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ORIGINAL RESEARCH

Characterisation and mapping of the surveillance system for antimicrobial resistance and antimicrobial use in the United Kingdom

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Abstract

Background: Surveillance of antimicrobial resistance (AMR) is an essential component of any strategy to mitigate AMR and needs regular evaluation to ensure its effectiveness. A first step for any evaluation is to describe the system and context. In this study, we aimed to characterise and map the surveillance system for AMR and antimicrobial use (AMU) in the United Kingdom (UK) using a One Health (OH) approach and to identify integration points in the system.

Methods: To describe the surveillance system for AMR/AMU, international guidelines for establishing surveillance systems for AMR and AMU were used. A review of the literature was conducted to collect information on the different parameters identified.

Results: Multiple data collection systems exist for AMU and AMR in humans, animals and food. Each sector is responsible for the planning, implementation, analysis and reporting of its own surveillance for AMR and AMU. Some cross-sectoral collaborative activities exist such as the UK AMR contingency plan and the publication of UK OH reports; there are opportunities for further integration such as the harmonisation of data analyses methods and interpretation across sectors and the publication of joint surveillance reports.

Conclusion: This overview of key stakeholders, data collection streams, reporting, linkages within and across sectors and international monitoring forms an important basis for future evaluation of the UK AMR/AMU surveillance system from a OH perspective.

KEYWORDS
AMR, AMU, antimicrobial resistance, antimicrobial use, One Health, surveillance

INTRODUCTION

Antimicrobial resistance (AMR) is a global health threat that has been met with intensified response from national and international organisations.[1,2] In 2015, WHO developed the Global Action Plan (GAP) on AMR in collaboration with the OIE and the Food and Agriculture Organisation (FAO).[3] This GAP required all countries to develop a National Action Plan (NAP) by 2017 and included five strategic objectives that provided a framework for NAPs to combat AMR. Moreover, in the UN General Assembly in 2016, heads of states committed to support and implement the GAP at national, regional and global levels.[1]

Surveillance is an essential component in the response to AMR and one of the strategic GAP objectives. It allows countries to collect data on AMU and AMR prevalence, monitor trends, detect emergence of new resistance, provide necessary data to conduct risk analysis and inform policy recommendations.[4] The inter-connected drivers of AMR that are active across sectors mean that surveillance data need to be collected from humans, animals, food and the environment in a coordinated and harmonised way to allow cross-sectoral analyses. This approach is also known as One Health (OH) surveillance. In order to assist countries in the development of integrated surveillance systems, the WHO advisory Group on Integrated Surveillance of AMR (AGISAR) developed in 2017 a guidance for the application of a OH approach to surveillance of AMR in foodborne bacteria.[5]

[1] https://www.un.org/pga/71/wp-content/uploads/sites/40/2016/09/DGACM_GAEAD_ESCAB-AMR-Draft-Political-Declaration-1616108E.pdf.

The government of the United Kingdom (UK) recognises the global threat of AMR and the need for coordinated national and international actions across sectors for risk mitigation.[6] Therefore, a 5-year AMR strategy based on a OH approach was developed in 2013, which was renewed in 2019.[7,8] The strategy is relevant in England, Northern Ireland, Scotland and Wales, but implementation can vary across the devolved administrations. Devolution is about the transfer of power by a central government to local or regional administrations. In the UK, there are distinct legislatures and governments in Scotland, Wales and Northern Ireland, which have powers over a range of policy areas.[2] The AMR strategies were developed by The Department of Health and Social Care (DHSC, previously the Department of Health), the Department for Environment, Food and Rural Affairs (DEFRA) and Public Health England (PHE) in collaboration with the UK devolved administrations. DHSC, DEFRA and PHE lead and coordinate the work of various organisations across the UK; the process is overseen by an interdepartmental High Level Steering group (HLSG). The devolved administrations are responsible for the implementation of the strategy in their own jurisdictions with some differences between the animal, environment and human sectors. For animals and the environment, DEFRA has some UK-wide responsibilities. For the human side, the implementation of the strategy is fully devolved. The UK government commissioned an independent review on AMR and the final report was published in 2016 with 10 recommendations, led by a call for a massive global awareness campaign, improved hygiene and infection prevention and a reduction in the unnecessary use of antimicrobials (AMs) in agriculture and their dissemination into the environment.[1] Based on these recommendations, the UK government made commitments across different sectors including the reduction of AMU in food producing animals (FPAs) and strengthening veterinary stewardship of antibiotics (ABs), particularly those of greatest importance to human health.[9] Some AB classes are categorised by WHO as critically important antibiotics (CIAs) for human use, of which quinolones, third- and fourth-generation cephalosporins, macrolides, glycopeptides and polymyxins are designated as 'highest priority critically important antibiotics' (HPCIAs).[10]

Surveillance systems need regular evaluation to ensure that they are operational, efficient and cost effective.[11] The evaluation of surveillance system from a OH perspective allows to assess whether cross-sectoral collaboration generates an added value.[12] The expected outcomes of integrated surveillance for AMR/AMU include increased understanding of AMR epidemiology at the interface across human health, animal health and the environment, and the changes in policy and behaviours resulting from OH information generated, which would lead ultimately to a reduction on AMR as a result of these changes.[13,14]

[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770300/IntroductionToDevolution.pdf.

To be able to capture these values and assess cross-sectoral collaboration in the surveillance system for AMR and AMU in the UK, it is essential to have a full understanding of the systems and the linkages. To the authors' knowledge, there is no overview available that map and describe the various surveillance programmes for AMR and AMU in the UK and their linkages.

The aim of this study was to characterise and map the current surveillance systems for AMR and AMU in the UK and identify integration points in the system. The findings would aid future evaluations of the surveillance system for AMR/AMU in the UK from a OH perspective.

METHODS

To describe the surveillance system, international guidelines related to surveillance for AMR and AMU were used. These include the standards described in the OIE *Terrestrial Animal Health Code*[15,16] that provide guidance for the development of national AMR surveillance and monitoring programmes in FPAs and food products and AMU in FPAs, and WHO guidance for establishing AMR surveillance in humans and for monitoring antimicrobial consumption (AMC).[17,18] In animals, the data collected for AMR included the followings: (1) Bacteria subjected to surveillance and monitoring; (2) target animal species; (3) sampling sources; (4) types of samples to be collected; (5) antimicrobial susceptibility testing (AST); (6) interpretation of data; (7) reference laboratory; and (8) annual reports. For AMU in animals, information was collected on (a) sources of antimicrobial data and (b) types and reporting formats for AMU data. For humans, AMR data collected included:(1) type of surveillance; (2) priority pathogens for surveillance; (3) pathogen-antimicrobial combinations targeted for AMR surveillance; (4) sampling setting; (5) specimens; (6) population covered; (7) test conducted; (8) interpretation of results and (9) reporting. For AMC, information was collected on: (a) data sources for consumption estimates; (b) denominator data; (c) Reporting metric and (d) contextual information relating to data collection (include any relevant information related to the data, for example if a group of patients or facility types are not included).

To collate information on these different parameters, a review of documents and literature was conducted. First, official UK documents were consulted such as the National Action Plans from 2013 and 2019; the UK AMR strategy annual progress reports; and surveillance reports for AMR/AMU in humans, animals and food across the four UK countries. The list of references in gathered articles then lead to the identification of further sources. Following an initial review, a literature search was conducted in Google to identify further sources in areas where there were gaps. The search terms used were: "antimicrobial resistance", "antibiotic resistance", "antimicrobial use", "antibiotic use", "AMR", "AMU", "surveillance",

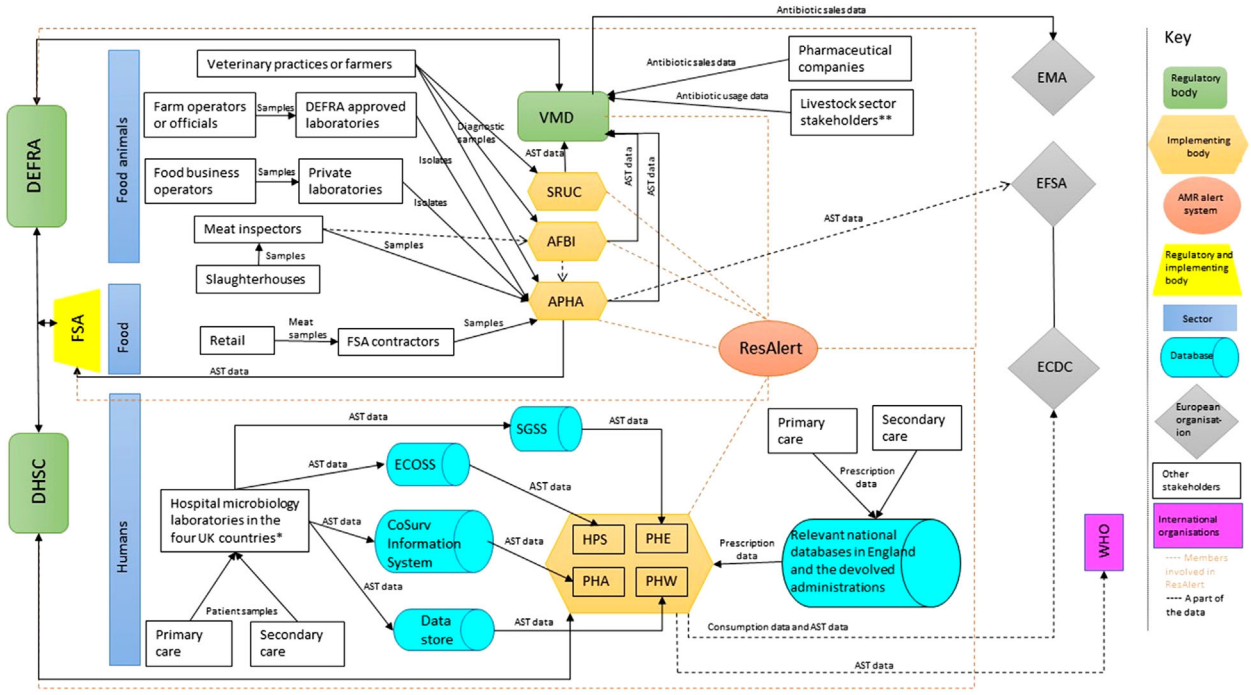

FIGURE 1 Graphical overview of the statutory elements of the surveillance system for antimicrobial use and antimicrobial resistance in the United Kingdom**.

Abbreviations: ResAlert: refers to the UK response to the identification of a resistant bacterial isolate from an animal considered to present a potential risk to human or animal health; DEFRA: Department for Environment Food and Rural Affairs; DHSC: Department of Health and Social Care; VMD: Veterinary Medicines Directorate; FSA: Food Standards Agency; APHA: Animal and Plant Health Agency; SRUC: Scotlands's Rural College; AFBI: Agri-Food and Biosciences Institute; PHE: Public Health England; HPS: Health Protection Scotland; PHW: Public Health Wales; PHA: Public Health Agency; DARC: Defra Antibiotic Resistance Coordination; SGSS: Second Generation Surveillance System (in England); CoSurv Information System in Northern Ireland; ECOSS: Electronic Communication of Surveillance in Scotland; Data Store System in Wales; ECDC: European Centre for Disease Prevention and Control; EFSA: European Food Safety Authority; EMA: European Medicines Agency; GLASS: Global Antimicrobial Resistance Surveillance System.

*Some of the isolates are submitted by Hospital Microbiology laboratories to a reference laboratory for confirmation and some of them are sent to the national databases. **Usage data are submitted voluntarily by livestock sectors.

"monitoring", "United Kingdom", "UK", "England", "Wales", "Scotland" and "Ireland". The review of the literature was conducted in June 2018 and then updated in December 2019. The surveillance activities considered were those that are part of the official structured surveillance system for AMR and AMU in the UK. The documents selected were read in full to extract the data required to describe the surveillance system as explained above; in addition, information was collected on the different stakeholders in the surveillance system. The data collected were synthesized to provide a detailed description of the different surveillance programmes in humans, animals and food; the key organisations involved; responsibilities and linkages. An overview map of the surveillance system was produced to provide a visual representation of the structure of the system and identify integrating points across sectors.

To validate the description of the surveillance programmes, two experts were consulted; one from the human health sector and one from the animal health sector. The experts were selected based on their involvement and knowledge on AMR and AMU surveillance in the UK; they were a Public Health Registrar with expertise on AMR and AMU surveillance and a Lead Epidemiologist working on a government lab on AMR surveillance in animals. The latter provided also feedback on AMR surveillance in food since all the samples from food are meat samples. For the environment, currently there is no official surveillance programme for AMR in the environment in the UK; therefore no expert was consulted from this sector. During the meetings, the data tables and map generated were presented to the experts and they were asked to provide feedback and identify potential gaps. Following this validation step, the description of the system was revised and finalised.

RESULTS

Overview map of the surveillance system for antimicrobial resistance and antimicrobial use

We identified 30 key organisations directly involved in the national surveillance system (Table 1). Out of these, 15 belong to government organisations, nine to the private sector and six to international institutions. Figure 1 represents an overview map of the key stakeholders, data collection streams, reporting and the linkages in the system. The surveillance activities of AMR and AMU are organised in each sector separately with presence of cross- sectoral integrated

TABLE 1 List of key organisations involved in the surveillance for AMR and AMU in the United Kingdom by sector

	Organisations	Sector
Government organisations	Department of Health and Social Care (DHSC)	Human health
	Department for Environment, Food and Rural Affairs (DEFRA)	Animal, plant and environment health
	Veterinary Medicine Directorate (VMD)	Animal health
	Food Standards Agency (FSA)	Food safety
	Environment Agency (EA)	Environment health
	Public Health England (PHE)	Human health
	Health Protection Scotland (HPS)	Human health
	Public Health Wales (PHW)	Human health
	Public Health Agency (PHA)	Human health
	Animal and Plant Health Agency (APHA)	Animal health
	Agri-food and Bioscience Institute (AFBI)	Animal health
	Scotland's Rural College (SRUC)	Animal health
	Centre for Environment, Fisheries and Aquaculture Science (CEFAS)	Environment health (Aquatic environment)
	Hospitals	Human health
	Primary care health centres (general practice, dental practice, walk-in centres, etc).	Human health
Private sector	British Veterinary Association (BVA)	Animal health
	Pharmaceutical companies	Drug manufacturing and distribution
	Livestock stakeholders	Animal production
	Responsible Use of Medicines in Agriculture Alliance (RUMA)	Animal production
	Private veterinarians	Animal health
	Private laboratories	Animal health
	Vet Compass	Animal health
	Small Animal Veterinary Surveillance Network (SAVSNET)	Animal health
	The Agriculture and Horticulture Development Board (AHDB)	Animal production
International organisations	World Health Organisation (WHO)	Human health
	World Organisation for Animal Health (OIE)	Animal health
	Food and Agriculture Organisation (FAO)	Animal health and food safety
	European Centre for Disease Prevention and Control (ECDC)	Human health
	European Food Safety Authority (EFSA)	Food safety
	European Medicines Agency (EMA)	Animal health

activities. Planning, data collection, analysis, interpretation and reporting are conducted by each sector separately with the exception of Scotland where there is an OH surveillance report (Scottish One Health Antimicrobial Use and Antimicrobial Resistance Report [SONAAR]).[19] There are also variations in the surveillance systems in the four UK countries, especially in humans where the implementation of the AMR strategy is fully devolved. In animals, there is a UK wide annual surveillance report for AMR and AMU, which is the Veterinary Antimicrobial Resistance Surveillance (VARSS) report, while in humans there are separate surveillance reports in each UK nation.

In terms of cross-sectoral collaboration, the most important activity is the ResAlert contingency plan, which refers to the response upon identification of a resistant bacterial isolate from an animal considered to pose a potential risk to human and/or animal health.[20] This is a UK wide plan initiated in 2015 and coordinated by the VMD in collaboration with government agencies covering human and animal health, food safety and the devolved administrations. Depending on the hazard identified, relevant advisory committees are notified by the relevant agencies.[20,21] Other examples of cross-sectoral collaborations include the UK OH reports and the DEFRA Antimicrobial Resistance Coordination (DARC) group. The UK OH report on human and animal antibiotic use, sales and resistance was produced by PHE and the VMD for the first time in 2015 and this helped to align the data across sectors and included also recommendations to address data limitations and to improve integrated analyses.[22] A second report was published in 2019, which in addition to the data included in the first report had also data on AMR in isolates from retail meat.[21] The DARC group coordinates, advises and reviews DEFRA activities on AMU in animals and AMR in micro-organisms from feedingstuffs, animals and

food. This advisory group has representatives from science and policy from England, Northern Ireland, Scotland and Wales covering human and animal health and the environment.[3]

The UK contributes to European and Global surveillance through different programmes that are represented as follows:

1. The European Antimicrobial Resistance Surveillance Network (EARS-Net): Run by ECDC and collects data on AMR in eight bacterial pathogens from invasive infections in humans (*Streptococcus pneumoniae*, *Staphylococcus aureus*, *Enterococcus faecalis*, *Enterococcus faecium*, *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa* and *Acinetobacter* spp.).[23]
2. The European Surveillance of Antimicrobial Consumption Network (ESAC-Net): Run by ECDC and collects data on the consumption of antimicrobial agents in humans.[23]
3. The European Food and Waterborne Diseases and Zoonoses Network (FWD-Net): Run by ECDC and collects data on AMR in *Salmonella* spp., *Campylobacter* spp. and Shiga toxin/verocytotoxin-producing *E. coli* (STEC/VTEC). The data contribute to the EFSA/ECDC annual summary report. To facilitate comparison of the data between countries and with results from the AMR monitoring performed in isolates from animals and food products, EU protocol for harmonised monitoring of AMR in human *Salmonella* and *Campylobacter* isolates was developed by the ECDC.[24,25]
4. The EU harmonised monitoring of antibiotic resistance in zoonotic and commensal bacteria from healthy FPAs and food: Run by EFSA and collects resistance data on *Salmonella* spp. and *Campylobacter* spp. and indicator *E. coli* and *Enterococcus* spp.[24]
5. The European Surveillance of Veterinary Antimicrobial Consumption (ESVAC): Run by EMA and collects data on the use of antimicrobial agents in animals.[26]
6. The Global Antimicrobial Resistance Surveillance System (GLASS): Run by WHO and collects information on resistance among human priority bacterial pathogens from clinical specimens considered a threat globally.[18]

The details of the sectoral structures and activities are provided in the following sections.

Surveillance of antimicrobial use and antimicrobial resistance in animals and antimicrobial resistance in food

In animals, the veterinary antibiotic resistance and sales data monitoring programme is commissioned and funded by the VMD, which is an executive agency of DEFRA. The VMD is also responsible for the publication of the VARSS report, which includes data on antibiotic consumption (sales data and usage data), and antibiotic resistance from animals in the UK.[9,27,28]

Antibiotic consumption

Antibiotic sales data are submitted annually by Veterinary pharmaceutical companies to the VMD; this has been a statutory requirement since 2005. The data are presented according to the Anatomical Therapeutic Chemical Classification System for veterinary medicinal products (ATCvet) and analysed using a Population Correction Unit (PCU). For usage data, the livestock industry and VMD developed collaboratively antibiotic usage data collection systems.[9] This initiative is coordinated by RUMA;[4] the UK agriculture and food industry alliance that promotes responsible use of medicines in farm animals. RUMA has 24 members including the British Veterinary Association (BVA) and the Agriculture and Horticulture Development Board (AHDB). Antibiotic usage data refer to the amount of ABs purchased, prescribed and/or administered. Usage data are available for meat poultry (chicken, turkey and duck), pigs, gamebirds, laying hens, dairy sectors, beef, trout and salmon industries.[27,28] Reporting coverage of AB use differs between sectors with coverage of 90% or more for poultry, laying hens and aquaculture sectors, 30% coverage for dairy and 5.5% in beef sector. For companion animals, antibiotic usage data are not systematically collected but the VMD funded studies to investigate it and the results were included in the UK-VARSS 2016.[9,29,30] These studies looked into AB prescriptions using the data that were extracted from practice management systems by VetCompass and the Small Animal Veterinary Surveillance Network (SAVSNET) system that are managed by the Royal Veterinary College and the University of Liverpool, respectively. Antibiotic sales data in dogs and cats were published in the UK-VARSS 2018.[28]

Antibiotic resistance

In England and Wales, antibiotic resistance data are produced and collected by APHA. In Scotland and Northern Ireland, this is done by SRUC Veterinary Services and AFBI, respectively. APHA is a reference laboratory for a range of infectious and non-infectious diseases in animals. In 2018, a UK International Reference Centre (IRC) for AMR was established jointly by APHA, VMD and Cefas. In 2019, this IRC was designated as an FAO Reference Centre for AMR.[31] There are two surveillance programmes for AMR: the EU Harmonised Monitoring and the clinical surveillance programme.[9,27,28,32] A description of AMR data collected from animals and food in the UK is presented

[3] https://www.gov.uk/government/groups/defra-antimicrobial-resistance-coordination-darc-group.

[4] http://www.ruma.org.uk/wp-content/uploads/2017/10/RUMA-Targets-Task-Force-Report-2017-FINAL.pdf.

in Table 2. The list of the drug–bacteria combinations tested is presented in Table S1.

The EU Harmonised Monitoring is a mandatory surveillance programme (Commission Implementing Decision 2013/652/EU[5]), which involves the testing and reporting of resistance isolates of zoonotic *Salmonella* spp., *Campylobacter* spp. and indicator *E. coli* from healthy FPAs at farm and/or slaughter and food products at retail. AST is carried out by the national reference laboratories (NRLs) and standardised methodologies are used.[28] The sampling and testing are organised following a rotation system. The sampling size and strategy are designed to provide a sample, which is representative of the wider population for each combination of bacteria and animal species. The competent authority in charge of surveillance in food is the FSA. The collection of meat samples at retail is conducted by FSA contractors, and the analysis and interpretation are conducted by APHA.[33] In addition to publishing data from this programme in the UK-VARSS report and in FSA reports for retail meat, the results are also submitted to EFSA for inclusion in the European Union Summary Report on AMR in zoonotic and indicator bacteria obtained from humans, FPAs and food.[24]

The clinical surveillance programme is based on passive surveillance and involves the collection of samples from carcasses or other diagnostic samples that have been submitted to government laboratories by farmers or private veterinary surgeons. When a potential bacterial pathogen is identified, AST is conducted. England and Wales have a combined clinical surveillance programme and AST is performed by APHA. Scotland and Northern Ireland conduct separate clinical surveillance programmes and AST are performed by SRUC Veterinary Services and AFBI, respectively. The main aim of this programme is to provide a diagnostic service for veterinarians, but it also helps to identify new and emerging patterns of resistance. Because samples are submitted voluntarily and representativeness is not known, results cannot be extrapolated to the whole livestock population.

In addition to the EU monitoring and clinical surveillance programmes, *ad hoc* surveys are also conducted to inform surveillance activities.[34] Any resistant bacterial isolate detected (through clinical surveillance or EU statutory surveillance) and considered to pose a potential risk to human or animal health is reported to the VMD for consideration and management in accordance with the guidelines of the AMR Contingency Plan (also known as the Res-Alert contingency plan).[20,28]

Surveillance of antimicrobial use and antimicrobial resistance in humans

The English Surveillance Programme for Antimicrobial Use and Resistance (ESPAUR) was established in response to the UK government's AMR strategy and is led by PHE.[23,35] In Scotland, the Control of Antimicrobial Resistance in Scotland (CARS) team in HPS is in charge of delivering the UK AMR strategy.[19,36] In Northern Ireland and Wales, PHA and PHW, respectively, are responsible for the implementation of the strategy.[37–39] A detailed description of antimicrobial resistance data collected, data sources, tests conducted, interpretative criteria and reporting is presented in Table 3. The full list of drug–bacteria combinations recommended for the monitoring of AMR as a part of the UK AMR strategy is presented in Table S3.

Antibiotic consumption

Prescription data are collected from primary care and secondary care in the four UK countries using a variety of systems. Antibiotics are prescribed in various settings including general practice (GP), dental practice, hospitals, out-of-hours services and walk-in centres. The different sources of data and reporting are presented in Table S2 . Antibiotic consumption data are classified based on the Anatomical Therapeutic Chemical classification system, using the WHO defined daily dose (DDD) per 1000 inhabitants and per day. For the denominator, mid-year population estimates are used to express DDDs per 1000 inhabitants/day. Data from private prescriptions dispensed in the community and private hospitals are not reported.[22,35,40]

Antibiotic resistance

To assess the impact of the strategy in slowing the growth of AMR, data on resistance trends in key bloodstream infections and gonorrhoea is monitored using the proportion of resistant pathogens to specific antibiotics as an outcome measures. In each UK country, AMR data are submitted voluntarily (passive surveillance) by microbiology laboratories and collated in separate national databases. The four UK countries all collect AMR data, but there are differences in data management. For example, in England, the Second Generation Surveillance System (SGSS) is maintained by PHE and contains data submitted electronically by approximatively 98% of NHS laboratories.[19,38,39]

DISCUSSION

This study showed that the surveillance system for AMR and AMU has a multitude of stakeholders, processes, activities, data sources, within the human, animal and food sectors. The graph and tables generated provide an overview of the stakeholders involved in the four UK countries in regulation, implementation and governance; data collection streams, reporting, linkages within and across sectors, and international

[5] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:303:0026:0039:EN:PDF.

TABLE 2 Description of antimicrobial resistance surveillance data collected from animals and food in the United Kingdom

Surveillance programme	Bacteria subjected to surveillance	Target animal species	Sampling source	Sample type	Output	Test conducted	Interpretive criteria	Reporting
EU harmonised antibiotic resistance monitoring* (active surveillance)	*Salmonella* spp.	Laying hens, broilers and fattening turkeys	Farm under NCP	Boot swabs/dust samples	Prevalence of resistant bacteria[a]	Bacterial isolation, serotyping and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
		Broilers and fattening turkeys	Processing plants	Carcass neck skin	Prevalence of resistant bacteria[a]	Bacterial isolation, serotyping and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
		Pigs	End of processing	Carcass swab	Prevalence of resistant bacteria[a]	Bacterial isolation, serotyping and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
	Campylobacter jejuni	Broilers and fattening turkeys	Slaughter	Caecal samples	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
	Indicator *E. Coli*	Broilers and Turkeys	Slaughter	Caecal samples	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
		Pigs	Slaughter	Caecal samples	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
	Extended Spectrum β-Lactamase (ESBL-), AmpC-, and carbapenemase-producing *E. coli*	Broilers and fattening turkeys	Slaughter	Caecal samples	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
		Pigs	Slaughter	Caecal samples	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	VARSS report, EU summary report
		Broilers	Retail	Fresh meat	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	FSA website, EU summary report
		Pigs and bovines	Retail	Fresh met	Prevalence of resistant bacteria[a]	Bacterial isolation and AST	EUCAST ECOFF and CBP	FSA website, EU summary report
Clinical surveillance of antibiotic resistance	Animal bacterial pathogens	Livestock animals	Not applicable	Carcasses and other diagnostic samples	Prevalence of resistant bacteria	Bacterial isolation and AST	BSAC[g] CBP for England, Wales and Scotland; and CLSI[h] in Northern Ireland	VARSS report, For Scotland, the results are also included in SONAAR report
(passive surveillance)	*Salmonella* spp. isolated as a part of the UK Zoonoses Order 1989	Animals and their environment	Not applicable	Samples from animals or their environment	Prevalence of resistant bacteria	Bacterial isolation, serotyping and AST	BSAC CBP for England, Wales and Scotland; and CLSI in Northern Ireland	VARSS report

*The sampling and testing are organised following a rotation system with monitoring of laying hens, broilers, fattening turkeys (and their products) in 2014, 2016, 2018 and 2020 and monitoring of pigs and bovines under 1 year, pig meat and bovine meat in 2015, 2017 and 2019.

**The programme incorporates also results from AST of Salmonella isolates recovered as a part of the UK Zoonoses Order 1989 (http://www.legislation.gov.uk/uksi/1989/285/made).

Abbreviations: AST, antimicrobial susceptibility testing; BSAC: British Society for Antibiotic Chemotherapy; CBP: Human Clinical Break Point (relates laboratory results to likely clinical treatment success or failure); CLSI: Clinical Laboratory and Standards Institute; ECOFF: epidemiological cut off (represents the point at which bacteria have developed a higher level of resistance to an antibiotic than the background level of resistance that exists naturally for that bacterial species); EUCAST: European Committee on Antimicrobial Susceptibility Testing; NCP, National Control Plan for *Salmonella*.

[a]The list of drug-bug combinations for EU harmonised monitoring is presented in Table S1.

TABLE 3 Description of antimicrobial resistance surveillance data collected in humans in the four countries of the United Kingdom

Country	Surveillance programme	Priority pathogens for AMR surveillance	Sources of data	Sampling setting	Test conducted	Interpretive criteria	Reporting
England	Second-Generation Surveillance System (SGSS)	- Key pathogens monitored as a part of the UK AMR strategy[a]. - Carbapenamase-producing organisms (CPO)	Hospital microbiology laboratories	Primary and secondary care	Species identification and AST	EUCAST CBP	ESPAUR, Fingertips portal*, EARS-NET
	Gonococcal Resistance to Antimicrobials Surveillance Programme (GRASP)	*Neisseria gonorrhoeae*	PHE's national reference laboratory	A network of sentinel genitourinary medicine clinics (in England and Wales)	Specie's identification and AST	EUCAST CBP	ESPAUR, Fingertips portal*, annual report, ECDC surveillance report
	Antifungal resistance	*Aspergillus* spp. and *Candida* spp.	CDR, National Mycology Reference Laboratory (MRL) in Bristol and Mycology Reference Centre (MRCM) in Manchester	MRL receives referred samples from NHS trusts, regional mycology reference centres and private microbiology laboratories throughout the United Kingdom. The MRCM works in partnership with the National Aspergillosis Centre and other hospitals to provide laboratory services to patients in the United Kingdom.	Antifungal susceptibility test	MRL uses CLSI and MRCM uses EUCAST	ESPAUR
Scotland	Electronic communication of surveillance in Scotland (ECOSS)	- Key pathogens monitored as a part of the UK AMR strategy[a]. - Carbapenamase-producing organisms. - Gastro-intestinal infections including *Salmonella* and *Shigella*. - *Candida* spp.	Hospital microbiology laboratories	Primary and secondary care	Species identification and AST	EUCAST CBP	SONAAR report, EARS-NET

(Continues)

TABLE 3 (Continued)

Country	Surveillance programme	Priority pathogens for AMR surveillance	Sources of data	Sampling setting	Test conducted	Interpretive criteria	Reporting
	Gonococcal antibiotic surveillance in Scotland (GASS)	*Neisseria gonorrhoeae*	The Scottish Bacterial Sexually Transmitted Infections Reference Laboratory (SBSTIRL)	Sexual health clinics	Specie's identification and AST	EUCAST CBP	SONAAR, annual report, ECDC surveillance report
Northern Ireland	Public Health Agency's CoSurv Information System	- Key pathogens monitored as a part of the UK AMR strategy[a]. - Carbapenamase-producing organisms.	Laboratories of the five Health and Social Care Trusts in Northern Ireland	Primary and secondary care	Species identification and AST	accredited CLSI methodology	Annual report, EARS-NET
	European Gonococcal Antimicrobial Surveillance Programme (Euro-GASP)	*Neisseria gonorrhoeae*	Royal Victoria Hospital, Belfast	Sexual health clinics	Specie's identification and AST	EUCAST CBP	Annual report, ECDC surveillance report
Wales	Welsh regional DataStore systems	- Top 10 bacteraemia pathogens - Urinary coliforms - Wound swab isolates (*Staphylococcus aureus*) - Other pathogens: *Streptococcus pneumoniae; Streptococcus pyogenes; Haemophilus influenza; Campylobacter* spp.	Hospital microbiology laboratories	Primary and secondary care	Species identification and AST	EUCAST CBP	Annual reports accessible online via Public Health Wales AMR programme website, EARS-NET
	Gonococcal Resistance to Antimicrobials Surveillance Programme (GRASP)	*Neisseria gonorrhoeae*	PHE's national reference laboratory	A network of sentinel genitourinary medicine clinics (in England and Wales)	Species identification and AST	EUCAST CBP	Annual report, ECDC surveillance report

Abbreviations: AST, antimicrobial susceptibility testing; EUCAST, European Committee on Antimicrobial Susceptibility Testing; CBP: Human Clinical Break Point (relates laboratory results to likely clinical treatment success or failure); CDR, Communicable Disease Reporting; CLSI, Clinical Laboratory and Standards Institute.

The table is based on information extracted from Refs. 19,23,35–38, and 40.

[a]Key pathogens are *Escherichia coli*, *Klebsiella pneumoniae*, Pseudomonas spp., *Streptococcus pneumoniae*, *Klebsiella oxytoca*, *Staphylococcus aureus*, Enterococcus spp. and Acinetobacter spp.

*Fingertips data portal: https://fingertips.phe.org.uk/profile/amr-local-indicators.

monitoring. They allow drawing comparisons across sectors and characterising existing integration and opportunities for future integration. Consequently, they form an important basis for any future evaluation of the UK AMR/AMU surveillance system from a OH perspective and are a resource for surveillance experts working on the design of cross-sectoral systems. Implications for surveillance system evaluations are discussed below.

The study highlighted that there are variations in the surveillance system for AMR and AMU between the four UK nations, and identified integration points as well as opportunities for further integration. In animals, surveillance of antibiotic consumption is mainly based on sales data, however these data are an estimate of the quantity of ABs used and do not enable detailed analyses such as the consumption by animal species or production system. Although AB usage data are submitted voluntarily by some livestock stakeholders, there are still substantial differences in reporting coverage between livestock sectors. For AMR surveillance in animals, one of the main programmes is the EU harmonised monitoring. However, with the uncertainties around Brexit, it is not known whether the UK would continue to contribute to this programme. In humans, surveillance of AMR is based on voluntary reporting by hospital microbiology laboratories. Although there is a high reporting rate, weaknesses of this system remain due to incomplete data collection. Also, resistance data are collected from clinical cases and do not include isolates from healthy persons. Regarding AMU in humans, data from private prescribers are not reported. Having a system that captures data from private healthcare practices is important to assess the extent of AMU from these sources.

There is a lack of data from the environment, which is considered to represent a significant pathway for the transmission of AMR to humans and animals.[41] This has been acknowledged by the UK government and one of the priorities in the new AMR strategy is to understand better the role of the environment in the spread of AMR.[8] In addition, in 2018, a network of 23 partners (including UK government agencies APHA, Cefas, EA, PHE and VMD) was awarded funding from the Joint Programme Initiative on AMR to identify robust, measurable surveillance indicators and methodologies for assessing AMR levels in the environment.[6] The UK contributes also to European and global surveillance through different programmes.[18,24,26,42] This collaboration helps harmonise how the data are collected and shared and allows comparison between countries. However, there remain significant differences on how these data are collected and analysed between the different sectors including the use of different laboratory methods and different interpretative criteria for resistance, which hinders cross-sectoral comparisons.[24,25]

In the UK , each sector is responsible for the planning, implementation, analysis and reporting of its own surveillance for AMR and AMU, with presence of cross-sectoral collaborative activities. These include: (1) the availability of a UK wide AMR contingency plan, which allows a timely response in the case of the discovery of a resistance that poses a risk to human or animal health; (2) the publication of the UK OH reports, with the aim of supporting cross-sectoral analyses; (3) the DARC group; and (4) the publication of an annual OH surveillance report in Scotland. To strengthen integration, actions can be taken at different levels. At the level of data collection, integration can be increased by including resistance data from companion animals and from locations in the environment; by including isolates from vegetables, fruits and herbs; by collecting antibiotic usage data from species that are not covered and by increasing coverage in species with low coverage. Integration can also be increased by harmonizing data analyses methods and interpretation across sectors to enhance the comparability of the information produced. This was highlighted in the new AMR strategy and one of the commitments is to "explore how to coordinate and harmonise surveillance schemes across the different sectors".[8] At the level of information dissemination, integration can be increased by moving from producing different surveillance reports for each sector to integrating all surveillance information in a joint report. Also, these surveillance reports need to include data for the whole of the UK.

We are aware that these results are based on surveillance activities that are part of the official surveillance programmes for AMR and AMU in the UK and do not include other non-official programmes, which constitutes a limitation. On the other hand, these are the main data used by the UK government to inform policy decisions and strategies on AMR and AMU. Also, the integrated activities listed in this paper were based on the activities reported in the documents reviewed and other forms of collaboration that might be taking place but not reported may have been missed.

Around the world, there are few countries with combined analysis and reporting of an integrated AMR/AMU surveillance programmes such as Denmark, Sweden, Canada and the Netherlands.[5,43,44] For example, the Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP) was established in 1995 as a collaboration between the Ministry of Health and the Ministry of Food, Agriculture and Fisheries and produces joint annual reports.[45] It is important to note that a greater level of integration in a system does not necessary result in a more cost-effective system. For this reason, countries need to know how to achieve integration in a cost-effective manner. A conceptual framework to assess the added value of OH surveillance for AMR/AMU was developed in Canada, which provides a conceptual basis for structuring the evaluation of different surveillance outcomes.[13]

Surveillance of AMR and AMU is crucial to provide evidence for decisions to develop interventions to mitigate AMR, and to assess the effectiveness of these

[6] https://www.jpiamr.eu/supportedprojects/7th-call-results/.

interventions by monitoring the rates of resistance following their implementation. This study allowed to characterise and map the surveillance system for AMR/AMU in the UK from a OH perspective and identify integrating points. In addition, suggestions have been made on opportunities for further integration. Surveillance is expensive and appropriate resources need to be allocated to integrated activities. To ensure that the surveillance programmes are operational and cost effective, regular evaluation is needed and an evaluation of the system from a OH perspective is essential to assess whether cross-sectoral collaboration generates an added value. This work has created a foundation for the evaluation of the performance of the AMR/AMU integrated surveillance system in the UK, an activity currently ongoing.

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ETHICS STATEMENT

There were no ethical concerns in relation to this study since experts were consulted only to check accuracy of information and answered in capacity of their professional role.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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