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Original research

United Nations AMR action: development and early validation of a real-time, dual-phase antimicrobial stewardship dashboard for full-pathway monitoring of empirical and subsequent antibiotic therapy

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► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjinnov-2025-001501).

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Received 12 November 2025
Accepted 24 August 2026

Check for updates

To cite: Abdelsalam Elshenawy R, Umaru N, Aslanpour Z. *BMJ Innov* Epub ahead of print: [please include Day Month Year]. doi:10.1136/bmjinnov-2025-001501

ABSTRACT

Background Antimicrobial resistance (AMR) is a major global health challenge, which caused an estimated 1.27 million deaths in 2019 and is projected to contribute to 10 million deaths annually by 2050. Strengthening antimicrobial stewardship (AMS) is critical to addressing this threat. However, stewardship monitoring systems remain fragmented and retrospective, limiting timely action. The COVID-19 pandemic further exposed these limitations, highlighting the need for innovative, accessible and real-time solutions to improve stewardship and patient safety.

Methods A four-phase methodology was employed. Phase 1 comprised a systematic review of antimicrobial stewardship (AMS) strategies before and during the COVID-19 pandemic. Phase 2 involved retrospective analysis of 640 patient records, while Phase 3 surveyed 240 healthcare professionals regarding AMS knowledge, attitudes and practices. Phase 4 focused on user-centred dashboard development. Validation incorporated technical testing, expert review, and patient and public involvement to assess accuracy, usability, and feasibility.

Results The dashboard enables dual-phase monitoring of empirical prescribing and subsequent antibiotic therapy across the antimicrobial pathway. Features include real-time visualisation, interactive filtering by temporal, spatial and clinical variables, and ward-level monitoring to support quality improvement. Early validation combined technical accuracy testing and expert feedback. High concordance was demonstrated between source data and dashboard outputs, with responsive performance under simulated load. Reviewers rated the dashboard favourably for usability, clinical relevance, feasibility, and operational resilience.

Conclusions This innovative AMS dashboard shifts stewardship from retrospective audit to proactive decision support. Its low-infrastructure dual-phase design offers sustainability within the NHS and scalability across healthcare

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Antimicrobial resistance is a major United Nations global health priority. Current antimicrobial stewardship monitoring systems remain fragmented, retrospective and insufficiently integrated with real-time clinical decision-making.

WHAT THIS STUDY ADDS

⇒ This study demonstrates the development and early validation of an innovative, real-time, dual-phase antimicrobial stewardship dashboard that integrates empirical prescribing and subsequent antibiotic therapy across the full antimicrobial pathway.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The dashboard provides a rigorous, scalable and low-cost model for ward-level stewardship monitoring, supporting proactive clinical decision-making, quality improvement, future policy implementation and the United Nations AMR action agenda across diverse healthcare settings.

settings, supporting global AMR action and the achievement of sustainable development (SDG) goals.

INTRODUCTION

The United Nations has identified antimicrobial resistance (AMR) as a global health emergency, threatening progress towards the sustainable development goals (SDGs). Globally, bacterial AMR directly caused 1.27 million deaths in 2019 and contributed to an additional 4.95 million deaths, a combined mortality burden comparable to HIV/AIDS and malaria. This escalating threat underscores the urgent need for innovative, sustainable and globally coordinated antimicrobial stewardship (AMS) strategies.[1–3]

In the UK, antimicrobial stewardship (AMS) is supported by the UK Health Security Agency's Start Smart, Then Focus (SSTF) framework in secondary (hospital) care and the TARGET toolkit in primary care.[4] Despite these initiatives, AMR caused over 67,000 infections and 2,200 deaths in 2023,[5] with up to 10 million deaths projected annually by 2050,[6] jeopardising essential interventions including surgery, cancer treatment and transplantation.[7,8] Pre-pandemic, multidisciplinary AMS teams achieved antibiotic discontinuation in 47% of cases and de-escalation in 37%.[9] However, COVID-19 interrupted reviews (81%), audits (70%) and IV-to-oral switches (67%),[10] exposing the need for resilient and scalable systems.[4,11]

As Deming stated, "You cannot manage what you cannot measure," emphasising the importance of quantifying stewardship activities.[12] While metrics like defined daily doses (DDD), days of therapy (DOT) and length of stay (LOS) are commonly used, their value emerges when consolidated into visual tools displaying data at institutional levels.[9,13] Digital dashboards offer visual representations of prescribing patterns and guideline adherence, yet current tools remain fragmented and insufficiently integrated across the full stewardship cycle.[14,15]

Existing surveillance systems operate at various scales: the ECDC Antimicrobial Consumption Dashboard enables cross-country comparisons,[16] ESPAUR monitors national trends[17] and WHO GLASS standardises global data collection.[18] However, hospital-level dashboards often remain retrospective and fragmented, lacking real-time clinical decision support integration.

Clinical decision support systems (CDSS) offer transformative potential by combining patient-specific information with evidence-based guidelines to generate real-time recommendations.[19] CDSS interventions consistently demonstrate reduced antibiotic use, narrower-spectrum prescribing and improved guideline adherence.[19] The pandemic further emphasised the need for resilient digital solutions, as virtual innovations enabled stewardship continuity despite system disruptions.[20,21]

To address these gaps, we developed and validated an innovative real-time AMS dashboard aligned with the UKHSA SSTF framework. Designed for sustainability within the NHS, the dashboard advances stewardship from retrospective auditing to proactive clinical decision support.[22] Its accessible architecture makes it scalable as a global model for AMR action.

METHODS

Study design and setting

A systematic four-phase development methodology was employed, informed by sequential empirical and observational studies conducted between 2019 and 2024 across two hospitals within an NHS Foundation Trust in the East of England. The aim was to design, implement and validate a dynamic AMS dashboard aligned with the SSTF framework. Development combined evidence synthesis, retrospective record review, stakeholder engagement, user-centred design, technical development and structured validation. Reporting followed SQUIRE 2.0 (quality improvement) and STROBE, with the RECORD extension for routinely collected data. Ethical approval: HRA (22/EM/0161) and University of Hertfordshire (LMS/PGR/NHS/02975); registered on ISRCTN (14825813).[23]

Foundational evidence base

Three complementary studies formed the foundation for the dashboard's design.

Study 1: systematic literature review

A systematic review explored AMS strategies and monitoring tools in acute care before and during the COVID-19 pandemic. Searches across nine databases identified 8763 articles, of which 13 studies met eligibility criteria. The review extracted information on AMS structures, processes, outcome measures and adherence to SSTF principles. Core strategies such as prospective audit and feedback, multidisciplinary AMS teams and quality indicator reporting were commonly described, yet significant gaps in visualisation and ward-level monitoring were evident. This study established the theoretical requirements and benchmarks for dashboard content.[9]

Study 2: retrospective cross-sectional record review

A chart-based analysis examined 640 medical records from adult inpatients with respiratory tract infections admitted in 2019 (pre-pandemic) and 2020 (pandemic). A validated data-extraction tool structured around SSTF principles was used to evaluate empirical prescribing, review timing, therapy appropriateness, AMS interventions and patient outcomes across eight decision points. This analysis provided empirical evidence of real-world stewardship performance, with antibiotic discontinuation and

Figure 1 Four-phase development framework for the antimicrobial stewardship dashboard. The dashboard was developed through a systematic four-phase methodology comprising: (1) evidence synthesis and gap analysis informed by a systematic review, retrospective record review, and healthcare professional survey; (2) user-centred design and stakeholder engagement; (3) technical development and dashboard construction and (4) content development, clinical integration and validation. The framework was designed to support real-time monitoring of empirical and subsequent antibiotic therapy across the antimicrobial stewardship pathway.

de-escalation rates of 47% and 37%, respectively, in pre-pandemic periods, and substantial disruption observed during COVID-19.[4 24]

Study 3: cross-sectional healthcare professionals survey

A descriptive survey of 240 doctors, nurses and pharmacists across two hospitals within the same NHS Foundation Trust examined knowledge, attitudes and perceptions of antimicrobial stewardship during and after the COVID-19 pandemic. The instrument was pilot-tested, demonstrated good internal consistency (Cronbach's α=0.80), and achieved the calculated sample size for a 5% margin of error at 95% confidence. The survey captured perspectives on prescribing challenges, barriers to review compliance and preferences for digital solutions, all of which informed user-centred design.[25]

The evidence synthesis informed the development of a dual-phase antimicrobial stewardship intelligence dashboard, enabling real-time monitoring of the initiation of empirical antibiotic therapy and its subsequent optimisation. The framework translates research into a scalable digital solution supporting quality improvement, stewardship governance and healthcare system impact.[9 11 25]

Phase 1: evidence synthesis and gap analysis

Foundational findings were integrated through a structured gap analysis. The systematic review showed that existing dashboards prioritised antibiotic consumption metrics over prescribing decisions.[9] The record review identified key SSTF monitoring indicators, demographics, diagnosis, appropriateness of initial therapy, review timing, and intervention outcomes,[4 11]

Table 1 Early validation of dashboard performance and usability

Validation domain	Method	Result
Data accuracy	Source-to-dashboard concordance across tested variables	Source-to-dashboard validation demonstrated high concordance, with dashboard outputs matching the source dataset across all 42 tested variables.
Responsiveness	Filtering/loading time across simulated datasets	0.4–0.8 s median response time across 8 simulated datasets
Usability	System usability expert panel	Assessed through structured expert review (n=7); across 3 review cycles, feedback informed iterative refinement
Clinical relevance	Expert panel feedback	Assessed through multidisciplinary expert review (n=7)
Feasibility	Expert panel feedback	Considered feasible by expert reviewers
Iterative refinement	Changes implemented after feedback	Dashboard refined following feedback from 7 reviewers across 3 review cycles

while the healthcare-professional survey highlighted time constraints, communication gaps and demand for digital decision support.[25] Benchmarking against ESAC-Net, ESPAUR and WHO GLASS confirmed that these provide valuable population-level surveillance but lacked ward-level decision support.[4 16–18] Together, these findings shaped a dual-phase dashboard spanning admission to discharge.

Phase 2: User-centred design

Stakeholder mapping identified three user tiers: primary (clinical pharmacists, infectious disease specialists, microbiologists), secondary (ward doctors, nurses) and tertiary (administrators, quality improvement teams).[26] Structured interviews across the East of England explored existing monitoring approaches, their limitations, and desired functionality, and user-journey mapping traced the antibiotic pathway to identify intervention points.[27] Design was informed by the Technology Acceptance Model (TAM), emphasising perceived usefulness and ease of use,[28 29] minimising cognitive load, prioritising key decision points and supporting accessibility. Iterative prototyping with clinical-stakeholder feedback refined layouts, filtering, and visualisations; supplementary materials provide demonstration versions and technical documentation.

Phase 3: Technical development

Following evaluation of NHS operational requirements, Microsoft Excel was selected to maximise accessibility, scalability, and implementation potential, leveraging existing infrastructure for rapid translation from research to practice without additional software investment.[30] Interactive functionality used advanced PivotTable and PivotChart features, supporting real-time analysis of temporal, ward-level, and clinical stewardship metrics, with optimised formulas and streamlined data structures maintaining responsiveness.[31] Data integration used the validated extraction tool from Study 2 for standardised capture across medical records, laboratory, and pharmacy systems, with validation ensuring accuracy and consistency.[11] The dashboard was built from variables captured by this tool, spanning patient demographics, clinical characteristics, investigations, prescribing, stewardship review, SSTF compliance and outcomes (online supplemental table 1).

Phase 4: Content development and clinical integration

Metric selection was evidence-based, combining insights from the literature with empirical analysis of the 640-patient dataset. Core indicators spanned process measures (review timing and intervention frequency), outcome measures (appropriateness of therapy and length of stay) and balancing measures (safety indicators, such as allergy documentation).[11] Indicators used defined daily dose and days-of-therapy methods where appropriate, supplemented by local quality-improvement metrics, and aligned with national and global stewardship points: empirical initiation, 48–72-hour review, microbiology-guided changes, de-escalation and discharge.[4 11] Threshold-based alerts flag overdue reviews or prolonged broad-spectrum therapy while avoiding alert fatigue, supporting ward-level improvement and benchmarking (figure 1).

Validation methodology

Robust technical validation assessed dashboard responsiveness, stability, and data accuracy. Load testing simulated concurrent users and large dataset sizes. Data outputs were systematically compared with source data to confirm calculation fidelity, demonstrating high concordance across all 42 tested variables. Functionality tests verified filtering, exporting and cross-version compatibility across Excel platforms. A structured panel of seven AMS experts, including antimicrobial pharmacists, microbiologists and quality improvement leads, evaluated the dashboard. Criteria included clinical relevance, usability, accuracy and feasibility of implementation. Mixed-

method feedback combined Likert-scale ratings with qualitative comments, enabling iterative refinements across three sequential review cycles (three experts in the first cycle, three in the second and two in the third). The process ensured alignment with evidence-based requirements while maintaining clinical utility (table 1).

Ethical considerations

All studies were conducted under appropriate ethical approvals (REC reference 22/EM/0161; UH LMS/PGR/NHS/02975).[23] Data from retrospective record review were anonymised prior to analysis. Survey participation was voluntary, with informed consent obtained from all respondents. No patient-identifiable data were included in the dashboard prototype.

Public and patient involvement (PPI) was integral to the design process. The East of England Citizens' Senate, with substantial representation from older adults and individuals with lived healthcare experience, reviewed the protocol, advised on the acceptability of data-collection approaches and provided feedback on dashboard usability. Their input strengthened both methodological rigour and patient-centredness.

RESULTS

Dashboard architecture and core functionality

The dashboard is structured around the antimicrobial prescribing pathway, spanning empirical and subsequent therapy. A dual-phase, real-time monitoring architecture supports stewardship across the continuum of care, with interactive analytics enabling temporal, ward-level and patient-level exploration, stratified by diagnosis, demographics, microbiology and antibiotic class. Built on dynamic Excel-based pivot tables, it allows drill-down from hospital-wide to ward-specific indicators for targeted interventions, while export functions provide standardised outputs compatible with NHS reporting and external benchmarking. Data integration accommodates electronic health records, laboratory and pharmacy systems, with built-in validation protocols that ensure data integrity and support multi-ward scalability. Online supplemental figure 1 presents the dual-stage stewardship pathway and dashboard framework spanning the empirical and subsequent therapy stages.

Stage 1 — Empirical (Initial) antibiotic therapy

The empirical therapy module visualises admission-phase metrics from the 640-patient dataset: age distribution (predominantly 66–85 years), gender, comorbidity and allergy patterns. Primary diagnoses show respiratory infections, with community-acquired pneumonia predominant (40%), alongside hospital-acquired and ventilator-associated pneumonia and COPD. Prescribing analysis displays the five most frequent empirical antibiotics, monitoring broad versus narrow spectrum use, while intervention tracking captures continue, switch, de-escalation and escalation decisions. Review-timing visualisation shows 48–72-hour compliance (47%) and professional-responsibility tracking identifies reviewers: microbiologists (37%), physicians (31%), pharmacists (19%) and AMS teams (13%) (figure 2).

Stage 2 — Subsequent / second-course antibiotic therapy

The subsequent therapy module supports culture-guided decision-making throughout hospitalisation, with temporal and ward-level filtering to target interventions. Real-time microbiological surveillance identifies prevalent isolates and emerging resistance, addressing recognised gaps in local awareness of resistance. Review-timing visualisation flags delays in reassessment, while intervention tracking captures

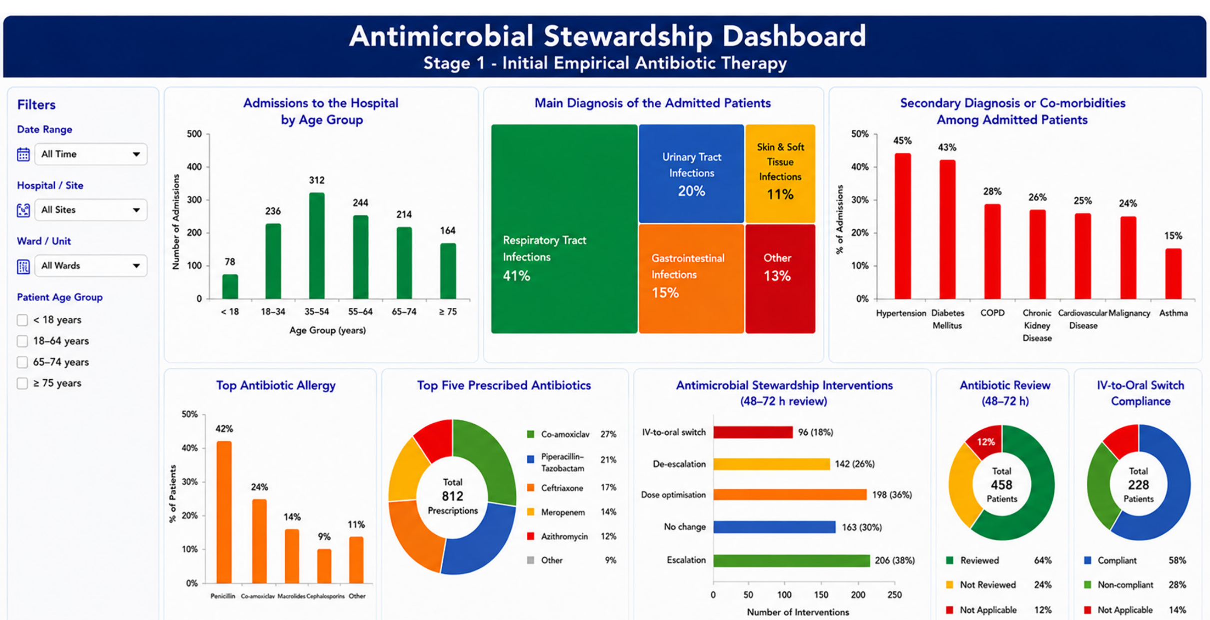

Figure 2 Real-time empirical antibiotic therapy dashboard (Stage 1). The dashboard visualises empirical prescribing activity, patient demographics, diagnoses, antibiotic selection, stewardship interventions, 48–72-hour review compliance and professional responsibility for antimicrobial review, supporting ward-level monitoring and quality improvement. COPE, chronic obstructive pulmonary disease; IV, intravenous.

optimisation actions, including continuation and intravenous-to-oral switches, supporting timely de-escalation. The discharge module monitors oral antibiotics, prescribing responsibilities and stewardship decisions (discontinuation, de-escalation, escalation, continuation and switch), while length-of-stay analysis explores associations between interventions and outcomes to optimise discharge prescribing (figure 3).

DISCUSSION

This study developed a real-time AMS dashboard that addresses the limitations of existing monitoring systems by using dual-phase surveillance aligned with the SSTF framework.[4] The dashboard demonstrated strong technical performance and underwent structured validation by a panel of seven experts (antimicrobial pharmacists, microbiologists and quality-improvement leads) across three review cycles. Findings indicate the dashboard is clinically relevant, usable and feasible for implementation.[32–34] Formal assessment using validated instruments such as TAM was beyond the scope of this prototype and will be incorporated into future multi-site evaluations of usability and user acceptance.

The design was grounded in an evidence base comprising a systematic literature review, retrospective chart review of 640 patients and a pharmacist survey.[10 11] These foundational studies collectively revealed critical gaps in current stewardship practices and monitoring mechanisms, particularly around visualising prescribing behaviour in real time. While national systems such as ESPAUR, ECDC's ESAC-Net and WHO GLASS have made valuable contributions to surveillance, they remain limited to consumption data or aggregate resistance trends and do not address clinical decision points at ward level.[16–19] In response, this study sought to reframe stewardship monitoring as a proactive, patient-centred process rather than a retrospective audit exercise.

Added value of the dual-phase approach

Building on established population-level surveillance systems, this dashboard integrates the complete stewardship pathway, empirical prescribing, 48–72-hour review, optimisation and discharge, within a single real-time platform. By combining prescribing, microbiology and stewardship-intervention data in a dual-phase framework, it adds ward-level granularity, live monitoring and rapid deployability in resource-constrained settings (table 2).

This design directly addresses a recognised weakness in stewardship monitoring: the disconnection between antibiotic initiation and subsequent optimisation.[4] To our knowledge, no existing tool spans both phases at ward level in real time, allowing clinicians to evaluate stewardship across the full patient pathway rather than at isolated points. These features address gaps identified in the literature and support more timely, clinically actionable interventions, providing a transferable model for stewardship monitoring across diverse health systems.[16 34]

In addition, the tool goes beyond traditional indicators of antibiotic consumption. It integrates clinically relevant measures, such as appropriateness of prescribing, timeliness of review, de-escalation rates

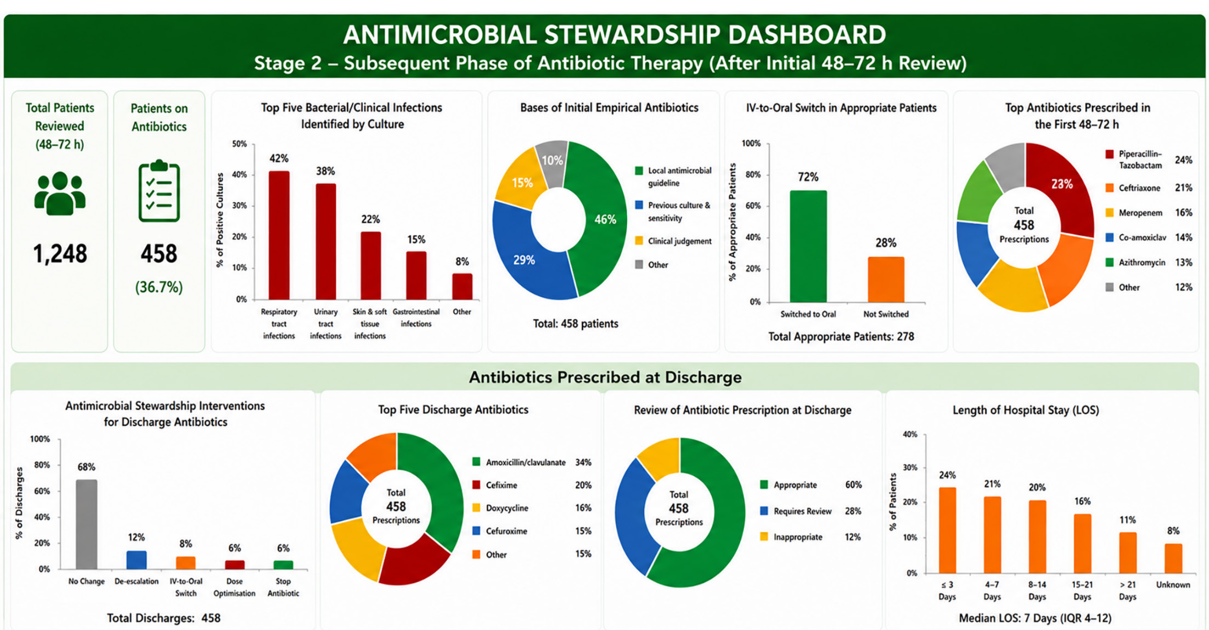

Figure 3 Real-time subsequent antibiotic therapy dashboard (Stage 2). The dashboard supports monitoring of pathogen-directed therapy, microbiological findings, antimicrobial optimisation, review timing, stewardship interventions, discharge prescribing and length-of-stay outcomes across the subsequent therapy stage. IV, intravenous; LOS, length of stay.

Table 2 Dashboard metrics aligned with stewardship frameworks

Pathway stage	Dashboard metric(s)	UKHSA SSTF milestone	WHO AWaRe / international alignment
Empirical (initial) therapy	Empirical agent; broad- vs narrow-spectrum; allergy documentation	Start Smart – prompt effective empirical therapy	AWaRe (Access/Watch/Reserve) classification of empirical agents
48–72-hour review	Review timing and compliance; intervention type; reviewing profession	Then Focus – mandatory 48–72-hour review	AWaRe – review and de-escalation prompts
Subsequent / second-course therapy	Pathogen-directed prescribing; second-course review timing; resistance pattern	Then Focus – pathogen-directed adjustment	AWaRe targeted therapy; WHO GLASS resistance alignment
Discharge	Discharge antibiotic; discharge reviewer; length-of-stay band	Then Focus – discharge optimisation	AWaRe – discharge prescribing

and professional responsibility for stewardship decisions.[17 19] These indicators are not merely descriptive but actionable: they provide insights that clinicians can use immediately to improve prescribing practice. In this respect, the dashboard transforms abstract stewardship principles into measurable activities directly linked to patient care, echoing calls for actionable quality metrics in infection management.[35]

Accessibility and sustainability of this dual AMS dashboard

A deliberate, pragmatic decision was made to use Microsoft Excel as the development platform, driven by accessibility, cost-effectiveness and scalability within NHS and comparable healthcare environments.[30] More sophisticated platforms may offer advanced features, but they require substantial IT infrastructure and financial resources that often limit adoption. By contrast, Excel is universally available across NHS systems, requires minimal training and can be rapidly deployed. This resonates with evidence from low- and middle-income countries (LMICs), where transferring high-resource stewardship interventions without contextual adaptation has often failed.[36–38] A lightweight, sustainable tool that operates within existing infrastructure offers a realistic pathway for wider uptake without precluding future migration to EHR platforms.

From passive audit to active decision support

Importantly, the dashboard functions as a decision-supportive stewardship intelligence tool rather than an automated, patient-level CDSS; it informs, but does not replace, clinician judgement. Filtering by demographics, diagnosis, antimicrobial class and ward lets clinicians rapidly identify high-risk cases, such as prolonged broad-spectrum therapy without microbiological justification,[39] moving stewardship from retrospective auditing toward real-time intervention and addressing review-compliance gaps highlighted in the foundational studies.[40] Evidence suggests targeted, pattern-based interventions outperform generalised policy,[41] and a Cochrane review found stewardship can raise policy compliance by around 15% and cut treatment duration by nearly 2 days without compromising safety.[41] The dashboard delivers precisely this granular, stratified data by temporal trend, clinical variable and intervention type, a resilience especially valuable during crises such as COVID-19.[9 42 43]

Educational applications

Beyond decision support, the dashboard holds educational value. Visualising real-time prescribing, review compliance and microbiological correlations provides a learning resource for trainees and practising professionals,[44] while interactive exploration highlights gaps in compliance or resistance awareness to inform targeted teaching.[45] Interprofessional education is particularly supported, as pharmacists, doctors and nurses interpret the same data through their professional lens.[46] This aligns with evidence that interactive, work-based AMS education influences behaviour more than didactic teaching.[44] Making stewardship visible and measurable also enables feedback and shared accountability, with potential to extend education into primary care.[47 48]

Limitations of current monitoring approaches

When benchmarked against existing systems, several limitations are evident. Population-level systems remain retrospective and aggregated, while hospital dashboards often emphasise consumption over clinical processes.[17–19] This tool addresses these deficiencies through ward-level monitoring and integrated prescribing, intervention and microbiology data delivered in real time.

Implementation considerations

Successful implementation of digital dashboards requires not only technical reliability but also attention to organisational and cultural factors. The Excel design minimises technical barriers, although scaling beyond a single site will require integration with existing EHR systems and automated data feeds.[49] Training needs are modest, but users must understand stewardship principles and data interpretation. Change-management strategies should emphasise clinical benefits, improved outcomes and workflow efficiency, rather than technological features, to secure clinician buy-in. Long-term sustainability depends on embedding dashboard maintenance within AMS teams, supported by governance and regular data-quality checks.[49]

Contribution to AMR mitigation

At a broader level, the dashboard contributes to the global effort to combat antimicrobial resistance by operationalising stewardship principles in a practical, data-driven manner. Ward-level monitoring supports national targets while also allowing local adaptation to patterns of institutional resistance. Making stewardship activities visible fosters accountability and supports continuous improvement, key elements for sustaining antimicrobial effectiveness. The tool's cost-effectiveness is particularly relevant for health systems with constrained resources, enabling them to expand stewardship capacity without prohibitive investment.[37 38] Its feasibility demonstrates that effective stewardship monitoring does not necessarily require advanced informatics systems, but can be achieved through well-designed, accessible tools.

Limitations and future directions

Several limitations warrant acknowledgement. First, the prototype was developed and validated at a single site, limiting generalisability. Multi-site testing will be essential to assess adaptability across settings. Second, while Excel is accessible, it has constraints in handling very large datasets and real-time integration, which migration to EHR-embedded platforms could overcome. Third, current metrics focus on prescribing and review, linking interventions to patient outcomes, such as mortality, readmission, or length of stay, would strengthen the evidence of clinical impact. Future work should explore machine learning and predictive analytics to forecast resistance and anticipate inappropriate prescribing, and extend the tool to primary care to bridge hospital and community stewardship.

CONCLUSIONS

This study demonstrates the development and early validation of an AMS dashboard enabling dual-phase monitoring aligned with the UKHSA SSTF framework. It shows how real-time integration of prescribing, microbiology and intervention data can shift stewardship from retrospective auditing toward proactive decision support. Its pragmatic, novel and innovative dual-phase design offers sustainability and adaptability within the NHS, with scalability to support the United Nations' global action against AMR and save patient lives. As a low-cost, transferable model, the tool has potential to strengthen quality improvement, education and patient outcomes across diverse health systems. Future priorities include multi-site validation and integration of artificial intelligence to enhance predictive capacity.

Contributors RAE conceived and designed the study, developed and validated the dashboard, collected and analysed the data, and drafted and revised the manuscript. ZA and NU supervised the study, contributed to study design and interpretation, and critically revised the manuscript for important intellectual content. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work. RAE is the guarantor.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved. All the studies were conducted under appropriate ethical approvals (REC reference 22/EM/0161; UH LMS/PGR/NHS/02975). Data from retrospective record review were anonymised prior to analysis. Survey participation was voluntary, with informed consent obtained from all respondents. No patient-identifiable data were included in the dashboard prototype. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. The anonymised patient-level data underpinning this study were collected under Health Research Authority approval (REC 22/EM/0161; CAG 22/CAG/0039) without patient consent, under Regulation 5 of the Health Service (Control of Patient Information) Regulations 2002. These data are not publicly available owing to the conditions of that approval, but may be obtained from the corresponding author on reasonable request, subject to the approvals in place and University of Hertfordshire sponsor governance. Methodological documentation (online supplemental material 1), technical specifications (online supplemental material 2), and a synthetic, non-identifiable interactive demonstration dashboard (online supplemental material 3) are provided as supplementary information, together with the dashboard variable list (online supplemental table 1) and the dual-stage stewardship pathway and dashboard framework (online supplemental figure 1).

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