes' responses overall indicate a positive methodological approach avoiding pitfalls for bias, whereas 'No' or 'Can't Tell' suggests increased susceptibility to bias.

Appendix 5: Data Extraction Table Full Version

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
Patient + Provider Studies (n=1)									
Mekuria et al, 2019 (148)	Kenya	Explanatory sequential mixed-methods study	Private not-for-profit outreach clinics in urban Nairobi slums	21,913 patients with 36,210 clinic visits from April–Dec 2016	Acute respiratory infections (ARIs)	M-TIBA mobile phone-based digital healthcare data and payment exchange platform	Standard non-digital antibiotic prescribing practices and national guidelines	Antibiotic use for ARI diagnoses, types prescribed and clinician/patient attitudes and reasons for overprescription	78.5% of ARIs treated with antibiotics, mainly Amoxicillin (45%)
Provider Studies (n=21)									
Langet et al, 2025 (149)	Kenya, Senegal	Quasi-experimental pre-post study	Primary healthcare facilities in Kakamega, Kitui and Uasin Gishu counties in Kenya and in five health districts of the Thiès region in Senegal	50,580 sick children aged 0–59 months	Acute childhood illnesses (including respiratory illnesses and sepsis)	Implementation of pulse oximetry and Clinical Decision Support Algorithms (CDSAs)	Pre-intervention vs post-intervention groups	Urgent referrals, antibiotic prescription rates, SpO_2 levels, referral completion, hospital admissions, caregiver-reported recovery and severe complications	Antibiotic prescriptions dropped by 14.6% (1–59 days) and 22.6% (2–59 months) post-intervention in the post-intervention period
Hürlimann et al, 2024 (152)	Somalia	Pre-post observational study	Seven health facilities in South-Central Somalia	1250 children aged 2–59 months	Childhood illnesses including URTI, diarrhoea, parasitosis, anaemia	ALMANACH - IMCI-based digital clinical decision support system	Pre-implementation routine care without ALMANACH	Reduced antibiotic prescriptions including less inappropriate URTI use and improved IMCI adherence	Antibiotic prescriptions fell from 58.1% to 16.0%, inappropriate URTI use dropped 30-fold, and danger sign checks rose from 1.3% to 99%
Tan et al, 2024 (147)	Tanzania	Cross-sectional cluster RCT	Rural and semiurban primary	450 children aged 2–59 months (225 in	General childhood illnesses	ePOCT+ digital clinical decision support	Usual care (without CDSA)	Mean assessment of 14 key IMCI signs, antibiotic prescription	Primary outcome improved (46.4% vs 26.3%, adj. diff.

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
			healthcare facilities in Mbeya and Morogoro regions	intervention and 225 in control)	assessed using the IMCI guidelines	algorithm + point-of-care tests (CRP, haemoglobin, pulse oximetry) + training + mentorship		rate, appropriateness of antibiotic use and quality of counselling and history-taking	15.1%, p=0.007); antibiotic use dropped (37.3% vs 76.4%, aRR 0.5, p<0.001) and appropriate prescribing rose (81.9% vs 51.4%, aRR 1.5, p=0.003)
Peiffer-Smadja et al, 2024 (157)	Senegal, Ivory Coast, Burkina Faso, Mali, Gabon	Qualitative implementation research (semi structured interviews)	Hospital-based and community healthcare settings	21 physicians, microbiologists, project managers, AMR experts, technical coordinators and an anthropologist	Antimicrobial resistance and prescribing practices	Antibioclic Afrique – CDSS for antimicrobial prescribing	None (pre-implementation exploratory study)	Identified CDSS implementation barriers and facilitators	Barriers included inconsistent prescribing training, workflow resistance, OTC access and absent guidelines. Facilitators were physician targeting, partnerships, training and academic channels
Tan et al, 2023 (139)	Tanzania	Cluster RCT	Rural and semiurban primary healthcare facilities in Mbeya and Morogoro regions	44,306 children aged 0–14 years	General febrile and acute paediatric illnesses	ePOCT digital clinical decision support algorithm with integrated point-of-care tests (CRP, haemoglobin, pulse oximetry), training and mentorship	Usual care (no CDSA)	Antibiotic prescription at first visit, clinical failure by day 7, death, reattendance, hospitalization, referrals and follow-up medications	Antibiotic use dropped (23.2% vs 70.1%, aRR 0.35); no difference in clinical failure (3.7% vs 3.8%), death, or hospitalization; unplanned reattendance slightly reduced
Schmitz T et al, 2022 (154)	Nigeria	Observational study (quasi-experimental, non-randomized controlled)	Primary health care facilities in rural Adamawa	1929 children aged 2–59 months	Common childhood illnesses (including pneumonia,	ALMANACH digital clinical decision support system	Standard care (no ALMANACH)	Caregiver-reported day 7 recovery, prescription rates (oral/parenteral), referrals, diagnosis and	Day 7 recovery was higher (85.4% vs 71.4%), with more referrals, better diagnosis

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
			State, North-Eastern Nigeria		diarrhoea, malaria, anaemia, malnutrition)			follow-up communication	communication and follow-up advice. Parenteral antibiotic use increased while oral antibiotic rates were similar (30.0% vs 34.0%)
Ellington et al, 2021 [159]	Uganda	Exploratory qualitative study (semi structured interviews)	Primary health centres (rural and peri-urban) in Jinja District	28 health workers, 3 administrators	Paediatric acute lower respiratory infections (ALRI)	Acute Lower Respiratory Illness Treatment and Evaluation (ALRITE) mHealth tool	Usual practice	Perceived acceptability, usability, feasibility, impact on decision-making and patient interaction and implementation barriers	ALRITE was found usable and helpful for support and training, with barriers like limited device access, stockouts, and provider–patient dynamics
Peiffer-Smadja et al, 2020 [162]	Burkina Faso, Togo, Senegal, Mali, Gabon, Guinea, Guinea-Bissau, Ivory Coast, Niger	Qualitative pre-implementation study	Primary care healthcare workers in West Africa	47 healthcare professionals (mainly from Burkina Faso)	37 infectious disease	Workshop introducing CDSS (Antibioclic) with questionnaire and roundtable discussion	No formal comparator, exploratory analysis of perceptions	Identification of CDSS implementation barriers and facilitators and perceptions of its impact on prescribing, knowledge and AMR surveillance	100% of participants believed CDSS would improve prescribing quality and guideline adherence; 91–94% saw benefits for patient care, error reduction and AMR control while 81% felt it would save consultation time
Tan et al, 2020 [144]	Tanzania	Post hoc subgroup analysis from RCT	Public outpatient primary care clinics in Dar es Salaam	106 febrile children aged 2–59 months	Severe malnutrition with acute febrile illness	ePOCT clinical decision algorithm using anthropometric measures (weight-for-age, MUAC)	ALMANACH algorithm using clinical signs (visible wasting, bipedal edema)	Clinical failure by Day 7, antibiotic prescription, hospital referral and admission, severe adverse events	Clinical failure was lower with ePOCT (1.8%) than ALMANACH (16.7%; RR 0.11, 95% CI 0.01–0.83); ePOCT had higher Day 0

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
									antibiotic use (98.2% vs 47.9%) and referral rates (98.2% vs 14.6%)
Bernasconi et al, 2019 (150)	Nigeria	Implementation research (pre-post comparison using two cross-sectional surveys)	6 primary Health Care Centres (PHCCs) in Adamawa State, a post-conflict region	424 consultations of children aged 2–59 months	Common childhood illnesses: malaria, URTI, pneumonia, acute watery diarrhoea, typhoid fever	ALMANACH: electronic CDSS based on IMCI	Baseline (pre-implementation) data from the same PHCCs	Improvements in quality of care including danger sign screening, correct diagnosis and treatment, appropriate antibiotic use	Improved danger sign screening (60% vs 37.1%), rise in correct treatment (29.5% to 48.4%) and antibiotic use dropped (77.7% to 69.8%). Nearly all caregivers (99.2%) found digital consultations more thorough
Keitel et al, 2019 (145)	Tanzania	Randomized controlled noninferiority trial (subgroup analysis)	Urban public outpatient clinics in Dar es Salaam	1726 children aged 2–59 months	Acute respiratory infections (suspected pneumonia)	CRP-informed strategy using ePOCT algorithm (CRP ≥80 mg/L plus clinical features)	WHO standard using respiratory rate ≥50 breaths/minute (ALMANACH algorithm)	Clinical failure by day 7 and antibiotic prescription at day 0, secondary hospitalization, death by day 30	Clinical failure was lower in the intervention group (2.9% vs 4.8%) by day 7; Day 0 antibiotic use was significantly reduced (2.3% vs 40.4%; RR 0.06, 95% CI: 0.04–0.09), and severe adverse events by Day 30 were fewer (0.5% vs 1.5%)
Bessat et al, 2019 (160)	Burkina Faso	Qualitative study (in-depth interviews and focus group discussions)	Primary healthcare facilities (CSPS) in rural Yako and Toma districts	21 primary healthcare workers	Childhood illnesses and antibiotic resistance	Electronic Integrated Management of Childhood Illness (eIMCI) via the REC tool	Paper-based IMCI consultations	Health workers' views on tool usability and antibiotic impact in addition to system changes, AMR knowledge, and training feedback	eIMCI was highly accepted and viewed as useful for managing antibiotic use. AMR/AMS were addressed, though knowledge gaps

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
									remained among lower-trained staff
Steinhardt et al, 2019 (143)	Malawi	Cluster RCT	105 outpatient health facilities in seven districts of southern Malawi	2360 patients (including children <5 years)	Malaria, pneumonia and diarrhoea	Text message reminders to health workers on malaria case management (arm 1) or on malaria, pneumonia and diarrhoea (arm 2)	Control arm with no messages (arm 3)	Correct management of uncomplicated malaria, including testing, treatment and counselling. Also covers appropriate care for pneumonia and diarrhoea including antibiotic use and health worker knowledge and practices	Correct malaria management improved in all arms but differences were not statistically significant. Antibiotic use for pneumonia in children rose overall but dropped slightly in Arm 2 (effect size −4.1%). Patient dosing knowledge significantly improved in Arm 2 (DiD +18.2%, p=0.012)
Bernasconi et al, 2018 (151)	Afghanistan	Pre-post implementation study	3 primary health centres (urban and rural) in Kabul province	Children aged 2–59 months (n=8047 during implementation; n=599 baseline)	Childhood illnesses (including URTI, pneumonia, diarrhoea, malnutrition, GAS pharyngitis)	ALMANACH – a tablet-based digital CDSS integrating IMCI guidelines	Paper-based IMCI guidelines	Antibiotic prescription rate, quality of diagnosis and treatment adherence to guidelines	Antibiotic prescription dropped from 63.9% to 21.8% (p<0.01), malnutrition screening increased from 1.8% to 4.4%, deworming increased from 7.5% to 50.2%, Wrong antibiotic use reduced by >50%
O'Donovan et al, 2018 (140)	Uganda	Pilot randomised controlled trial	3 sub-counties in Mukono	129 Community Health Workers (CHWs)	Pneumonia in children under 5	Tablet-based training using locally made	Traditional one-day in-person training session	Change in knowledge acquisition (MCQ test scores) and clinical	Both groups had improved in test scores post-

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
			District (Mpatta, Nakisunga, Mpunge)			educational videos on pneumonia		assessment performance. CHW feedback and satisfaction with tablet-based training	training, but the difference wasn't significant (t = 1.15, p = 0.254). In the control group, more years of education correlated with greater improvement (r = 0.26, p = 0.03). Most CHWs found tablets useful for training, though some faced technical issues (n = 9)
Rambaud-Althaus et, 2017 (141)	Tanzania	Pilot cluster-randomized implementation study	9 urban primary healthcare facilities in Dar es Salaam	504 children aged 2–59 months	Common childhood illnesses including pneumonia, diarrhoea, malaria, UTI, viral infections	Use of ALMANACH clinical decision support tool	Routine standard practice (no ALMANACH)	Assessment completeness, antibiotic prescribing, classification accuracy, treatment appropriateness and danger sign recognition	Danger sign checks: 74% (electronic) vs 41% (paper) vs 3% (control); antibiotic prescriptions: 25%, 26%, 70% respectively. Appropriate management: 63% (electronic), 62% (paper), 37% (control). Electronic arm improved assessment and viral diagnosis (aRR 2.2, p=0.001)

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
Keitel et al, 2017 [146]	Tanzania	Randomized controlled non-inferiority trial	9 outpatient clinics in Dar es Salaam	3192 children aged 2–59 months	Febrile illnesses including respiratory infections, malaria, etc	e-POCT algorithm using host biomarker POCTs (CRP, PCT, Hb, oximetry, glucometer, mRDT)	ALMANACH electronic algorithm (IMCI-derived)	Clinical failure by day 7, antibiotic prescription on day 0, primary referrals, severe adverse events by day 30 (hospitalizations/deaths)	e-POCT reduced clinical failure (2.3% vs 4.1%, RR 0.57), severe adverse events (0.6% vs 1.5%, RR 0.42), and antibiotic use (11.5% vs 29.7%, RR 0.39) compared to ALMANACH. Versus routine care, e-POCT cut clinical failure by 49% and antibiotic use from 94.9% to 11.5%
Shao et al, 2015 [155]	Tanzania	Controlled non-inferiority interventional study	4 health facilities in Dar es Salaam	1467 children aged 2-59 months	Common childhood illnesses (including pneumonia, malaria, diarrhoea)	ALMANACH mobile decision support algorithm implemented on smartphones	Standard Integrated Management of Childhood Illness (IMCI) paper guidelines	Proportion of clinical cure at day 7 and 14. Antibiotic prescription rate, re-consultation rate, danger sign identification	Clinical cure in ALMANACH group was 97.3% vs 92.0% in control (non-inferior); antibiotic prescription reduced by ~50% with ALMANACH. 130/842 (15.4%) in ALMANACH and 241/623 (38.7%) in control arm were diagnosed with an infection in need for antibiotic
Shao et al, 2015 [158]	Tanzania	Qualitative study (in-depth interviews and	6 public primary health	Primary health workers (n=40. 24 in-depth	Childhood illnesses (including	ALMANACH algorithm implemented via	Routine practice (no structured electronic	Health worker perceptions of uptake and usability of	Health workers found ALMANACH on

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
		focus group discussions)	facilities in Dar es Salaam	interviews, 16 focus group participants)	respiratory infections, diarrhoea, malaria)	smartphones and tablets	clinical decision support)	ALMANACH via mobile devices. Perceived effects on antibiotic prescribing, diagnostic accuracy, workflow, trust, technical usability and health system barriers	mobile devices useful for diagnosis and reducing unnecessary antibiotics. Barriers included longer consultations, staff shortages, dual documentation, and limited incentives. Devices were accepted by patients, but uptake was constrained by systemic issues
Perri-Moore et al, 2015 (142)	Tanzania	Cluster-randomized controlled trial	6 government clinics in Dar es Salaam	41 providers and 172 caretakers (eIMCI); 25 providers and 180 caretakers (pIMCI) of children aged 2–59 months	Childhood illnesses (including malaria, pneumonia, diarrhoea) under IMCI protocol	Electronic IMCI-derived decision support protocol with embedded counselling messages and summary screen	Paper-based IMCI protocol	Provider explanation and caregiver recall of key treatment and follow-up details, including illness understanding, medication use and return visit instructions	eIMCI improved provider communication (98.8% vs. 77.8%) and caretaker recall of condition and return instructions (22.9% vs. 50%) but not recall of medication frequency or duration
Mitchell et al, 2012 (161)	Tanzania	Qualitative pilot study nested within a quantitative implementation study	4 districts in the Pwani Region, including Bagamoyo, Morogoro Town,	11 health care providers and 20 caretakers at 12 Ministry of Health centres	Childhood illnesses (including malaria, pneumonia, diarrhoea)	Electronic IMCI (eIMCI) via handheld PDAs	Paper-based IMCI protocol	Perceived improvement in clinical workflow and adherence to IMCI. Caretaker satisfaction, perceived provider competence,	Providers and caregivers viewed eIMCI positively; providers found it faster, easier and helpful for IMCI adherence, while

Author, Year	Country	Study Type	Settings	Population	Disease	Intervention	Comparison	Outcomes Studied	Findings
			Mkuranga and Morogoro Rural		under IMCI protocol			thoroughness of examination	caregivers noted better service, thorough examination of their child and more knowledgeable providers
Policymaker Studies (n=2)									
Jones et al, 2025 [156]	Nepal	Participatory Research (Qualitative Case Study Evaluation)	1 urban and 1 peri-urban community in Bhaktapur and Chandragiri municipalities	20 community members (diverse demographic representation) with no prior AMR knowledge or video experience	Antimicrobial resistance (AMR)	Participatory video (PV) production workshops with AMR education and community showcasing events	No formal control group – qualitative evaluation of perceptions pre- and post-intervention	Community engagement, knowledge-sharing, empowerment and advocacy reach in addressing AMR in addition to policymaker attitudes	PV empowered communities to advocate against AMR while policymakers found the videos effective for AMR education, highlighting PV's potential as a grassroots AMS tool in LMICs
Sawant et al, 2024 [153]	India	Cross-sectional descriptive study	Rural households in two blocks (Junnar – tribal/distant, and Mulshi – rural/urban-adjacent) in Pune District	443 rural households	Not disease-specific – focuses on predictors of over the counter (OTC) antibiotic use	Machine Learning algorithms (stepwise logistic, lasso, random forest, XGBoost and Boruta)	Not applicable (no formal control group; predictive modelling framework)	XGBoost+Boruta with 7 predictors was the top model for predicting OTC antibiotic use, identifying key factors like perceived usefulness, eye-related use, high dose and long duration	OTC antibiotic use prevalence: 35.9% (95% CI: 31.6–40.5). XGBTree+Boruta with AUROC: 0.934 (95% CI: 0.891–0.978), log-loss: 0.279