

Structural implementation profiles of Antimicrobial Stewardship programmes in German hospitals: Evidence from an explorative cluster-analysis

Sophia-Helen Sass

sophia-helen.sass@ukdd.de

University Hospital Carl Gustav Carus

Alina Zimmermann

TUD Dresden University of Technology

Gesche Först

University of Freiburg

Winfried V. Kern

University of Freiburg

Katja de With

University Hospital Carl Gustav Carus

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Abstract

Background

Antimicrobial stewardship (AMS) programs promote rational anti-infective use, improve patient outcomes, and are cost-effective. In Germany, the absence of secured funding for AMS positions means that implementation of guideline-recommended structures largely depends on local initiatives, resulting in variation between hospitals. Previous studies have provided descriptive insights but lack a comprehensive understanding of implementation profiles and their underlying drivers.

Methods

We conducted a nationwide web-based survey among AMS-trained physicians and pharmacists across 253 German acute care hospitals in 2024. Structural AMS quality indicators (QIs) were assessed. An explorative cluster analysis identified AMS implementation profiles. Associations between implementation profiles, hospital characteristics, and interrelations among QIs were analysed.

Results

Two implementation profiles were identified, reflecting higher and lower levels of AMS structural quality. Differences between profiles were primarily driven by resource- and expertise-intensive measures, including AMS ward rounds, guideline-conform AMS teams, infectious disease consultation services, and dedicated staff positions. In contrast, legally mandated surveillance measures were implemented at consistently high levels across hospitals, while documentation-related and resource-intensive surveillance measures were rarely implemented. Larger hospitals were more likely to report advanced implementation of AMS programmes, whereas university status was not independently associated.

Conclusion

Variation in AMS implementation appears to be primarily associated with the availability of dedicated personnel resources and specialized expertise, which seem to enable more resource-intensive AMS activities. Digital infrastructure and the prioritization of AMS activities may additionally contribute to differences in implementation profiles. Overall, structural QIs differed in their ability to distinguish between implementation profiles, highlighting the need to further develop the assessment of structural quality in AMS programmes. Strengthening core AMS structures while focusing measurement on informative indicators may support more targeted development of AMS programmes across different hospital settings.

Background

Antimicrobial stewardship (AMS) programmes promote the rational use of antimicrobial agents^{1–3}. Consequently, AMS programmes are associated with improved patient outcomes as for example shorter length of hospital stays and improved cost-effectiveness of antimicrobial therapies^{4,5}. In Germany, however, the absence of legally secured funding for AMS structures and staff positions limits their implementation. As a result, the implementation of guideline-recommended structures largely depends on local initiatives, often without dedicated funding, or on selective funding opportunities^{6,7}.

Several surveys have previously been developed to assess the implementation of AMS programmes in Germany and other European countries have mainly collected information on AMS quality indicators (QIs). QIs serve as quantitative measures for healthcare quality⁸ and are commonly used to evaluate the degree of AMS programme implementation and to identify areas for improvement⁹. QIs are derived from evidence-based recommendations and are intended to be relevant, valid, and feasible in routine care¹⁰. In this study we focus on structural QIs, which assess the organisational structures, resources, information technology and digital infrastructure and evaluation tools available for implementing AMS programmes^{8,11}. These include for example the availability of dedicated personnel and interdisciplinary teams, formal mandates and institutional support, surveillance of antimicrobial consumption and resistance data, information technology infrastructure, strategies to optimise prescribing behaviour like educational activities, regular AMS ward rounds, and the timely communication of microbiological findings.

In the German context, evolving survey instruments have been used over the past two decades to assess structural QIs and to monitor the development of AMS implementation^{7,12–15}. During this period, AMS measures shifted from isolated antibiotic use surveillance and respective control measures toward formal, interdisciplinary, comprehensive data-driven AMS programmes although uniform, durable integration across hospitals has not yet been achieved. Overall, structural AMS quality has improved in Germany over time^{7,12–14,16,17}. Previous studies further indicate that implementation varies by hospital type regarding institutional capacity (with larger and university-affiliated hospitals generally showing higher implementation levels)^{13,17}, local microbiology¹⁷ and infectious-disease resources^{18,19}, leadership commitment²⁰, and whether programmes have continuing staff rather than one-time training or project support^{7,14}.

However, these surveys were often limited in scope as they focused predominantly on intensive care units, tertiary or university hospitals, and underrepresented the regular treatment settings and smaller institutions, which make up a substantial share of acute care in Germany²¹. In particular, it remains unclear which AMS activities can be realised under constrained resources, which depend on dedicated staffing and more extensive infrastructure. It is also unknown how individual structural components of AMS interact with one another and which structural QIs are most informative about differences in AMS implementation between hospitals. This limits the ability to identify elements that are broadly feasible across settings and those that require substantial institutional support. At the same time, the continued development of measurement instruments has reduced comparability across previous surveys. To date,

a differentiated understanding of AMS implementation in German acute care hospitals is limited, which constrains targeted strategies for the development of AMS practice and recommendations.

The present study addresses these gaps by moving beyond descriptive analyses of individual QIs towards a comprehensive, profile-based assessment of AMS implementation. Using structural QIs, we aim to identify empirical implementation profiles, i.e., typical patterns of AMS program implementation across hospitals, and to determine which QIs are most informative in distinguishing between these profiles. We further explore factors underlying differences in implementation by assessing how AMS implementation profiles relate to hospital characteristics and by analysing associations between individual QIs. To this end, we conducted a nationwide web-based survey among physicians and pharmacists actively involved in AMS practice in 253 German acute care hospitals in 2024. By combining the largest and most diverse sample of AMS professionals in Germany to date with an exploratory cluster-analytical approach, this study advances the field both empirically and methodologically. While previous analyses are based on predefined assumptions about hospital characteristics that influence implementation of AMS programmes, our approach derived profiles directly from questionnaire responses and potential drivers of variation are assessed post hoc.

Methods

Survey

We conducted a web-based survey²² amongst AMS professionals from German acute care hospitals in 2024. Eligible participants were pharmacists and physicians who had completed the full formal AMS training programme provided by the German Society for Infectious Diseases, leading to qualification as an “AMS Expert” in Germany. The questionnaire (Supplementary Material) consisted of multiple-choice items assessing the implementation of AMS structures and measures across several domains, which included team composition, expertise and funding, education, information technology and digital infrastructure, consultation services and bedside AMS interventions, local treatment recommendations, regulation of antimicrobial therapy, pathogen and antimicrobial consumption surveillance, and documentation practices. Participants additionally provided information on their professional background, current role, and hospital characteristics. A separate section included partly open-ended questions on subjective evaluations of AMS implementation. The questionnaire followed an adaptive design with conditional skip patterns. Participants responded to minimum of 38 and a maximum of 86 items per completion. Participants who worked for a hospital network comprising several sites were allowed to complete hospital-specific sections multiple times separately for each institution. The average completion time was approximately 15 minutes. The questionnaire was based on previous surveys and further developed by infectious disease physicians and a clinical pharmacist with AMS expertise.

Sample

Participants were recruited via a national AMS professional network mailing list. Survey invitations were sent to 1,354 AMS experts affiliated with about 700 German hospitals. In total, 420 completed questionnaires were received. We excluded responses from rehabilitation hospitals, as well as datasets lacking information on AMS team structures or the affiliated hospital. After these exclusions, the final sample comprised 356 valid questionnaires from 337 individual respondents (response rate: 26%). Four participants completed the survey for more than one hospital, and for 64 hospitals, more than one respondent participated. These responses represented 253 distinct hospitals. Most respondents were specialist physicians involved in direct patient care (n = 206), with internal medicine (n = 98) and anaesthesiology (n = 69) being the most frequently represented specialties. Among specialist physicians, n = 43 had completed additional training in infectious diseases, including 34 internists, five anaesthesiologists, and four physicians from other specialties. Pharmacists accounted for about a quarter of the sample (n = 82), with about half of them holding specialised training in infectious diseases (n = 43). Detailed characteristics of participating AMS-professionals are reported in the Supplementary Material Table S1.

For all analyses, individual responses referring to the same hospital were aggregated into a single hospital-level dataset (see Supplementary Material for details on data aggregation procedure). The sample included responses from 36 university hospitals and 217 non-university hospitals, mostly of medium size with 200-399 beds (34%) or 400-800 beds (36%), less frequently from large (>800 beds, 19%) or small institutions (<200 beds, 10%). Detailed hospital characteristics are reported in Table 1.

	Hospital size category (n beds)			
	<200	200-399	400-800	>800
Hospitals assessed n	26	86	92	49
n beds mean	133	295	547	1153
n beds standard deviation	48	56	109	295
University hospital affiliation n	0	0	6	30
In-hospital pharmacy % (n)	80 (20)	88 (74)	92 (84)	100 (49)
In-hospital microbiology laboratory % (n)	20 (5)	17 (15)	30 (27)	71 (35)

Table 1: Characteristics of hospitals included in the study sample.

Data analysis

AMS-implementation profiles

All data analyses were carried out using R²³. Data analysis was performed in four steps. First, we selected the most relevant survey items for similarity-based hospital profiling. Second, we conducted cluster analysis to identify hospital implementation profiles. Third, we assessed associations between these profiles and hospital characteristics (size and university status). Fourth, we analysed associations among individual QIs to explore their interrelations.

In the first step, we selected relevant survey items for the analysis. We included items capturing the presence of structural AMS features recommended in the German national guideline. Follow-up items assessing these features in greater detail, which were only presented if the respective structural feature was reported as present, were excluded. Additionally, items with low variance were removed if at least 95% of responses fell into the same category, as they do not contribute to differentiating between hospitals. To reduce redundancy, we further excluded items that were highly intercorrelated, defined as a Spearman's $\rho > 0.9$. This selection process resulted in a final set of 17 items included in the cluster analysis (see Table 2).

In a second step, we conducted a cluster analysis to identify groups of hospitals with similar AMS implementation profiles. The analysis was conducted using the R-package "cluster", version 1.2.8.2²⁴. To quantify the (dis)similarity of hospitals, we calculated pairwise differences across all selected items using Gower's distance^{25,26}. This measure allows to compare hospitals based on their responses across all items, which is then summarized in a composite value. The resulting dissimilarity values range from 0 (completely identical responses) to 1 (completely different responses). All pairwise comparisons were combined into a dissimilarity matrix, which served as the basis for clustering hospitals.

We applied a partitioning around medoids (PAM)^{27,28} algorithm to identify clusters of hospitals based on their previously computed dissimilarity values. This method groups hospitals into a number of clusters k by selecting representative hospitals (so-called medoids) that best reflect the characteristics of each group. Each hospital is then assigned to the cluster whose representative hospital it most closely resembles. In this way, clusters consist of hospitals with similar patterns of AMS implementation.

The algorithm operates in an unsupervised manner, meaning that no predefined group labels are used. Instead, it iteratively evaluates different combinations of hospitals as potential representatives (medoids) and selects the configuration that results in the most coherent grouping for various numbers of clusters k , i.e., where hospitals within a cluster are as similar to each other as possible. Compared to predefined group comparisons, an important advantage of this approach is that it identifies patterns in the data in an exploratory, data-driven manner and does not require prior assumptions about relevant grouping variables, e.g., hospital size.

To determine the optimal number of clusters into which the dataset could be partitioned, average silhouettes²⁹ were computed across different solutions of k . For each hospital, the silhouette compares

its average dissimilarity to its own cluster with its dissimilarity to alternative clusters and ranges from -1 to 1, with higher values indicating better separation.

Association between structural AMS QIs and hospital characteristics

In a third step, we analysed associations between cluster membership and hospital size as well as university status to assess how AMS implementation profiles relate to hospital characteristics. Cluster membership was modelled in a binomial logistic regression model, with hospital size (number of beds) as a continuous predictor and university status as a binary predictor (R-package “stats”, version 4.6.1²³). This approach allowed us to estimate the odds of belonging to the respective cluster in relation to hospital characteristics.

Associations between structural QIs

In a fourth step, we assessed pairwise associations between all QIs to explore whether certain structural QIs were implemented together. Pairwise associations were analysed using Cramér’s V (R-package “rcompanion”, version 2.5.2³⁰) This measure is based on the chi-squared (χ^2) test and quantifies the strength of association between categorical variables on a scale from 0 (no association) to 1 (perfect association). The test evaluates whether the observed frequency of occurrence of two QIs differs from what would be expected if they were independent. To account for multiple testing, p-values were adjusted using the Benjamini-Hochberg procedure.

Results

AMS-implementation profiles

For the present data, the optimal number of clusters into which the data could be grouped was $k = 2$, based on the highest average silhouette width (see Supplementary Material Figure S1 for the distribution of silhouette values across different numbers of clusters). The average silhouette widths were 0.22 and 0.37 for clusters 1 and 2, respectively, indicating fair to moderate separation between clusters²⁹. The response patterns of the representative hospitals (medoids), which can be considered typical examples for each cluster, are shown in Supplementary Material Figure S2.

To characterize the identified clusters by their AMS implementation profiles, we calculated the proportion of hospitals fulfilling each structural AMS QIs within each cluster. QIs were subsequently grouped by the magnitude of the between-cluster difference in fulfilment with either major or minor differences (Figure 1).

The two clusters reflected broadly higher and lower implementation levels, respectively. Hospitals in the first cluster reported consistently higher frequencies of meeting structural quality standards according to the national guideline across all QIs, whereas those in the second cluster showed more limited

implementation. Based on this pattern, we defined the clusters as “high implementation” and “low implementation” based on their response profiles.

However, the extent of differences in the implementation of structural QIs between these profiles varied. Differences between profiles were primarily driven by the implementation of resource-intensive QIs requiring dedicated time, personnel, and/or expertise (major cluster differences). In particular, regular AMS ward rounds and guideline-conform AMS team structures showed the largest differences in implementation frequency. Substantial differences were also observed for the availability of infectious diseases consultation services (and consequently the availability of infectious disease specialists), dedicated staff positions or protected time for AMS activities, as well as more demanding surveillance activities such as systematic prescription surveys and for the implementation of bloodstream infection reporting systems.

In contrast, other QIs did not substantially contribute to differences between hospitals. Some of these QIs were implemented at consistently high levels across hospitals, particularly legally mandated surveillance activities such as the presentation of surveillance data within clinical governance structures. Others were implemented at generally low levels, notably technically definable regulatory measures related to antimicrobial prescribing, such as mandatory, documented reassessment of antibiotic therapy after 48-72 hours and documentation of indication for antibiotic prescription.

Associations between structural AMS QIs

We assessed pairwise associations between all structural AMS QIs. Many QIs showed at least weak associations, which is not surprising given their conceptual linkage within an AMS programme. In the following, we describe the strongest and most relevant associations. Associations are visualized in Figure 2, if they are statistically significant (χ^2 test, adjusted $p < 0.05$) with at least moderate strength (Cramér's $V \geq 0.3$). The complete results are provided in the Supplementary Material.

The availability of dedicated mandates, protected time, and guideline-conform team structures was associated with the implementation of AMS ward rounds, which in turn were associated with the presence of an infectious disease consultation service. An infectious disease consultation service was further associated with reporting and surveillance measures, including reporting system for bloodstream infection and more complex prescription analyses. More comprehensive surveillance activities, such as point prevalence analyses, were then associated with documentation-related measures concerning antimicrobial prescribing. However, both domains were only rarely implemented in our dataset overall.

As might be expected, the strongest associations were observed between QIs within the same domain of AMS measures. In particular, moderate to strong associations were found within surveillance and feedback, bedside AMS interventions, and documentation measures. For example, legally mandated surveillance activities were closely linked. Hospitals performing prescription analyses were also more likely to conduct point prevalence surveys across both general wards and intensive care units, and vice

versa, although these measures were rarely implemented overall. Regarding bedside AMS interventions we found that hospitals conducting ward rounds on general wards were also more likely to perform them in intensive care units and to have access to an infectious disease consultation service, and vice versa. The two documentation-related QIs (reevaluation and indication of prescription) were also strongly associated, but rarely implemented in general. An additional association was observed between the presence of reporting systems for bloodstream infections and antibiotic prescribing.

Association with hospital characteristics

To assess the association between cluster membership and hospital characteristics, we performed a logistic regression analysis with cluster assignment (high vs. low implementation) as the dependent variable. Cluster-specific distributions of hospital size and university status are presented in Figure 3.

Hospital size, measured as the number of beds, was significantly associated with cluster membership (odds ratio = 1.002 per additional bed, 95% confidence interval = 1.001 - 1.003, $p = 0.001$), corresponding to approximately 20% higher odds of belonging to the high-implementation cluster per additional 100 beds. University hospital status was not significantly associated with cluster membership when accounting for hospital size (odds ratio = 1.48, 95% confidence interval = 0.40 - 6.33, $p = 0.571$). Despite university hospitals being substantially larger than non-university hospitals, multicollinearity was low (variance inflation factor = 1.52), suggesting that implementation differences were primarily related to hospital size per se rather than university affiliation.

Discussion

The present study assessed implementation profiles of AMS structural quality in German acute care hospitals based on questionnaire responses of practicing AMS professionals and provides an updated overview of the current state of implementation. Moreover, drivers of between-hospital variation were explored, including associations between structural QIs and with hospital characteristics.

We identified two AMS implementation profiles reflecting higher and lower levels of implementation. Differences between these profiles were primarily driven by (i) the implementation of AMS ward rounds, (ii) guideline-conform AMS team structures, (iii) infectious diseases consultation services, (iv) dedicated AMS staff resources, and (v) the conduction of more demanding surveillance activities. Overall, hospitals with more advanced implementation profiles were mainly distinguished by the availability of personnel resources and specialized expertise.

Staffing and team structures were associated with resource-intensive bedside AMS interventions, which in turn were linked to additional AMS activities. This corroborates that dedicated time and expertise function as key enabling factors for broader AMS implementation as has been argued in previous studies^{31–34}. In particular, the role of infectious diseases specialists has been highlighted as contributing to improved quality of care and the implementation of AMS interventions, further supporting their

importance as a key enabling factor³⁵. This may be particularly relevant for AMS activities that require specialized clinical and methodological expertise, such as bloodstream infection reporting systems or more complex surveillance measures, where infectious diseases expertise may shape both the prioritization and implementation of these interventions.

Consistent with the observed association between resource availability and implementation level, larger hospitals, which are typically better equipped in terms of personnel and infrastructure, were more likely to have higher implementation levels. However, advanced AMS implementation was also observed in some smaller hospitals. This suggests that while staffing and expertise are important prerequisites, they are probably not sufficient on their own. The observation that some smaller hospitals implemented advanced AMS programmes indicates, in line with previous findings^{36,37}, that institutional prioritization of AMS, organizational commitment, and leadership support are also important determinants of successful programme implementation.

While the implementation of resource-intensive measures is likely constrained by available staff and expertise, variation may also reflect differences in prioritization under constrained resources. Hospitals may prioritize AMS activities according to local capacities as well as organizational priorities and allocate limited personnel and expertise to those interventions considered most feasible or of greatest local relevance. For example, resource-intensive surveillance activities such as regular point prevalence analyses of antibiotic prescriptions may be weighed against other more clinical AMS interventions. Consistent with previous studies, mandatory documentation practices were also rarely implemented.³⁸ This pattern may reflect limited acceptance or perceived utility of these restrictive AMS measures in clinical practice. Stronger institutional regulatory measures and integration into electronic prescribing systems may facilitate implementation and provide a basis for improved AMS monitoring and evaluation of prescribing appropriateness.³⁹ In general, future AMS guideline development and evaluation of QIs could benefit from considering how hospitals and AMS professionals can prioritize and sequence AMS activities under constrained resources. However, further research is needed to better understand why certain AMS measures are prioritized, how resource allocation under constraints is managed, and to assess potential motivational factors, for example through qualitative approaches.

Additionally, the low proportion of implementation of the documentation and advanced surveillance measures may reflect the level of established digital infrastructure. A certain level of digital infrastructure is required to perform advanced surveillance analyses within a reasonable amount of time and effort and to implement mandatory documentation practices in routine care. The present results further indicate gaps in digital infrastructure, as comprehensive electronic prescribing systems were not available in a substantial proportion of participating hospitals.

While these electronic support systems can be effective in improving the rational use of antibiotics⁴⁰, such infrastructure should be considered a supporting component of broader stewardship structures, as its effective use depends on the availability of personnel resources and specialist expertise to design, implement, and maintain these systems. However, besides potentially still low availability of fully

established digital infrastructures⁴¹, the generally low implementation rates of both domains may also indicate limited prioritization or acceptance of these measures in clinical practice. This could reflect perceived inefficiencies, limited clinical utility, or insufficient incentives for their adoption.

Regulatory requirements appear to play an additional role in explaining implementation profiles. In Germany, surveillance of antibiotic consumption and resistance is mandated by law and was implemented at consistently high levels across hospitals, with only minor variation. This is in line with previous findings indicating that legal requirements can increase implementation rates, particularly for reporting and monitoring measures^{42,43}. However, regulatory mandates alone are insufficient. The extent to which formal requirements translate into effective AMS programmes likely depends on staffing, funding, and enforcement. In resource-constrained settings, hospitals may prioritize mandatory tasks, potentially limiting the capacity to implement additional, non-mandated AMS activities.

Taken together, our findings suggest that variation in AMS implementation is driven by the availability and prioritization of resources required to support AMS activities. Hospitals with more advanced AMS implementation profiles were characterized by the availability of dedicated personnel resources and specialized expertise and, correspondingly, by the implementation of more resource-intensive AMS interventions. In contrast, hospitals with less advanced implementation profiles were primarily characterized by the implementation of legally mandated AMS activities. Although the observed associations between QIs cannot be interpreted as causal, they provide important hypotheses for future research. Overall, the results suggest that AMS implementation is structured around different domains, with staffing including infectious diseases expertise as central enabling factors, while surveillance and digital systems for reporting and documentation represent additional, only partly dependent components. Strengthening these core structural elements is therefore likely to facilitate the implementation of multiple AMS activities simultaneously.

Our findings are consistent with previous studies, which have repeatedly highlighted the importance of staffing for AMS implementation. While the overall level of implementation in Germany appears broadly unchanged compared to earlier surveys, our data suggest a slight increase in the availability of dedicated staff time for AMS activities^{12,13,17,44}. At the same time, differences between studies may reflect the broader and more diverse sample in the present study, providing a more comprehensive picture of AMS structural quality across hospitals.

Our findings also have methodological implications, as they suggest that not all structural QIs equally contribute to differentiating hospitals with regard to AMS implementation. Some QIs showed little variation across hospitals or did not meaningfully distinguish between implementation profiles. This highlights the need to further evaluate measurement instruments and to assess which structural QIs are most informative for capturing relevant differences in AMS implementation. Future research and guideline development should therefore consider which QIs are most suitable for inclusion in national AMS recommendations.

Strengths and limitations

A major strength of this work is the large and comprehensive sample to asses AMS structural quality in Germany, covering a broad range of hospital types and characteristics. Notably, it includes a substantially higher proportion of small and medium-sized hospitals compared to previous studies, which is essential for capturing a more realistic picture of AMS implementation and for understanding implementation profiles, particularly in resource-limited settings typical of smaller and non-university hospitals that constitute the majority of healthcare facilities in Germany.

Several limitations should be considered. First, cluster separation was only fair to moderate based on silhouette values, indicating that the identified structure should be interpreted as exploratory and may benefit from alternative analytical approaches in future work to assess characteristics and heterogeneity in AMS program implementation.

Second, the validity of the survey data may be limited, as respondents may not have had complete oversight of all structural aspects, and post hoc aggregation at the hospital level may have introduced misclassification.

Finally, the sample of 253 hospitals is not representative of all hospitals in Germany, limiting the generalizability of the findings. The data rely on self-reported information from AMS experts. Hospitals that lack an AMS expert have not been captured in the sampling frame. Nevertheless, the study represents one of the most comprehensive datasets currently available on German AMS structures.

Conclusion

The implementation of AMS programmes across German hospitals can primarily be distinguished by the availability of dedicated personnel resources and specialized expertise, which appear to be key prerequisites for more resource-intensive AMS activities. Digital infrastructure and the prioritization of AMS activities may additionally contribute to differences in implementation profiles. Overall, structural QIs differed in their ability to distinguish between implementation profiles, highlighting the need to further develop the assessment of structural quality in AMS programmes. Strengthening AMS structures while focusing measurement on informative indicators may support more targeted development of AMS programmes across different hospital settings.

Abbreviations

AMS	Antimicrobial Stewardship
QIs	Quality indicators

Declarations

Human Ethics and Consent to Participate declarations

According to institutional requirements, formal ethics approval was not required. Participation was voluntary. Participants received information about the purpose of the survey and gave consent before accessing the questionnaire.

Consent for publication

Not applicable.

Clinical trial number

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are available in the institutional research data repository of TUD Dresden University of Technology [link will be inserted upon publication].

Competing interests

The authors declare that they have no competing interests.

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Author contributions

SHS conceptualized the analytical approach, developed the analysis strategy, performed all statistical analyses, created all figures, and wrote the original manuscript. AZ contributed to data preprocessing and supported the descriptive analyses. GF conducted the questionnaire and cleaned and aggregated the data for analysis. GF, WVK, and KdW conceptualized the questionnaire, developed the questionnaire, and acquired funding for the project. All authors reviewed the manuscript.

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Table

Table 2 is available in the Supplementary Files section.

Figures

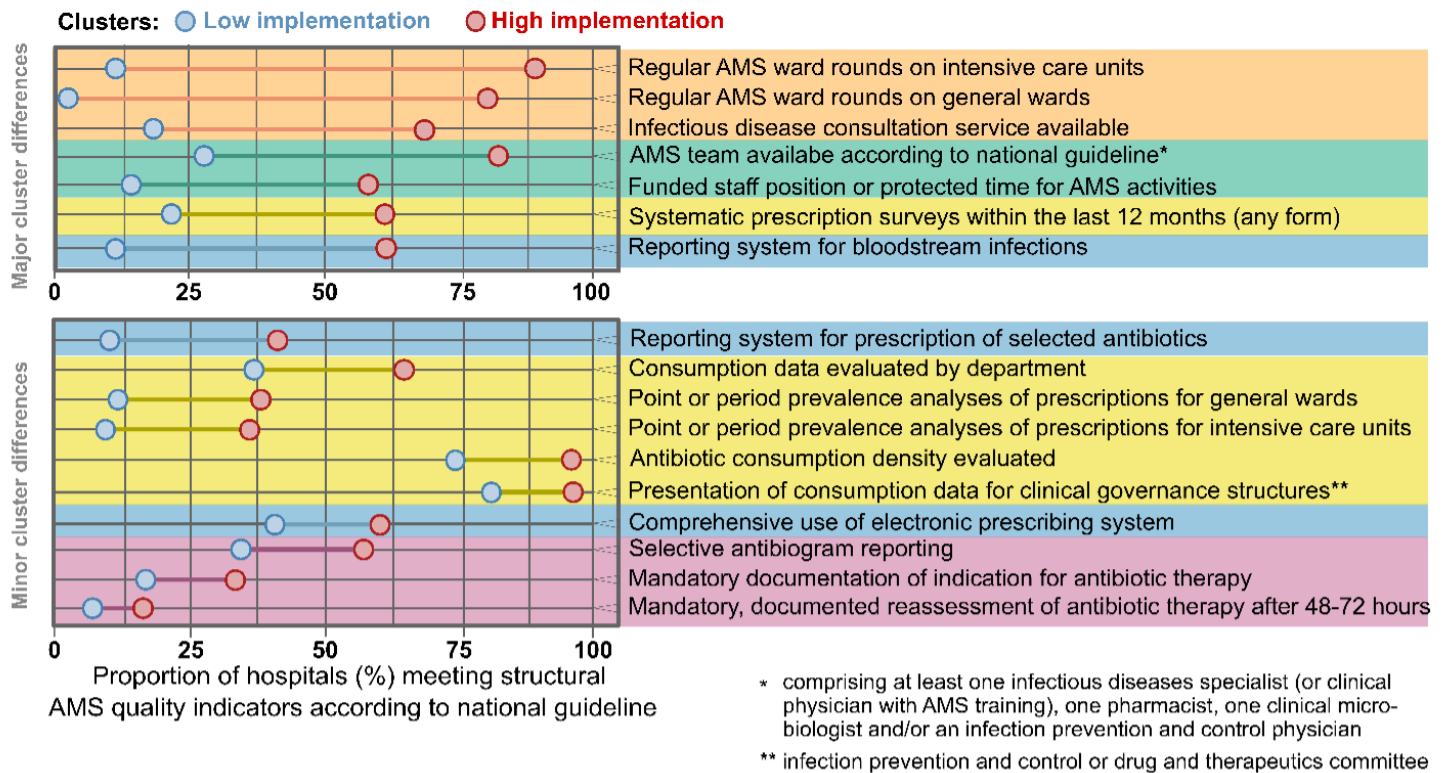


Figure 1

Implementation clusters of AMS programmes based on structural AMS QIs. Proportion of hospitals in the low implementation (blue) and high implementation (red) clusters fulfilling individual structural AMS QIs derived from the national guideline. Differences in proportions between clusters are indicated by connecting lines.

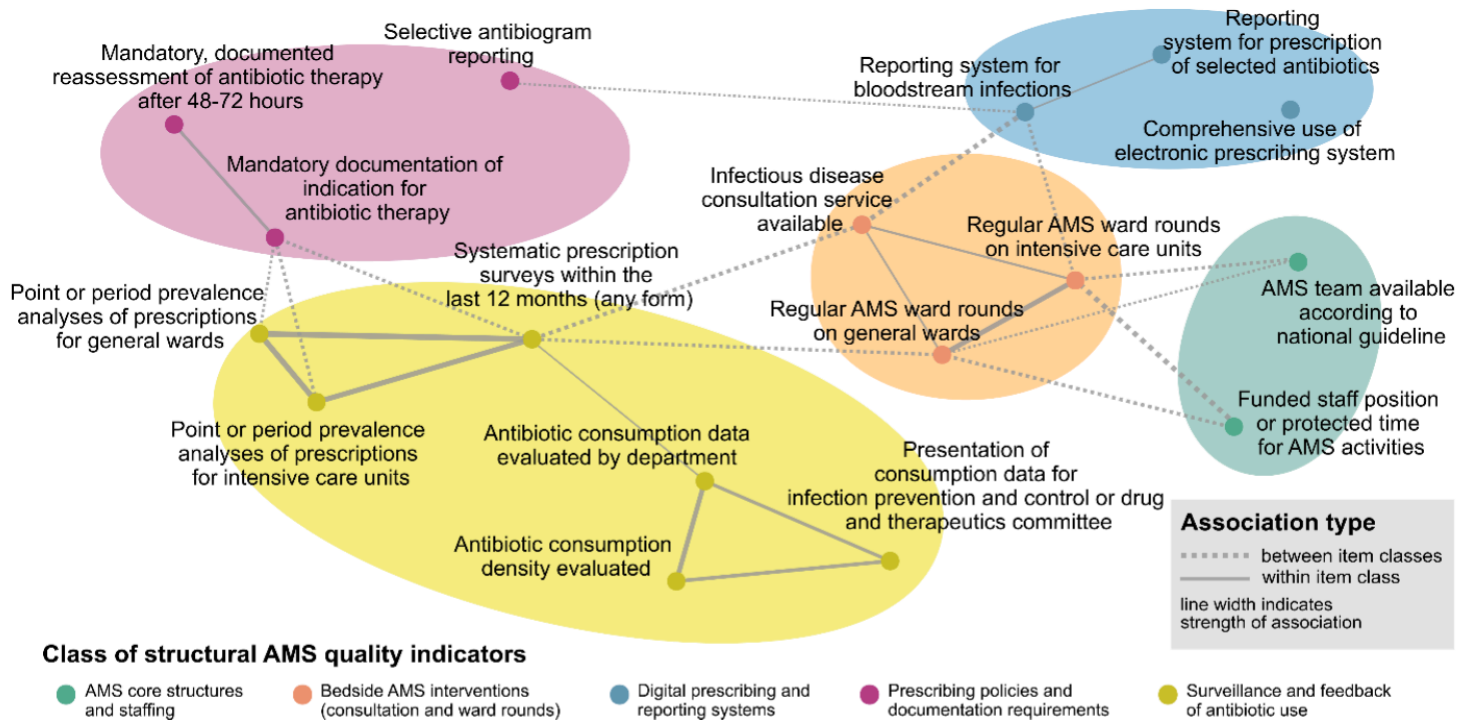


Figure 2

Network of pairwise associations between structural AMS QIs. Each node represents a structural QI and is colour-coded according to five predefined indicator categories. Edges indicate statistically significant pairwise associations between QIs (χ^2 test, $p < 0.05$, Benjamini–Hochberg correction for multiple testing) with at least moderate effect size (Cramér’s $V \geq 0.3$). Edge width indicates the relative strength of association, with thicker edges representing stronger associations. Edge lengths are determined by the layout and do not carry substantive meaning.

Hospital type

- Non-university hospital
- University hospital

AMS implementation cluster

- Low implementation
- High implementation

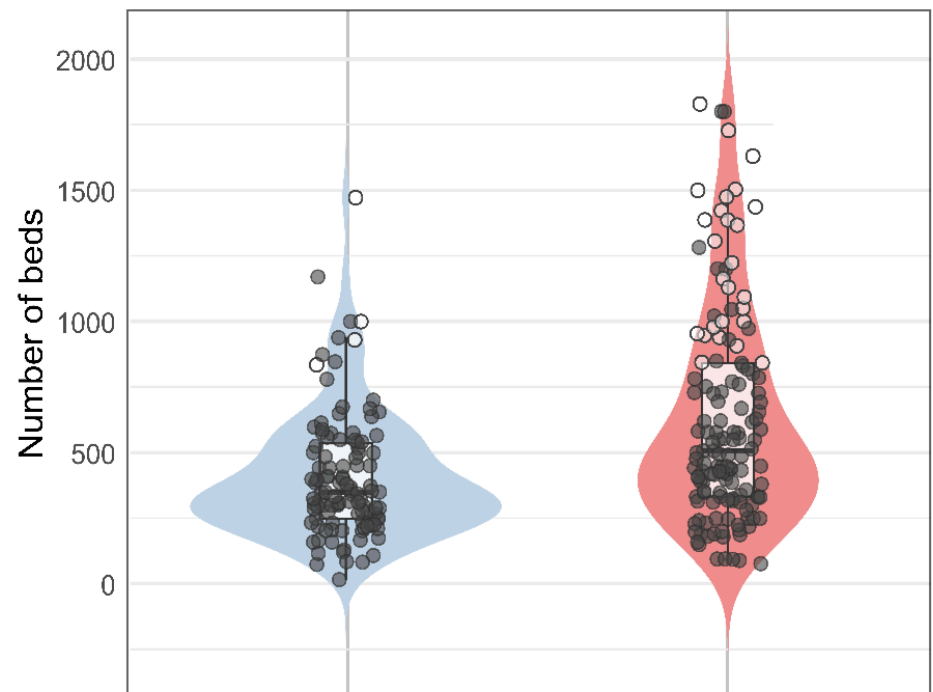


Figure 3

Distribution of hospitals by size and university status in each implementation cluster. Colours indicate cluster membership (blue: low implementation; red: high implementation). Filled points represent non-university hospitals, open points represent university hospitals.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryMaterialAMSIImplementationProfiles.pdf](#)
- [TABLE2.docx](#)