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Review Article

Roadmap for integrated One Health AMR surveillance in Nordic countries

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ABSTRACT

Objectives: Outline the basis for integrated One Health AMR surveillance in the Nordic region by mapping existing surveillance systems and research assets, identifying key challenges to cross-border alignment, and proposing practical steps toward coordinated cross-sector, cross-country surveillance.
Study design: Mapping and review of Nordic AMR infrastructure.
Methods: We mapped AMR data sources and surveillance infrastructure across the Nordic countries and compiled the findings into an online resource (www.nomoreamr.org). We also assessed requirements for linking national systems, including ethical, legal, and data-sharing considerations relevant to establishing an integrated regional framework.
Results: The Nordic countries have well-established AMR surveillance systems supported by digital infrastructure, longstanding public health collaboration, and similar socio-economic organization. However, surveillance is currently conducted independently, with limited cross-border data sharing and coordination. Synchronizing national systems would strengthen regional preparedness by enabling earlier detection of emerging threats and supporting more consistent, evidence-based policies and coordinated antimicrobial stewardship. A shared Nordic surveillance network could also serve as an adaptable model for other regions.
Conclusions: Establishing an integrated Nordic One Health AMR surveillance is feasible but requires structured linkage of existing national systems and clear ethical and legal frameworks for data access and sharing. The compiled mapping resource can support the technical and governance steps needed to advance regional integration.

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1. Introduction

Antimicrobial resistance (AMR) is a public health threat that transcends borders. As the EU One Health Action Plan notes, "resistant bacteria and infectious diseases do not respect borders".[1] The WHO has further warned that AMR has reached alarming levels, straining health systems worldwide.[2] Consequently, there is a broad consensus that isolated national actions cannot mitigate the impact of AMR. Instead, harmonized, multisectoral approaches are needed. Recent European assessments further indicate that fragmented governance and limited cross-sector coordination, particularly in surveillance, continue to hinder timely AMR detection and response.[3]

To address these challenges, several international initiatives have sought to strengthen cross-sectoral surveillance of AMR and antimicrobial use. Global systems such as the World Health Organization (WHO) Global Antimicrobial Resistance and Use Surveillance System (GLASS), the World Organization for Animal Health (WOAH) ANIMal Antimicrobial USE database (ANIMUSE), and the Food and Agriculture Organization of the United Nations (FAO) International Antimicrobial Resistance Monitoring system (InFARM) collect surveillance data across human, animal, and agrifood sectors. These efforts form part of the broader One Health agenda led by the Quadripartite organizations (FAO, WHO, WOAH, and the United Nations Environment Programme [UNEP]), which are developing the Global Integrated System for Surveillance of Antimicrobial Resistance and Antimicrobial Use (GISSA) to facilitate cross-sectoral data integration and coordinated analysis. Despite these advances, surveillance infrastructures remain largely organized within sector-specific frameworks and national systems, limiting interoperability and coordinated interpretation across domains. This highlights the need for practical regional models that can operationalize integrated One Health surveillance while building on existing national infrastructure.

The Nordic region is well-positioned to address this challenge. The Nordic countries were early adopters of AMR and antimicrobial use surveillance in humans and animals (Fig. 1) and share legislative and societal features that facilitate coordinated actions (Table 1). Furthermore, their universal healthcare supports preventive strategies and evidence-based policies,[4] while nationwide registries enable linkage of clinical and sociodemographic data.[5] The region also produces rich datasets, including genomic, metagenomic, and wastewater-based AMR data, with a density of publicly available genomic sequences in Nordic countries over seven times the global average.[6]

Yet Nordic AMR surveillance remains organized at the national level, with cross-border data exchange primarily occurring through European or international platforms that often lack the resolution of national systems (Fig. 2). Together, the region's shared features and technological strengths provide a unique opportunity to move beyond separate national systems toward an integrated One Health AMR surveillance, a goal supported by the Nordic Council of Ministers and the European Commission.[7]

In this report, we outline the foundation for such an approach by investigating AMR surveillance systems and research assets in the Nordic region. We identify the challenges to integration, highlight opportunities for alignment, and propose practical steps towards coordinated cross-sector, cross-country surveillance. While implementation is complex, the Nordic region offers an optimal testbed for advancing comparability, interoperability, and collaborative governance in AMR surveillance.

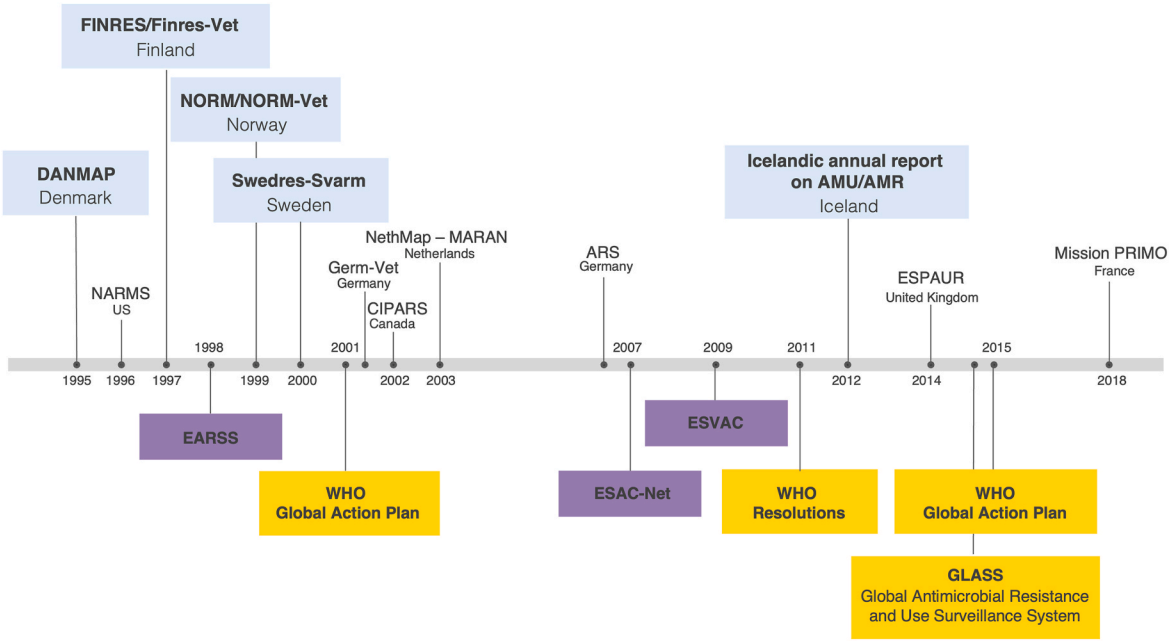

Fig. 1. Selection of the major AMR surveillance initiatives established across European countries. DANMAP: Danish Integrated Antimicrobial Resistance Monitoring and Research Program; NARMS: National Antimicrobial Resistance Monitoring System, US; FINRES/Finres-Vet: Finnish (Veterinary) Antimicrobial Resistance Monitoring and Consumption of Antimicrobial Agents; EARSS: European Antimicrobial Resistance Surveillance System; NORM/NORM-Vet: Norwegian (Veterinary) Surveillance System for Antimicrobial Drug Resistance; Swedres-Svarm: Swedish Antibiotic Sales and Resistance in Human Medicine; WHO Global Action Plan: the first WHO global strategy of 2001; Germ-Vet: National resistance monitoring of animal-pathogenic bacteria, Germany; CIPAR: Canadian Integrated Program for Antimicrobial Resistance Surveillance; NethMap - MARAN: report about consumption of antimicrobial agents and AMR among medically important bacteria in the Netherlands; ARS: Antimicrobial Resistance Surveillance, Germany; ESAC-Net: The European Surveillance of Antimicrobial Consumption Network; ESVAC (became ESUAvet from 2023): The European Sales and Use of Antimicrobials for Veterinary Medicine; WHO Resolutions: the World Health Assembly resolutions of 2011; Icelandic annual report on AMU/AMR: Annual report on antimicrobial consumption and antimicrobial resistance in humans and animals in Iceland; ESPAUR: English surveillance programme for antimicrobial utilisation and resistance; GLASS: Global Antimicrobial Resistance and Use Surveillance System; WHO Global Action Plan: the second WHO global strategy of 2015; Mission PRIMO: Prevention and control of infection in medico-social establishments and community care, France. Nordic countries are highlighted in light blue text boxes. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2. Methods

We conducted a descriptive mapping of antimicrobial resistance (AMR) surveillance systems and research assets across the Nordic countries. Information on national surveillance programs, data infrastructures, and relevant institutional actors was collected through publicly available reports, surveillance publications, and institutional documentation. The results were compiled into an online resource (www.nomoreamr.org). We also assessed the technical, legal, and ethical considerations relevant to linking national systems and enabling cross-border data sharing within a regional One Health surveillance framework.

3. Results

3.1. Human AMR surveillance across Nordic countries

The Nordic countries have well-established national systems for human AMR surveillance, based on routine antimicrobial susceptibility testing performed in clinical microbiology laboratories in hospitals and primary care (Table 1). These systems cover both invasive and community-acquired pathogens and report to European and global platforms, including European Antimicrobial Resistance Surveillance Network (EARS-Net) and GLASS, enabling international trend monitoring and threat detection.

Although surveillance structures differ in scope and implementation, they share a high degree of methodological alignment. Several countries have expanded beyond standard Antimicrobial Susceptibility Testing (AST) to include metadata, protocol-based surveys, and increasing use of molecular methods. Denmark, for example, integrates primary care data and routinely applies whole-genome sequencing for multiple pathogens, while Finland and Sweden leverage nationwide registries and automated laboratory reporting to achieve broad population coverage.[8,9] Norway and Iceland complement routine reporting with targeted surveys and notification-based systems for priority resistance phenotypes.[10–12] Overall, Nordic surveillance systems are technically mature, increasingly molecularly informed, yet underused as a collective regional resource.

3.2. Animal and food AMR surveillance in Nordic countries

Although only three of the five Nordic countries described here are EU members, all five participate in the EU-harmonized system for monitoring AMR in animals and food, with national data reviewed by the European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDC), and published in the EU Summary Report. In parallel, each Nordic country operates a national animal and food AMR surveillance programme, often with a broader scope or higher resolution than required under EU legislation (Table 1).

Across the region, animal and food surveillance targets zoonotic bacteria transmissible to humans, indicator organisms used to track resistance trends, and animal pathogens. Data are collected from multiple settings, including farms, slaughterhouses, veterinary clinics, and food products, and are complemented by national monitoring of antimicrobial use in animals based on sales and prescription data. The surveillance systems share a common structure, but their scope reflects national priorities. Finland and Sweden focus on monitoring of food-producing animals and routinely collect diagnostic samples from diseased animals, with Finland also collecting data from the fur industry and companion animals. Norway extends surveillance to aquaculture, food, feed, and wild animals, and conducts MRSA screening in the pig population. Denmark operates one of the most comprehensive programmes through DANMAP (Danish Integrated AMR Monitoring and Research Program), with sustained monitoring of indicator bacteria beyond EU requirements to ensure continuity. Iceland maintains a centralised system focused on indicator and zoonotic bacteria in livestock, meat, and animal products, supported by regular national surveys. Together, these programmes provide a regional foundation for One Health surveillance. Still, an absence of routine mechanisms for cross-border integration and joint interpretation limits their impact.

3.3. Environmental AMR surveillance

Despite awareness that the environment acts as both a reservoir and a transmission route for AMR, as of 2025, there is no systematic environmental AMR surveillance in Europe.[13] Most data come from research-driven initiatives, often designed as point-prevalence studies with limited representativeness.[13–16] Proof-of-concept environmental AMR monitoring has been conducted in several contexts, including weekly wastewater treatment plant sampling since 2015.[17]

Table 1
Overview of the AMR surveillance systems in the Nordic countries.

Country		DENMARK	FINLAND	ICELAND	NORWAY	SWEDEN
AMR surveillance program		DANMAP	FINRES/FINRES-Vet	Icelandic annual report on AMU/AMR	NORM/NORM-Vet	Swedres-Svarm
Human surveillance	Collecting data from clinical microbiology laboratories Mandatory notifications of AMR infections	The Statens Serum Institute (SSI)	Finnish Institute for Health and Welfare (THL)	Centre for Health Security and Communicable Disease Control, Directorate of Health	Norwegian Institute of Public Health (NIPH) and University Hospital of North Norway	Public Health Agency of Sweden
	Data on antibiotic sales and consumption	Danish Health Data Authority - Register of Medicinal Product Statistics and SSI	The Finnish Medicines Agency (Fimea)		NIPH	Swedish eHealth Agency
Animal surveillance	Data on pathogenic, zoonotic, and indicator bacteria	Danish Veterinary and Food Administration, DK-Vet consortium, and DTU National Food Institute	THL and Finnish Food Authority	Icelandic Food and Veterinary Authority (MAST)	Norwegian Veterinary Institute	Swedish Veterinary Agency (SVA)
	Data on antibiotic sales and consumption	Danish Veterinary and Food Administration and DTU National Food Institute	Fimea		The Norwegian Food Safety Authority and NIPH	SVA and Swedish Board of Agriculture
Environmental surveillance	Wastewater monitoring	Pilot and research-based				
	Routine environmental monitoring	Pilot and research-based				

In practice, environmental AMR surveillance has largely been equated with wastewater monitoring. Analysis of untreated wastewater provides a snapshot of AMR circulating in human populations, whereas monitoring treated wastewater can detect antibiotic resistance genes and resistant bacteria released into surface waters or agricultural soils via effluents and sludge. These data can inform potential environmental exposure,[18] but their ability to anticipate novel or emerging resistance threats is limited.[19] However, as we discuss below, extending surveillance beyond wastewater to other environments raises methodological challenges, including decisions about what to monitor, how to standardise sampling across diverse matrices, and how to interpret findings in terms of public health relevance.

At the same time, international organizations and national governments increasingly recognise that effective AMR surveillance must include the environment.[20,21] There are already established systems for monitoring water quality and chemical pollutant levels in surface waters in many countries, but these do not yet include AMR. At the EU level, the EU Council has called for surveillance frameworks that encompass soil and water alongside human, animal, and food sectors.[7] Moreover, the European Environment Agency and its partners are piloting surface-water AMR monitoring across Europe. Most notably, a recent Urban Wastewater Treatment Directive 2024/3019 introduces mandatory AMR surveillance in urban wastewater, formally recognising wastewater as an AMR reservoir and transmission route.[22]

Implementing environmental AMR surveillance at scale will require addressing multiple barriers, including fragmented governance, limited engagement of environmental authorities, insufficient baseline data, and the absence of internationally harmonized protocols. Without coordinated solutions to these challenges, the environmental dimension risks remaining the weakest link in otherwise increasingly integrated One Health surveillance systems.

4. Discussion

4.1. Coordinated AMR surveillance in the Nordic Countries: Challenges and solutions

Developing and implementing regional AMR surveillance will entail multiple challenges, including ethical, legal, financial, and logistical ones. We have identified five main obstacles to integrated AMR surveillance and propose several solutions (Table 2).

A central barrier is limited access to high-resolution data. National AMR reporting largely relies on aggregated, standardised summaries, whereas effective regional surveillance needs data of sufficient granularity to track the emergence and spread of resistance in space and time. Access to individual-level data is constrained by data protection regulations, particularly under the GDPR, and by fragmented approval processes. It will thus be essential to develop a regulatory framework that enables access to aggregated summaries, raw, anonymized data, and eliminates the need for institutional clearance applications. Achieving this will require addressing legal, ethical, and technical challenges related to data privacy and cross-border data sharing, as well as establishing a secure joint platform for the collected data. In the meantime, combining access to both national summaries and detailed datasets could be a pragmatic solution.

Lack of harmonisation in data reporting further limits comparability across countries.[23] Although the Nordic countries follow EUCAST guidelines, the breakpoints that determine antibiotic susceptibility are updated regularly as scientific evidence, resistance mechanisms, and antibiotic dosing regimens evolve. Consequently, when breakpoints change, historical data stored as categorical susceptible–intermediate–resistant (S/I/R) interpretations are no longer comparable with current data, leading to a false impression of rising or falling resistance. It is not always feasible to retrospectively reanalyze historical data using new breakpoints because raw data are rarely retained (only the S/I/R interpretation). Also, EUCAST breakpoints are increasingly defined for specific clinical entities (*e.g.*, urinary tract infections, meningitis, endocarditis). The S/I/R interpretation for individual isolates thus depends on the clinical setting, compromising S/I/R reports as a valid strategy for monitoring the bacterial population. Hence, implementing a policy for storing raw minimum inhibitory concentration and disk zone data in national databases could solve the S/I/R reporting biases.[24,25]

Beyond differences in laboratory breakpoints, several systemic factors also affect the comparability of AMR surveillance data across countries. Resistance estimates depend not only on laboratory methods but also on clinical practices, including how often samples are taken and under which indications patients are tested. Differences in diagnostic stewardship and sampling intensity influence the total number of patients or samples tested (the denominator used to calculate resistance

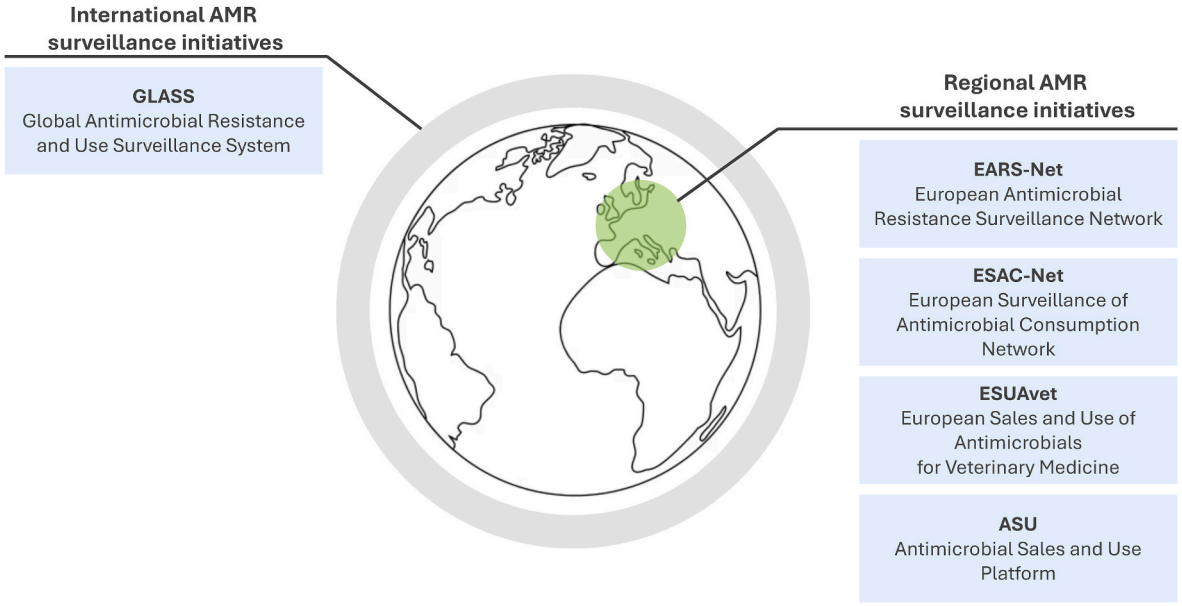

Fig. 2. International and EU-related surveillance systems. The figure highlights antimicrobial resistance (AMR) and antimicrobial use (AMU) surveillance systems, such as GLASS (WHO), and regional networks, including EARS-Net, ESAC-Net, ESUAvet, and ASU.

Table 2
Current challenges to integrated AMR surveillance and proposed solutions.

Current problems	Explanation	Solution/ Mitigation	How it helps
Reporting of aggregated data	Many surveillance systems provide only summaries or aggregated results, which prevents reanalysis or adaptation to different research questions.	Develop systems allowing access to raw data.	Enables flexible analysis, improves transparency, and allows integration across datasets and countries.
Antimicrobial susceptibility testing reporting	Results are often reported as "susceptible, standard exposure", "susceptible, increased exposure," or "resistant" without underlying quantitative data. This reporting results in the loss of valuable information on resistance trends.	Store raw MIC (minimum inhibitory concentration) and disk zone diameter data.	Preserves granularity, allows reclassification if breakpoints change, and provides richer insights into emerging resistance patterns.
Lack of link between clinical isolates and diagnosis	Laboratory results may not be connected to patient records, limiting the ability to interpret AMR in the context of infection type, patient history, or treatment outcomes.	Develop a secure system that connects laboratory results with clinical information while respecting patient privacy.	Improves clinical relevance of surveillance data, supports better treatment guidelines, and strengthens One Health integration.
Lack of real-time data sharing	Data may be reported annually or quarterly, which delays outbreak detection and timely interventions.	Develop a system for near-real-time data sharing among laboratories, hospitals, and public health authorities.	Allows early detection of resistance trends, supports rapid response, and strengthens international collaboration.
Sampling bias	Data often come mainly from hospital patients or diagnostic submissions, which may not represent the wider community or animal reservoirs.	Sample both healthy and sick individuals across human, animal, and environmental sectors. Monitoring of sewage as a composite sample of the entire population of a city.	Provides a more comprehensive and unbiased picture of AMR prevalence in the population and across ecosystems.

proportions). As a result, observed resistance rates may reflect variations in testing practices rather than true differences in underlying resistance patterns. Linking microbiological results with clinical information could help improve the interpretation of surveillance data. In the Nordic countries, nationwide personal identification numbers enable linkage across health registries within the human sector, but the secondary use of such data for cross-sectoral surveillance is governed by strict legal and regulatory frameworks, including national data protection legislation and the EU General Data Protection Regulation (GDPR).

Another limitation is the weak linkage between microbiological data and clinical information.[25] Bacterial isolates are typically reported with resistance profiles; however, they are not always linked to the clinical context, such as the patient's diagnosis and outcome, due to limited IT infrastructure and privacy concerns. This disconnection obscures the clinical impact of AMR and complicates efforts to design targeted interventions. To overcome this issue, it will be necessary first to develop national systems that securely connect microbiological results with clinical information. This could be achieved by leveraging national electronic medical record platforms and existing health data registries, and by ensuring interoperability among laboratory information management systems, hospital IT systems, and public health databases. A first step towards this goal would be to adopt standardized data formats (*e.g.*, WHO GLASS-compatible frameworks) and unique patient identifiers that enable cross-dataset linkage without compromising privacy. Ongoing pilot programs (*e.g.*, EHDS@LV pilot and HealthData@EU Pilot) involving collaborative data-sharing agreements among hospitals, laboratories, and public health authorities can serve as scalable models for national implementation.

Furthermore, all Nordic countries report to the EU EARS-Net and WHO GLASS systems and have aligned AMR policies with those of the EU. Yet, reliance on EU structures for AMR surveillance has drawbacks, including challenges with real-time data sharing stemming from reporting delays and difficulties with data integration. International systems often have to wait for data from other countries or networks, which slows decision-making and response times. Practically, any real-time surveillance will be linked to a notification system with a limited number of target pathogen/drug combinations. This is based on the rationale that routine data typically have a high noise-to-signal ratio, making them less useful for rare events. Timely data is crucial for detecting emerging resistance trends, outbreaks, and cross-border transmission events. Some measures have already been addressed by different national notification systems for selected resistant phenotypes, providing a groundwork to build on.

Finally, a vast amount of data is generated in the Nordics, which can be used for both AMR surveillance and research. In addition to genomic and metagenomic datasets deposited in public databases, data on AMR in both animals and humans, collected by national programs, as well as socio-economic and environmental variables that can be used to predict AMR, are also available. In some Nordic countries, pharmaceutical and bioprospecting companies generate enormous amounts of data that are not freely available but could be valuable sources for AMR research. The many benefits of secondary data reuse include avoiding time-consuming and costly sample collection, promoting efficient use of public funds, and enabling comprehensive monitoring of resistance trends. However, drawbacks include that the data were collected for a different purpose and that legal restrictions associated with secondary use and intellectual property apply. While efforts have been made to promote secondary use[26] and cross-border data sharing, these efforts are often hindered by national regulations, including those within the Nordic countries.

The reuse of sensitive data, particularly in fields such as health and AMR research, requires secure computing environments that comply with data protection regulations, such as the GDPR. A tension exists between the strict security requirements of organizations handling sensitive data, often demanding high-level, certified infrastructure, and the reality that many researchers rely on flexible, innovative software tools that, in general, are not formally regulated or certified. Addressing this gap will be crucial to enabling responsible and effective use of sensitive data in modern research environments. It also opens the door to the development of novel computational analysis strategies for sensitive data environments.

4.2. *Vision - Better coordination and comparability of AMR surveillance*

The Nordic countries are uniquely positioned to move from parallel national surveillance systems to an integrated regional approach. All five described countries have mature national AMR surveillance across

the human, animal, and food sectors, aligned with EU standards underpinning comparable laboratory practices and data infrastructures. This shared technical and institutional foundation reduces many barriers to regional integration and creates opportunities to advance coordinated One Health surveillance.

An integrated Nordic AMR surveillance should prioritise comparability by design. Coordinated sampling strategies and harmonized susceptibility testing across sectors, supported by epidemiological, microbiological, and computational methods, would enable consistent interpretation of resistance patterns across countries and sectors.[25] Standardisation alone, however, is insufficient. Sustained investment in joint training and capacity-building for surveillance professionals, alongside broader engagement with policymakers and the public, will be essential to disseminate evidence-based best practices and raise broader awareness of AMR in society.[27]

We propose a model for integrated AMR surveillance that follows the principle of decentralized data collection and centralized insight. It builds on existing national AMR surveillance systems in each country, aiming to collect and share data via an integrated platform to enable regional surveillance. Enhanced cooperation could benefit from federated machine learning methods that enable joint analysis across datasets that cannot be shared directly.

There are many benefits of cross-border AMR surveillance systems. Such systems would facilitate more efficient resource use by enabling countries to coordinate efforts, avoid duplication, and leverage each other's strengths. Creating shared infrastructure, data systems, and open data analytical methods and workflows would allow harmonized reporting, centralized analysis, and easier access. By sharing geographic and sectoral coverage, regions can design complementary rather than overlapping surveillance networks. Coordinated detection of emerging resistance will enable early action at the regional level. Furthermore, enabling access to integrated datasets and developing international training activities will facilitate AMR research and collaboration, with greater data integration boosting statistical power and improving trend detection.

Although our focus is limited to five Nordic countries, the proposed integrated cross-border surveillance offers a scalable and adaptable template for other countries worldwide. By demonstrating how harmonized data collection, multisectoral coordination, and One Health principles can be implemented across national boundaries, this model would be a proof of concept for other regions. At a time when AMR continues to outpace national responses, advancing regional integration is no longer optional but essential for effective surveillance, timely action, and global cooperation.

Ethical statement

Not required for this study, as it did not involve human participants, patient data, or biological samples.

Author contributions

This report was initiated through a semi-structured discussion during a 3-day meeting at DTU, Denmark, which included VKP, YW, AA, SS, LL, KP, AB, and GSS, and was hosted by PM. Further contributions were made by JBP, ADO, NMS, KR, ASRD, KOH, and AMH. AA drafted the initial manuscript, and VKP supervised manuscript preparation. All authors provided critical feedback on the manuscript and approved the final version for submission.

Use of artificial intelligence tools

Artificial intelligence tools were used for language editing, and all outputs were reviewed and verified by the authors.

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Declaration of competing interest

None declared.

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Data availability

www.nomoreamr.org.

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