Quadripartite guidance on One Health integrated surveillance of antimicrobial resistance and use

Food and Agriculture Organization of the United Nations
UN environment programme
World Health Organization
World Organisation for Animal Health

Quadripartite guidance on One Health integrated surveillance of antimicrobial resistance and use

Food and Agriculture Organization of the United Nations
UN environment programme
World Health Organization
World Organisation for Animal Health

Quadripartite guidance on One Health integrated surveillance of antimicrobial resistance and use

ISBN (WHO) 978-92-4-010986-5 (electronic version)
ISBN (WHO) 978-92-4-010987-2 (print version)
ISBN (FAO) 978-92-5-139820-3
ISBN (UNEP) 978-92-807-4261-9
DOI (UNEP) https://doi.org//10.59117/20.500.11822/49175
DOI (WOAH) https://doi.org/10.20506/woah.3585

© World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme and World Organisation for Animal Health, 2025

Some rights reserved. This work is available under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 IGO licence (CC BY-NC-SA 3.0 IGO; https://creativecommons.org/licenses/by-nc-sa/3.0/igo/).

Under the terms of this licence, you may copy, redistribute and adapt the work for non-commercial purposes, provided the work is appropriately cited, as indicated below. In any use of this work, there should be no suggestion that the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP) or World Organisation for Animal Health (WOAH) endorse any specific organization, products or services. The use of WHO, FAO, UNEP or WOAH logos is not permitted. If you adapt the work, then you must license your work under the same or equivalent Creative Commons licence. If you create a translation of this work, you should add the following disclaimer along with the suggested citation: "This translation was not created by the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP) or World Organisation for Animal Health (WOAH). WHO, FAO, UNEP and WOAH are not responsible for the content or accuracy of this translation. The original English edition shall be the binding and authentic edition".

Any mediation relating to disputes arising under the licence shall be conducted in accordance with the mediation rules of the World Intellectual Property Organization http://www.wipo.int/amc/en/mediation/rules.

Suggested citation. Quadripartite guidance on One Health integrated surveillance of antimicrobial resistance and use. Geneva: World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme and World Organisation for Animal Health; 2025. Licence: CC BY-NC-SA 3.0 IGO.

Cataloguing-in-Publication (CIP) data. CIP data are available at http://apps.who.int/iris.

Sales, rights and licensing. To purchase WHO publications, see https://www.who.int/publications/book-orders. To submit requests for commercial use and queries on rights and licensing, see http://www.who.int/copyright.

Third-party materials. If you wish to reuse material from this work that is attributed to a third party, such as tables, figures or images, it is your responsibility to determine whether permission is needed for that reuse and to obtain permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

General Disclaimers. The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO, FAO, UNEP or WOAH concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

The mention of specific companies or of certain manufacturers' products, whether or not these have been patented, does not imply that they are endorsed or recommended by WHO, FAO, UNEP or WOAH in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

All reasonable precautions have been taken by WHO, FAO, UNEP and WOAH to verify the information contained in this publication. However, the published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall WHO, FAO, UNEP and WOAH be liable for damages arising from its use.

Contents

Foreword v
Acknowledgements vi
Abbreviations vii
Glossary viii

1 Introduction 1

2 Purpose, scope and target readership 5
2.1 Purpose 5
2.2 Target readership 5
2.3 Scope of the Guidance 6
2.4 Scope of integrated surveillance of antimicrobial resistance (AMR) and antimicrobial use (AMU) 6
2.4.1 One Health sectors 6
2.4.2 One Health interfaces 7

3 Definition and purposes of One Health integrated surveillance of AMR and AMU 8
3.1 Definition 8
3.2 Examples of systems for sector-specific and integrated surveillance of AMR and AMU 8
3.3 Goals and objectives 11
3.3.1 Objective 1. Provide information on patterns, trends and potential associations 11
3.3.2 Objective 2. Support and inform risk analysis for AMR 12
3.3.3 Objective 3. Alert authorities about emerging and re-emerging AMR and changes in patterns of AMU 12
3.3.4 Objective 4. Inform development of and assess the effectiveness of interventions to address AMR and improve public health and sector-specific outcomes 12
3.4 Where integrated surveillance can inform action 13
3.5 Stages in establishing, building or improving One Health integrated surveillance for AMR and AMU 13
3.5.1 Stage 1: Situation analysis, planning and resourcing 17
3.5.2 Stage 2: Sampling and data collection 28
3.5.3 Stage 3: Sample processing, laboratory analysis and quality control 28
3.5.4 Stage 4: Data integration, analysis, reporting and communication 30
3.5.5 Stage 5: Monitoring and evaluation 31
3.6 Data access, confidentiality and sharing 32
3.7 Data repositories 33

4 Priority microbial targets, metrics and indicators 34
4.1 Introduction 34
4.2 Characteristics of microbial targets for AMR surveillance at the interface between two or more sectors 34
4.2.1 Priority microorganisms and antimicrobial agents to be considered as biological and antimicrobial targets and indicators 34
4.2.2 Metrics for One Health integrated surveillance of AMR 37
4.2.3 Characteristics of indicators for AMU surveillance in two or more sectors 38
4.3 Data analysis and interpretation 40
4.4 Communication and reporting 41

5 Resources and requirements 43
5.1 Introduction 43
5.2 Potential points of integration 44
5.2.1 Human resources 44
5.2.2 Infrastructure 44
5.2.3 Consumables 45
5.2.4 Capital investment and expenditure for maintenance 45
5.3 Benefits, enablers and challenges in resource allocation in a One Health context 47

References 48

Annex 1. Considerations for implementation and operationalization of integrated surveillance 55

Annex 2. Detailed methodology 58

Tables

Table 1. Existing sector-specific surveillance systems 3
Table 2. Integrated surveillance of AMR/AMU: country examples and global guidance 9
Table 3. Suggested epidemiological data requirements for AMU 21
Table 4. Suggested core epidemiological and microbiological data requirements for reporting data and pathogen identification in isolates 22
Table 5. Antimicrobial classes and subclasses proposed for an antimicrobial panel for testing bacteria in an integrated surveillance system 29
Table 6 Microbial targets for One Health integrated surveillance according to evidence for transmission of AMR among sectors 35
Table 7. AMU metrics for One Health integrated surveillance 38
Table 8. Suggested core requirements and resources for undertaking One Health integrated surveillance of AMR and AMU 46

Figures

Fig. 1. AMR and AMU surveillance in the One Health approach 2
Fig. 2. Venn diagram of potential One Health interfaces for integrated surveillance 7
Fig. 3. Use of outputs of integrated surveillance of AMR and AMU at various levels 13
Fig. 4. Approach A. Use of existing surveillance systems 14
Fig. 5. Approach B. Building a new integrated surveillance system 15
Fig. 6. Stages and steps in establishing One Health integrated surveillance of AMR and AMU 16
Fig. 7. Setting priorities for epidemiological design of a One Health integrated surveillance system 19
Fig. 8. Joint integration and coordination of an integrated surveillance system 27
Fig. 9. National entity to coordinate, integrate and analyse data on AMR and AMU collected by entities or institutions in each sector 27

Foreword

Antimicrobial resistance (AMR) is a global health threat. Increasing use and misuse of antimicrobials are among the factors in its development. Preventing and controlling the spread of AMR are critical for preserving the efficacy of existing antimicrobials to safeguard human and animal health, sustain global food and water security and ensure achievement of global targets. A One Health approach, which is an interlinked, collaborative, multilateral strategy spanning ecosystems, disciplines and national boundaries, is crucial for mitigating AMR.

Integrated surveillance of AMR and antimicrobial use (AMU) in the human, animal, crop/plant and environmental sectors is integral to the One Health response to AMR. It comprises continuous, collaborative, coordinated, systematic collection, collation, analysis, interpretation, communication and sharing of data on AMR and AMU for the development of actionable public health policies. Therefore, integrated surveillance is a critical priority of the Quadripartite organizations[1] and the Global Leaders Group on AMR. For this, it is necessary to ascertain the needs, scope and format of integrated surveillance, review and refine the current definition of integrated surveillance and provide global guidance applicable to context-appropriate national systems and establishment of effective capacities for integrated surveillance.

This overarching publication on One Health integrated surveillance of AMR and AMU is designed to provide such guidance. It includes a range of validated methods for AMR and AMU surveillance that can generate comprehensive, robust and actionable data to address the needs of countries, regions and the global community. The Guidance is a living document that provides purpose-driven, context-appropriate road maps for developing and strengthening One Health-based integrated surveillance of AMR and AMU systems.

In line with the role of the Quadripartite in coordinating the global One Health response to AMR, we emphasize the crucial need for ministries responsible for the One Health sectors to collaborate in strengthening multisectoral national AMR governance and its inclusion in national action plans. We call on all stakeholders, including implementers, resource partners, academia, the private sector and civil society, to support adoption and implementation of the recommendations provided in this Guidance to generate data for action. This will improve human, animal, plant and environmental health, promote economic national, regional and global growth and advance progress towards global targets.

Qu Dongyu
Director-General
Food and Agriculture Organization of the United Nations

Inger Andersen
Executive Director
United Nations Environment Programme

Tedros Adhanom Ghebreyesus
Director-General
World Health Organization

Emmanuelle Soubeyran
Director-General
World Organisation for Animal Health

1 The Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO) and the World Organisation for Animal Health (WOAH) are collectively referred to as the "Quadripartite".

Acknowledgements

The Quadripartite thanks the following contributors

The Quadripartite Technical Group on Integrated Surveillance on antimicrobial use and resistance (QTG-AIS): Muna Abu Sin (Federal Ministry of Health, Germany), Oluwawemimo Adebowale (Federal University of Agriculture Abeokuta, Nigeria), Laurence Armand-Lefevre (Université Paris Cité, France), John Berezowski (Scottish Rural College, United Kingdom of Great Britain and Northern Ireland [United Kingdom]), Rajesh Bhatia (India), Damien Bouchard (French Agency for Veterinary Medicinal Products/French Agency for Food, Environmental and Occupational Health and Safety, France), Carolee Carson (Canadian Integrated Program for Antimicrobial Resistance Surveillance, Canada), Biyun Ching (National Parks Board, Singapore) Rungtip Chuanchuen (Chulalongkorn University, Thailand), Sabiha Essack (University of KwaZulu-Natal, South Africa), Teresa Estrada Garcia (Instituto Politécnico Nacional, Mexico), Marquita Gittens-St Hilaire (The University of West Indies, Barbados), David Graham (Newcastle University, United Kingdom), Rene Hendriksen (National Food Institute, Technical University of Denmark), Xian-Zhi Li (Health Products and Food, Health Canada), Mashkoor Mohsin (University of Agriculture, Pakistan), Arshnee Moodley (International Livestock Research Institute, Kenya), Rosa Perán I Sala (Ministry of Health, Welfare and Sport, Department International Affairs, Netherlands [Kingdom of the]), Amy Pruden (Virginia Polytechnic Institute and State University, USA), Heike Schmitt (Delft University of Technology, Netherlands [Kingdom of the]), Katharina Stärk (Federal Food Safety and Veterinary Office, Switzerland), John Stelling (Brigham and Women's Hospital, USA), Philip Taylor (CAB International, United Kingdom), Jaap Wagenaar (Utrecht University, Netherlands [Kingdom of the]), Dariuz Wasyl (National Veterinary Research Institute, Poland) and Yong-Guan Zhu (Research Center for Eco-environmental Sciences and Institute of Urban Environment Chinese Academy of Sciences, China).

Declarations of interest were collected and thoroughly reviewed according to WHO standard operating procedures. No competing interests were found for any of the experts during the period in which contributions were made (December 2022–December 2024).

The Quadripartite Core Group: Alejandro Dorado Garcia, Agnes Agunos and Francesca Latronico (FAO); Aitziber Echeverria (UNEP); Jorge Matheu Alvarez, Sergey Eremin, Arno Muller and Chinyere Okoro (WHO); and Delfy Gochez, Ana Luisa Pereira Mateus and Holy Akwar (WOAH).

AMR and AMU teams at the headquarters of the Quadripartite organizations: Norma Sofisa Hurif (FAO); Ludovic Bernaudat, Susan Grooters, Fernando Iturburu, Haosong Jiao, Miguel Salazar and Victor Hugo Estellano Schulze (UNEP); and Chiara Achangwa and Afeke Kambui (WHO).

The Quadripartite thanks the following peer reviewers:

Headquarters: Junxia Song, Thanawat Tiensin (FAO); Anand Balachandran, Silvia Bertagnolio, Anna Dean, Haile Getahun, Breeda Hickey, Yvan Hutin, Benedikt Huttner, Kavita Kothari and Jean-Pierre Nyemazi (WHO).

Regional and country offices: Kuastros Belaynehe, Nicolas Keck, Muhammad Usman Zaheer, Ruth Omani and Marie Verhaegen (FAO); Pilar Ramon-Pardo, Benyamin Sihombing and Bassim Zayed (WHO); and Nadia Brik, Marina Sokolova and Pondpan Suwanthada (WOAH).

WOAH collaborating and reference centres: National Veterinary Assay Laboratory (Japan) and Food and Drug Administration and Center for Veterinary Medicine (USA).

Financial support: Funding for development of the Quadripartite guidance on One Health integrated surveillance of antimicrobial resistance and use was kindly provided by the Ministry of Health and Welfare, Republic of Korea, and the Deutsche Gesellschaft für Internationale Zusammenarbeit, Germany.

Abbreviations

AMR	antimicrobial resistance
AMU	antimicrobial use
ANIMUSE	global database on antimicrobial use in animals (WOAH)
ARG	antimicrobial resistance gene
AST	antimicrobial susceptibility testing
CIPARS	Canadian Integrated Program for Antimicrobial Resistance Surveillance
DANMAP	Danish Antimicrobial Resistance Monitoring and Research Programme
ESBL	extended beta-lactamase
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GLASS	Global Antimicrobial Resistance and Use Surveillance System (WHO)
HR	human resources
IT	information technology
InFARM	International FAO Antimicrobial Resistance Monitoring System
JIACRA	Joint Inter-agency Antimicrobial Consumption and Resistance Analysis (European Union)
MARAN	Monitoring of Antimicrobial Resistance and Usage in Animals in the Netherlands
MGE	mobile genetic element
MIC	minimum inhibitory concentration
NARMS	National Antimicrobial Resistance Monitoring System (USA)
PCR	polymerase chain reaction
SDG	Sustainable Developmental Goal
SOP	standard operating procedure
SWOT	strengths, weaknesses, opportunities and threats
UNEP	United Nations Environment Programme
USA	United States of America
WHO	World Health Organization
WOAH	World Organisation for Animal Health

Glossary

Active surveillance: regular outreach to prompt reporting of specific diseases or microorganisms. It is often used to validate data from passive reporting or can be used in specific epidemiological investigations. In the case of AMR, proactive active surveillance is often used for systematic collection and analysis of samples from apparently healthy individuals (i.e. showing no signs of illness) to monitor the presence and levels of AMR in populations *(1)*, to identify potential risks of transmission to other sectors through direct contact or through the food chain.

Antimicrobial resistance: AMR occurs when bacteria, viruses, fungi and parasites no longer respond to antimicrobial agents. As a result of drug resistance, antibiotics and other antimicrobial agents become ineffective, and infections become difficult or impossible to treat, increasing the risk of disease spread, severe illness and death *(2).*

Antimicrobial use indicator: An AMU indicator consists of a numerator and a denominator to monitor and assess the patterns, quantities and types of antimicrobial agents used or disposed of in various sectors (human health, animal, plants/crops and environment) *(3–7)*. "Antimicrobial compound indicators" are for residues in the environment *(8,9).*

AMU metrics: A system or standard of measurement of AMU, antimicrobial quantities and antimicrobial compounds in human health, animals, plants/crops and the environment *(3–7).*

Antibiotic: A naturally occurring, semi-synthetic or synthetic substance that kills or inhibits the replication of bacteria *(10,11).*

Antimicrobial compound: Antimicrobial compounds and their metabolites in the environment *(8,9).*

Antimicrobial compound concentration: Concentrations of antimicrobials, their metabolites and other potentially co-selective chemical agents, such as heavy metals, in the environment *(8).*

Antimicrobial: Agent used to prevent, control and treat infectious diseases in humans, animals and plants. They include antibiotics, fungicides, antiviral agents and parasiticides. Disinfectants, antiseptics, other pharmaceuticals and natural products may also have antimicrobial properties *(2).*

Consumable: A commodity or good that people buy regularly to be used once or a few times and is replaced often.

Data: Microbiological and epidemiological information, such as on demographics from surveillance systems that include human and animal health facilities, food chain, farms and the environment.

Effectiveness: Production of the intended results.

Efficiency: Working well in an organized way, without wasting time or energy.

Infrastructure: Physical resources and non-physical systems that require maintenance.

Maintenance expenditure: Recurrent expenditure for the upkeep of resources.

Microbial target: A target used in AMR surveillance is defined as "a microorganism or resistance gene" or a "molecular marker or surrogate" or a microbial population with reduced susceptibility to an antimicrobial or antifungal agent, used to measure or quantify the level of AMR in a complex biological sample among selected antimicrobial agents.

One Health interface: The interface of sectors at which humans, animals, plants/crops and the environment overlap, intersect or interact (see section 2.4.2).

One Health: An integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems. It recognizes that the health of humans, domestic and wild animals (aquatic and terrestrial), plants, agri-food systems, and the wider environment (including ecosystems) are closely linked and interdependent.

One-Health integrated surveillance of AMR and AMU. Continuous, collaborative, coordinated, systematic collection, collation, analysis, interpretation, communication and sharing of data on AMR and AMU and associated metadata. These includes data from humans, animals and products thereof, plants/crops and products thereof, and the environment to provide harmonized information that can be used as a basis for decisions and actions to reduce the burden of AMR and preserve the effectiveness of antimicrobial agents,

Passive surveillance. Systems in which information on AMR events and AMU is brought to the attention of authorities without them actively seeking it.

Resource. The input that the surveillance system requires to function, which can be summarized in three categories – human resources (HR), infrastructure, and consumables – in addition to one-off capital investment and/or recurring maintenance costs.

Sample. For the purposes of this Guidance, the term refers to biological specimens collected from humans, animals and animal-derived products, plants/crops and products, and/or natural and built environments to test for the presence and characteristics of antimicrobial-resistant microorganisms, antimicrobial resistance genes (ARGs) or mobile genetic elements (MGEs).

Surveillance: Continuous, systematic collection, analysis and interpretation of health-related data on human, animal, plant/crop and environmental health. It includes timely dissemination of information so that action can be taken *(3–7).* Data from surveillance serve as the basis for detection of potential outbreaks in an early warning system to prevent what could become a public health emergency. It enables monitoring and evaluation of the impact of an intervention, helps track progress towards specified goals and clarifies the epidemiology of health issues.

1 Introduction

Antimicrobial agents such as antibiotics are used to treat, prevent and control infections. Resistance to such agents can develop in microorganisms, making them less effective and increasing rates of morbidity and mortality. During the past 80 years of widespread use of antimicrobial agents, resistance has emerged in nearly all bacterial pathogens. Antimicrobial resistance (AMR) has thus become a global threat to humans *(11,12)*, animals *(13)*, plants/crops *(14–16)* and ecosystems *(17–28).*

If no action is taken, AMR could result in US$ 1 trillion of additional health-care costs per year by 2050 and US$ 1–3.4 trillion of loss in gross domestic product per year by 2030 *(29).* Treatment of antimicrobial-resistant bacterial infections alone could cost up to US$ 412 billion annually, with workforce participation and productivity losses of up to US$ 443 billion *(30).* AMR is also predicted to be responsible for an 11% decrease in livestock production in low-income countries *(29,31).*

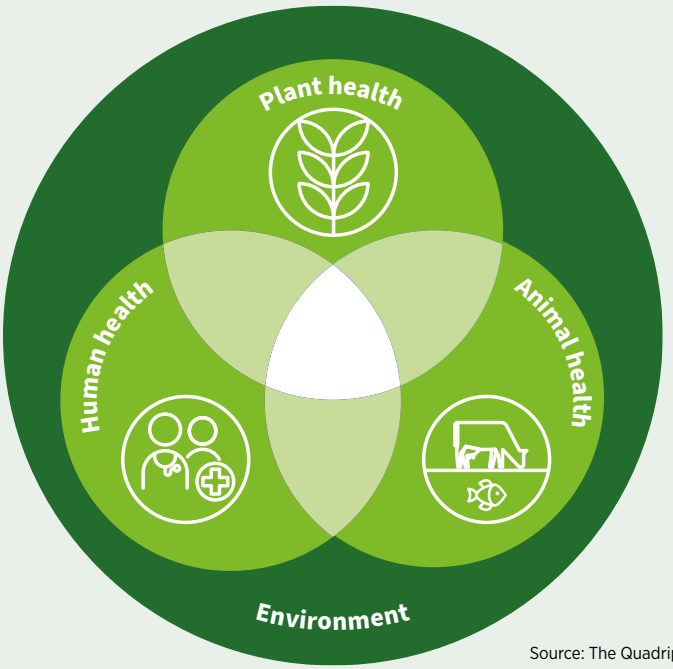
Increased use and misuse of antimicrobials in various sectors and other microbial stressors, such as pollution (e.g. sewage), create favourable conditions for microorganisms to develop, transmit and spread resistance in humans, animals, plants and the environment. Preventing and controlling the selection, emergence, transmission and spread of resistant microorganisms is critical for preserving the efficacy of existing antimicrobials and protecting the integrity of human and animal health, food safety and food security, water supplies and the environment *(32).* Such action would also contribute to achieving the United Nations Sustainable Developmental Goals (SDGs), including those of ensuring health and well-being (SDG 3), achieving food security and sustainable agriculture (SDG 2) and addressing inequality (SDG 10), while promoting responsible consumption and production (SDG 12) and global partnership (SDG 17).

A One Health approach is pivotal for successful mitigation of AMR (Fig. 1). The Quadripartite organizations – the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO) and the World Organisation for Animal Health (WOAH) – subscribe to the operational definition of One Health of the One Health High-level Expert Panel *(32)* as an

integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes that the health of humans, domestic and wild animals (aquatic and terrestrial), plants, agri-food systems and the wider environment (including ecosystems) are closely linked and interdependent.

This approach requires a synergistic, collaborative strategy that traverses ecosystems, economic sectors, scientific disciplines and national boundaries *(33–36).*

Fig. 1. AMR and AMU surveillance in the One Health approach



Source: The Quadripartite organizations *(36)*

Integrated surveillance of AMR and antimicrobial use (AMU) across sectors is a vital part of the One Health response to AMR *(19,20)* and is a critical priority for the Quadripartite organizations *(37–39).* In the past, surveillance of AMR and AMU was usually sector-specific, with separate frameworks for human and animal health, plant/crop health, derived animal and non-animal food products and the environment. Efforts have been made, however, to integrate surveillance within and across One Health sectors, as seen in several cross-sectoral initiatives involving collaboration between two or more organizations, such as the guidance of the WHO Advisory Group on Integrated Surveillance of AMR for integrated surveillance, published in 2013 and updated in 2017, which addressed foodborne bacteria in the food chain. The guidance was based on the experience of country programmes, such as the Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP) *(40)*, the National Antimicrobial Resistance Monitoring System (NARMS) in the USA) *(41)*, NethMap and Monitoring of Antimicrobial Resistance and Antibiotic Usage in Animals in Netherlands (Kingdom of the) (MARAN) *(42)* and the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) *(43).*

WHO has developed a model protocol for establishing an integrated surveillance programme, with one indicator, extended beta-lactamase-producing *Escherichia coli* (ESBL *E. coli*) in three main sectors: human, animal and environment. The approach focused on strengthening integrated surveillance in low- and middle-income countries *(44).* The Codex Alimentarius, through the Codex Alimentarius Commission, developed the Guideline of Integrated Surveillance of Foodborne AMR in the Joint FAO/WHO Food Standards Programme to assist countries in designing and implementing integrated monitoring and surveillance programmes along the food chain *(7).* The programmes are based on sector-specific guidance and standards for AMR and/or AMU surveillance and on integrated surveillance in specific sectors.

The Quadripartite is developing a global integrated surveillance architecture to facilitate the collection, collation, analysis and sharing of data on AMR and AMU data among all sectors. At the heart of the architecture are global systems such as the International FAO Antimicrobial Resistance Monitoring System (InFARM) *(45,46)*; WHO's Global Antimicrobial Resistance and Use Surveillance System (GLASS) *(3)* and WOAH's Animal Antimicrobial Use Global Database (ANIMUSE) *(47)* (Table 1). Guidance for the use of each of these global information systems has been published. The systems will be converged in the Quadripartite's Global Integrated System for Surveillance of Antimicrobial Resistance and Antimicrobial Use, thus creating a comprehensive repository of AMR and AMU data among sectors.

Table 1. Existing sector-specific surveillance systems

Quadripartite Organization	Sector	Global system	Description	Link to guidance protocol
FAO	Animal, food, crops and plants	International FAO Antimicrobial Resistance Monitoring (InFARM) system	InFARM is a global information system consisting of an information technology (IT) platform and related FAO activities that assist countries in collecting, collating, analysing, visualizing and effectively using their AMR monitoring and surveillance data, primarily from livestock, fisheries and aquaculture, and their associated food products.a	*(45,46)*
UNEP	Environment	Guidance on wastewater and solid waste management for manufacture of antibiotics	Guidance on an independent scientific basis for inclusion of targets in binding instruments to prevent the emergence and spread of AMR, best practices for risk management, including internal and external audit and public transparency, progressive implementation, and stepwise improvement when necessary, recognizing the importance of protecting and strengthening the global supply and ensuring appropriate, affordable, equitable access to quality-assured antibiotics.	*(8,9,156)*
WHO	Human	GLASS-AMR	GLASS-AMR provides a standardized approach to the collection, analysis, interpretation and sharing of data by countries; actively supports capacity-building; and monitors the status of existing and new national surveillance systems. GLASS includes epidemiological, clinical and population-level data.	*(3)*
	Human	GLASS-AMU	GLASS-AMU monitors AMU at national level. AMU data are estimates derived from aggregated data sources (ranging from macro-level, such as imports, distribution and sales, to micro-level, such as data on prescriptions, dispensing and insurance). Use and consumption indicate the types and quantities of antimicrobials used in specific settings over a specific period	*(3)*
WOAH	Animal	ANIMUSE	ANIMUSE is an interactive, automated database for countries to report, access, analyse and communicate data on antimicrobials intended for use in animals. It includes reporting, error detection and data visualisation tools. Its aim is to improve the practices of veterinary and aquatic animal health services in countries with respect to AMU.	*(47)*
Quadripartite	One Health	Global Integrated System for Surveillance of Antimicrobial Resistance and Antimicrobial Use	A comprehensive repository of global AMR and AMU data from all sectors to facilitate the collection, collation, analysis and sharing of AMR and AMU data among sectors	In development

a The InFARM system and its IT platform also include AMR data from food production environments, and other animals, such as companion, recreational and wild animals, under a One Health lens and as part of the expanding efforts on AMR monitoring and surveillance. Additionally, the system is currently incorporating the collection of data on the use of antimicrobials in plant production.

Although not all resistant bacteria and resistance traits cross human, animal, plant and environmental sectors, their interconnectedness necessitates an integrated approach for the surveillance of AMR and AMU at One Health interfaces *(48,49)*. Several international recommendations have stressed the importance of integrated surveillance for AMR and AMU, and some countries and regions have already established cross-sectoral harmonization at strategic and operational levels *(43,45).*

Lack of common overarching objectives, coordination and governance for integration, the diversity of surveillance frameworks, from sampling to communicating results, laboratory testing procedures and sector-specific indicators, complicate harmonization of sectors *(50,51)*. For surveillance data from different sectors to be effective, they must be representative of AMR and AMU and harmonized to allow comparison and meaningful interpretation. This is essential for risk-based decision- and policy-making, targeted interventions and evaluating progress towards defined purposes and targets.

Integration of surveillance of AMR among One Health sectors requires a stepwise approach, starting with strengthening sector-specific surveillance, followed by integration of One Health sectors at one or more stages. As global guidance must be appropriate for regional and country systems and be used to build capacity for integrated surveillance, this Quadripartite Guidance is based on collaboration among FAO, UNEP, WHO and WOAH for a coordinated global One Health response to AMR. Integration can also be done in sectors, when both AMU and AMR data are collected and analysed as part of sector-specific surveillance systems. In One Health integrated surveillance systems, AMU data collected during sector-specific surveillance (in animals, humans and plants) can be used to explore potential associations between use of specific antimicrobial agents and classes and the emergence and occurrence of particular antimicrobial resistance patterns in commensal and/or pathogenic bacteria within and across sectors at certain interfaces and to gain better understanding of the mechanisms and the epidemiology of AMR in a systems-based approach.

The Guidance includes a range of common and harmonized approaches for AMR and AMU integrated surveillance, from surveillance strategies at inception to mature surveillance systems to enhance the comprehensiveness, accuracy and timeliness of actionable data.

This Guidance is a living document and will be updated to reflect advances in laboratory and epidemiological methods, emerging evidence and the impact of AMR at One Health interfaces for which there is not yet substantive evidence, regulatory frameworks and the changing needs of countries, regions and the global community. This Guidance provides context-appropriate road maps for developing and strengthening One Health-based integrated surveillance of AMR and AMU systems.

The One Health Approach addresses interfaces of different magnitudes at which human, animal, plant, agri-food systems and environmental sectors overlap. The interfaces represent avenues for the emergence and transmission of AMR (see One Health Priority Research Agenda for AMR *(36)*). In this Guidance, references to the animal and plant health sectors include their derived food products.

2 Purpose, scope and target readership

2.1 Purpose

The purpose of this Guidance is to propose and present context-appropriate, technically feasible proposals for countries to coordinate and establish a national integrated surveillance system for AMR and AMU for collection of evidence of AMR and AMU and to set strategies to contain and control AMR development and spread in the One Health sectors. To establish such a system, countries should consider the interfaces of human, animal and plant/crop health, food safety and security, agriculture and the environment.

The Guidance describes the outcome of establishing a coordinated, collaborative, evidence-based response to the global challenge of AMR in sectors under the One Health approach.

The Guidance may be expanded in the future to include implementation of integrated surveillance systems according to national, regional and global needs.

2.2 Target readership

The Guidance is intended to serve as a resource for:

- governments, national authorities, ministries of health and agriculture, national veterinary authorities, food safety authorities, ministries of the environment or national environmental programmes;
- members of competent national authorities, including all components of AMR/AMU national surveillance systems, drug regulatory authorities, national coordinating centres for surveillance, national AMR laboratory networks, AMR multisectoral coordination committees and other One Health multisectoral governance and coordination structures that collaborate in designing, funding and implementing integrated surveillance;
- professionals and technical personnel involved in direct implementation of AMR and AMU surveillance, including public health professionals, field officers, researchers, academics, plant pathologists and agronomists, environmental scientists, epidemiologists, microbiologists, animal health professionals, risk managers and assessors, competent authorities, regulators, policymakers and technicians at national, regional and global levels; and
- international organizations, and nongovernmental entities involved in AMU and AMR surveillance and the One Health response to AMR.

2.3

Scope of the Guidance

While we recognize the importance of surveillance and the mandates of each sector, the aim of this document is to provide guidance and indicate resources and approaches for integrated surveillance among One Health sectors. Countries should initiate integrated surveillance programmes in at least two One Health sectors with the intention of extending it to include all relevant sectors (Fig. 1) and to promote collaboration and coordination at various stages of integration at subnational, national, regional and global levels. This document therefore includes an overview and consideration of:

- the design of a surveillance system for AMR/AMU according to the objective or intended outcomes;
- data to be collected, sampling approaches and common surveillance targets for each One Health sector;
- laboratory and epidemiological requirements for integrated AMR surveillance; and
- personnel requirements for collecting and analysing AMU data and options for integrated data analysis, interpretation, data sharing and communication that ensure valid, reliable, representative findings and comparability within and among sectors at national and international levels.

This document focuses on use of and resistance related to antibiotics (antibacterials) that are important in at least two One Health sectors in terms of their potential impacts on health, productivity and ecosystems. Elements that were considered to be out of the scope of this Guidance were:

- resistance to antiparasitic, antiviral and antifungal agents;[2]
- guidance for surveillance of heavy metals;
- antimicrobial chemical residues in animal tissues (which is well described in other guidance documents);
- conducting cost–benefit analyses; and
- estimation of the burden of impact or of illness related to AMR in any of the One Health sectors and resulting interfaces.

2.4

Scope of integrated AMR and AMU surveillance

2.4.1 One Health sectors

Integrated surveillance is conducted in the One Health sectors shown in Fig. 1, which are those in which use of antibiotics and/or the emergence, transmission and spread of AMR occur

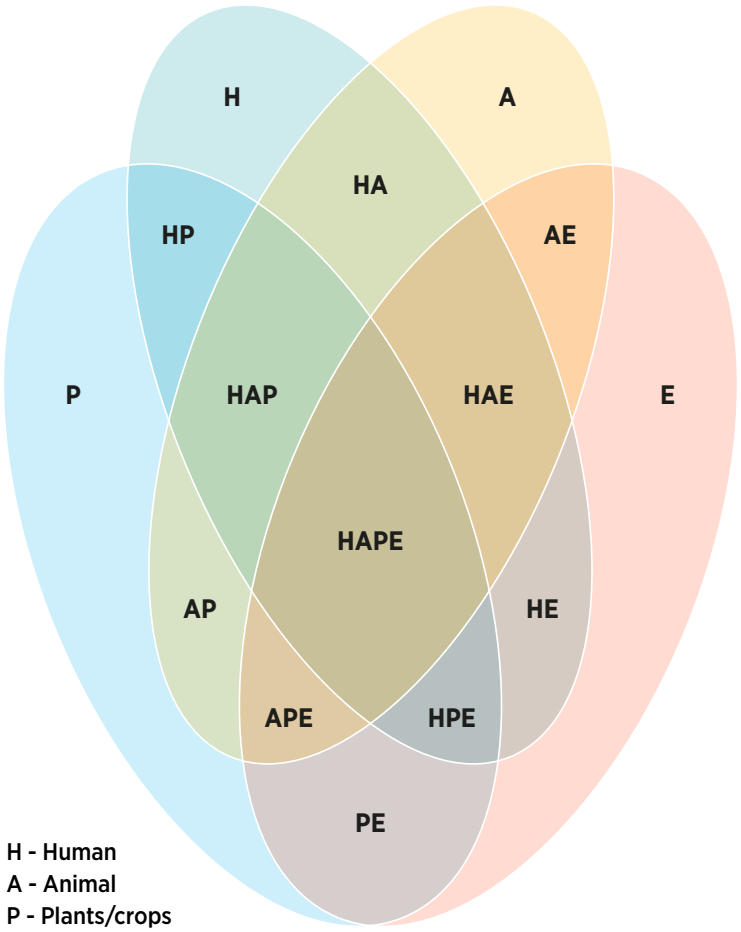
- human: health-care and community settings;
- animals (including their derived food products): e.g. veterinary practice settings, including food- and non-food producing aquatic and terrestrial animal breeding, rearing and shelter facilities, farms, slaughterhouses, food processing plants, packaging facilities, wholesaler and retailers;
- plants/crops (including their derived food products): e.g. fruit orchards, vegetable produce, grains, flower production facilities, food processing plants, packaging facilities, wholesalers and retailers; and
- environment: e.g. the built environment, including hospitals (internal and external environments), food production facilities, water and wastewater infrastructure, drug manufacturing plants and natural environments (water, soil and air in contact with domestic and wild animals, plants/crops and humans).

2 The approaches described in this Guidance can be applied in extending surveillance to other antimicrobial classes, such as antiparasitic, antiviral and antifungal agents.

2.4.2 One Health Interfaces

The interfaces of the sectors are those at which humans, animals, plants/crops (and their products) and the environment overlap, intersect or interact[3] and are thus at potential risk of AMR emergence and its transmission and spread directly (e.g. animal–human contact) or indirectly (e.g. food). In Fig. 2, each sector is represented by a coloured oval; the intersections represent sectoral overlaps. Up to 11 overlaps are depicted in the figure, which are proxies for One Health interfaces and represent avenues for the emergence, transmission and spread of antimicrobial-resistant microorganisms, AMR genes (ARGs), mobile genetic elements (MGEs) and antimicrobial compounds and their metabolites across two or more sectors. While there is limited information on AMR transmission dynamics for all the potential interfaces of the One Health sectors, this Guidance addresses interfaces for which there is evidence of AMR transmission across sectors.

Fig. 2. Venn diagram of potential One Health interfaces for integrated surveillance



3 interactions can result in direct transmission (direct contact between sectors, e.g. animal and farmers) or indirect transmission of AMR via food or environments (e.g. food products–consumers or water/soil from different sources–humans).

3 Definition and purposes of One Health integrated surveillance of AMR and AMU

3.1

Definition

Integrated surveillance of AMR and AMU consists of continuous, collaborative, coordinated, systematic collection, collation, validation, analysis, interpretation, communication and sharing of data on AMU and AMR. The data include data from humans, animals and products, plants/crops and products and the environment, which are used to provide information for sectors and actions to reduce the burden of AMR-associated infections and preserve the efficacy of antimicrobial agents in all One Health sectors.

Integrated surveillance of AMR and AMU consists of continuous (without interruption), collaborative (involving two or more sectors working together within and beyond sectors) activities by diverse stakeholders to achieve specific objectives. This requires effective coordination to harmonize different elements and often complex activities.

Integrated surveillance requires sharing of data, laboratory and epidemiological resources and expertise to maximize synergies and reduce the cost of surveillance. Strong collaboration should therefore be established among competent national authorities in relevant sectors. Stakeholders in the private sector should be engaged if necessary, through public–private partnerships, if this could result in data and resource sharing (e.g. access to AMR data from commercial diagnostic laboratories).

3.2

Examples of systems for sector-specific and integrated surveillance of AMR and AMU

As countries have different capacities, resources and contexts, they may choose to prioritize activities in specific sectors or at interfaces. Table 2 lists examples of national and regional integrated surveillance systems and guidance and guidelines that provide evidence of AMR transmission across sectors. For integrated surveillance, countries could begin by addressing interfaces between at least two sectors by adapting guidance documents such as the WHO AGISAR guidance *(52)*, WHO Tricycle protocol *(44)*, the Codex Guidelines on Integrated Monitoring and Surveillance of Foodborne Antimicrobial Resistance *(53)*, the WOAH Terrestrial and Aquatic codes and other national integrated surveillance programmes *(5,6)*.

The examples provided have been focused on the food chain and prioritize the human–animal–food interface. Some countries have established integrated surveillance of AMR/AMU with the purpose of ensuring food safety and protecting consumers. These surveillance programmes address mainly food-producing animals, animal-derived food products and humans and have contributed to the body of evidence to inform risk analysis exercises on the transmission of AMR traits and resistant commensal and foodborne pathogenic bacteria from animals to humans through the food chain. Nevertheless, gaps remain, as currently there is scarce evidence that AMR in non-food producing animals (e.g. companion animals), crops or the environment is detected by established surveillance. Countries can extend the interfaces after a situational analysis, according to the resources available.

Table 2. Integrated surveillance of AMR/AMU: Country examples and global guidance

Example of integrated surveillance systems	Competent authority	Sectors represented[a]	Interfaces included
WHO Integrated Surveillance of Antimicrobial Resistance in Foodborne Bacteria – Application of a One Health Approach – AGISAR guidance *(52)*	All relevant multisectoral national, regional and global authorities	Humans (H) Food of animal origin (A) Animals (A)	Humans, animals, food of animal origin (HA)
Codex Guidelines on Integrated Monitoring and Surveillance of Foodborne Antimicrobial Resistance *(7,53)*	All relevant multisectoral national, regional and global authorities	Food-producing animals and derived food products (A) Plant/crops (P) Environment (E)	Food producing animals, derived products, food production environment (AE) and wastewater from farms (AE or PE)
WOAH Aquatic Animal Health Code. Chapter 6.4. Development and harmonization of national antimicrobial resistance surveillance and monitoring programmes for aquatic animals *(5)*	Veterinary or other government authority of a member country with responsibility and competence to ensure or supervise aquatic animal health and welfare measures, international health certification and other standards and recommendations in the Aquatic Code over the whole territory.	Animals (aquatic) (A) Food of animal origin (aquatic) (A)	Animals and food derived from animal products throughout the food chain (HA)
WOAH Terrestrial Animal Health Code. Chapter 6.8 Harmonisation of national antimicrobial resistance surveillance and monitoring programmes *(6)*	Veterinary authority or other government authority of a member country with the responsibility and competence to ensure or supervise animal health and welfare measures, international veterinary certification and other standards and recommendations in the Terrestrial Code and in the WOAH Aquatic Animal Health Code over the whole territory.	Animals (terrestrial) (A) Food of animal origin (terrestrial) (A) Animal feed (AF) Environment (E)	Animals and food derived from animal products throughout the food chain (farm, slaughterhouse, processing and packaging facilities, retail) Points in the feed supply chain, including processing, retail and use. Animals' immediate environment and/or wider environment (AP, AE, HA, HAE)
InFARM *(45,46)*	National structures that oversee AMR surveillance; peripheral and national reference laboratories that generate AMR data	Animals (terrestrial) (A) Food of animal origin (terrestrial) (A) Animals (aquatic) (A) Food of animal origin (aquatic) (A) Food of plant origin (P) Food production environment (E) AMU in plant production and protection (P)	Provides guidance to countries for participating in the InFARM system, supporting collecting, collating, analysing, visualizing and effectively using AMR monitoring and surveillance data throughout the food chain, from livestock, fisheries and aquaculture, with food products (according to Codex and WOAH standards) and AMU in plant production and protection (AP, AE, PE, HAP, HAE, HPE, APE, HAPE)

a H, human; A, animal; P, plants/crops; E, environment

Example of integrated surveillance systems	Competent authority	Sectors represented[a]	Interfaces included
European Joint Inter-agency Antimicrobial Consumption and Resistance Analysis (JIACRA) *(54,55)*	European Centre for Disease Prevention and Control; European Food Safety Authority; European Medicines Agency	humans and food-producing animals (HA)	Humans, animals, food-derived from animal & plant products (HA, AP, HAP)
CIPARS *(43)*	Canadian Ministry of Health under the auspices of the Public Health Agency of Canada	Human (H) Food-producing animals (A), Food of animal origin (A), Environment (E)	Animal-derived food products or direct contact with animals and/or their waste (HA), environment (sick animal environment, surface and irrigation water) (E)
Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP) *(40)*	The Danish Integrated Antimicrobial Resistance Monitoring and Research Programme. Supported by a Steering Committee made up of the National Food Institute and the Statens Serum Institute	Companion animals (A) Food-producing animals (A) Food of animal origin (A) Humans (H)	Food-producing animals, food of animal origin and humans
NARMS *(41)*	Partnership between the Food and Drug Administration, the Centers for Disease Control and Prevention, the US Department of Agriculture, the Environmental Protection Agency and the National Center for Biotechnology Information	Human (H) Food-producing animal and derived products (HA)	humans, retail meats, and food animals (HA)
Consumption of antimicrobial agents and AMR among medically important bacteria in Netherlands (Kingdom of the) NethMap and MARAN *(42)*	The Dutch Foundation of the Working Party on Antibiotic Policy, in collaboration with the Centre for Infectious disease control of the National Institute for Public Health and the Environment	Human (H) Animals (A) Food of animal and plants/crop origin (HAP)	Human-animal-food (HA, AP, HAP)

a H, human; A, animal; P, plants/crops; E, environment

Example of integrated surveillance systems	Competent authority	Sectors represented[a]	Interfaces included
WHO integrated global surveillance on ESBL-producing *E. coli* in a "One Health" approach: The Tricycle Protocol *(44)*	National level: A national multidisciplinary, integrated core group comprising individuals from each of the human, food chain and environment by the WHO Country Office AMR focal point are the contact points for regional and global levels for all matters concerning implementation of Tricycle and the national action plan. Regional level: WHO AMR regional focal points will support, facilitate and link activities from national to global level. Global level: WHO will coordinate implementation and monitoring of surveillance at global level. On request through the WHO country office, WHO supports countries with assessment visits and/or training to assist in selection of sampling sites, methods, data collection and analysis.	Human (H) Food-producing animals (A) Environment (E)	Human (healthy and sick)/ food chain/ environment (wastewater plants and river) (HA, AE, HAE)

3.3 Goals and objectives

One Health integrated surveillance of AMR and AMU can meet several goals in the protection of public health, animal health and welfare, environmental health and ensuring food security, livelihoods and fair practices in food trade. Each purpose requires specific considerations in terms of surveillance design and resources (human and financial).

3.3.1 OBJECTIVE 1

Provide information on patterns, trends and potential associations

What this means:

- For AMR: the objective is to obtain data by observing trends in frequencies of resistance and/or resistance patterns (i.e. in drug-resistant bacteria, ARGs or MGEs) in all sectors (interfaces).
- For AMU: the objective is to obtain data to find patterns and trends in use of antimicrobials in a sector (comparative antimicrobial selective pressure) or in two or more sectors (e.g. on plants/ crops or as animal feeds, across the interface between plants/crops and animals).
- Integrated analysis of AMR-AMU: the objective should be timely integrated analysis and reporting of comparable data on AMU and AMR from all sectors to enable public health interventions that minimize the emergence and spread of AMR and its impact. Within sectors, the objective could be to integrate AMR and AMU data collected in the system to observe patterns and trends.

a H, human; A, animal; P, plants/crops; E, environment

3.3.2
OBJECTIVE 2

Support and inform risk analysis for AMR

What this means:

- Surveillance of the use of antimicrobial agents and the prevalence of foodborne AMR provides information that includes baseline data, which is useful throughout risk analysis. Data can be used to explore potential relations between use of antimicrobial agents and the prevalence of AMR microorganisms in humans, food-producing animals, crops, food, feed, feed ingredients and biosolids, wastewater, manure and other waste-based fertilizers, for risk profiling and risk assessment, to measure the effect of interventions and to identify trends.

3.3.3
OBJECTIVE 3

Alert authorities about emerging and re-emerging AMR and changes in patterns of AMU

What this means:

- For AMR: Detection of marked increases and emerging risks (antimicrobial-resistant microorganisms, ARGs, MGEs and antimicrobial compounds) to identify and respond swiftly to potential threats before they spread.
- For AMU: Frequent collection of data (e.g. daily or monthly) allows better documentation of local, national, regional and global selection pressure to drive resistance and better assessment of the effectiveness of policies and antimicrobial stewardship. Alerts can be designed for detection of increasing and new uses of antimicrobials in one sector, how they are used in another sector, such as new uses of an antimicrobial class in humans. An example is use of colistin as a last-resort antimicrobial to treat multidrug-resistant pathogens, with consideration that the antimicrobial class may have been used for several years in food-producing animals before its authorization for human use (e.g. use of colistin as an antimicrobial growth promoter and as treatment in food-producing animals for conditions such as colibacillosis in poultry).
- For antimicrobial compounds and their metabolites: for detection of increasing use and use of new antimicrobial compounds at interfaces with the environment from one or more sectors (e.g. human health-care settings, farms, veterinary clinics, drug manufacturing sites).

3.3.4
OBJECTIVE 4

Inform the development of and assess the effectiveness of interventions to address AMR and improve public health and sector-specific outcomes

What this means:

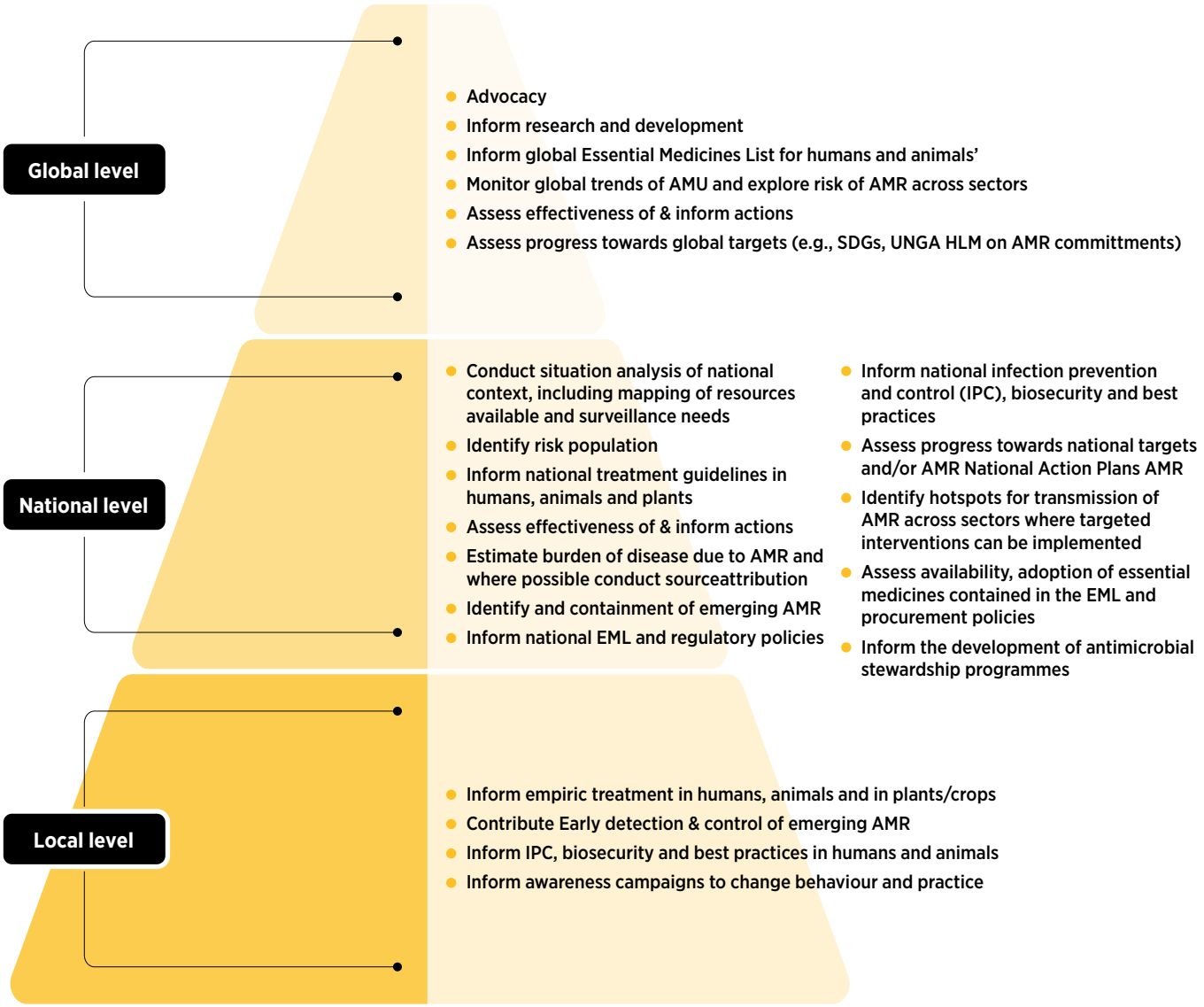
- to measure, assess, reformulate and improve appropriate, responsible use of antimicrobials in all sectors to ensure that AMU targets (e.g. use only for veterinary or phytosanitary purposes, not for growth promotion, alignment with the political declaration of United Nations General Assembly for countries to reduce AMU) are reached without compromising human, animal or plant health and within the country context;
- to obtain more evidence of the impact of AMR at the interfaces of the One Health sectors through research and innovation to improve the effectiveness of public health interventions; and
- to identify areas on which to focus human and financial resources, to measure the impact of interventions and to develop targeted interventions and policies to mitigate AMR in a sustainable, cost-effective manner.

3.4

Where integrated surveillance can inform action

The outcomes of integrated surveillance can inform local, national or global action. Fig. 3 shows examples of types of actions or uses of integrated surveillance data at these levels. At global level, this could be the provision of data to the global database on AMU and AMR; the global

Fig. 3. Use of outputs of integrated surveillance of AMR and AMU at various levels



3.5

Stages in establishing, building or improving One Health integrated surveillance of AMR and AMU

One Health integrated surveillance of AMR and AMU requires a stepwise approach, starting with strengthening surveillance in each sector or establishing an integrated system de novo. Countries either build on existing systems or select context-appropriate entry and enhancement points at which each stage of the surveillance system can be integrated, depending on the objective, the expected output and available resources. The two approaches and stages for establishing or expanding an integrated surveillance system are outlined below.

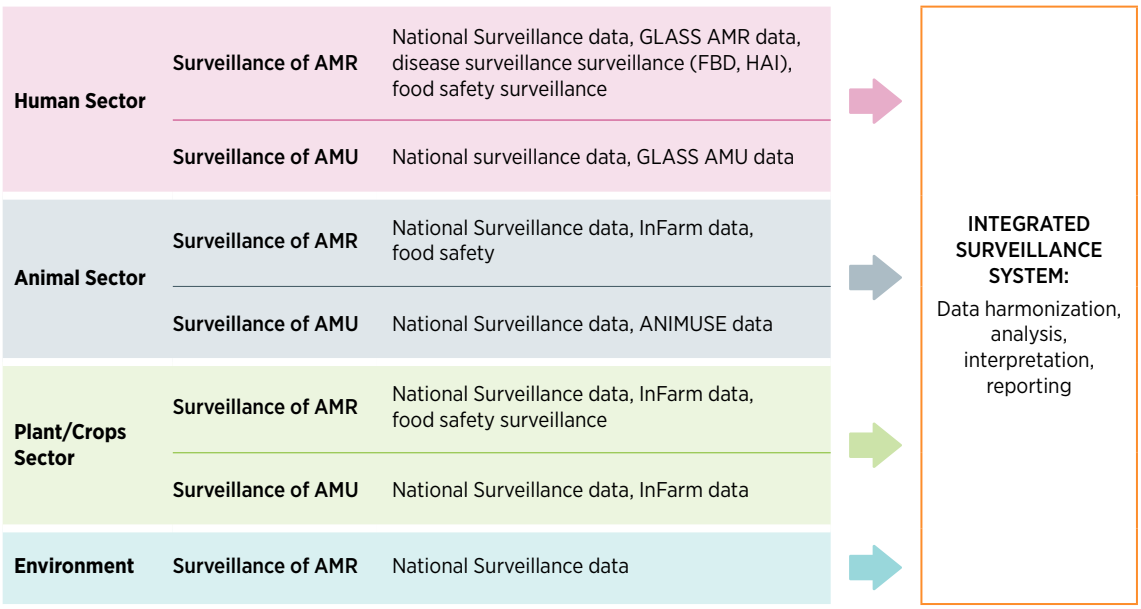
Approach A:
Using existing sector-specific surveillance systems

When surveillance systems for AMR and AMU are already in place in each sector, the first step is to assess their adaptability to an integrated surveillance system. The assessment includes any multi-sectoral disease surveillance system, such as a food safety programme (Fig. 4). This is the case, for instance, of surveillance in the European Union (EU), where data on AMU and AMR in humans and animals are analysed to determine how AMU in animals can impact the occurrence of AMR in pathogens and commensal bacteria relevant to human health. Such assessments require that data-sharing agreements be established between various EU agencies (such as the European Food Safety Authority with respect to AMR in food-producing animals and food products derived from animals; the European Medicines Agency with respect to AMU in humans and animals; and the European Centre for Disease Prevention and Control for AMR in humans), which collate, validate and analyse sector-specific data on AMU and AMR reported by EU countries on humans, animals and food, as mandated by EU legislation *(55)*. Other national integrated surveillance systems, such as DANMAP, NARMS, MARAN and CIPARS, are funded similarly to the European JIACRA and most focus on foodborne bacteria and collection and analysis of data from different national agencies working on sector-specific AMR or AMU surveillance.

The steps in integration are:

- adapting or extending the scope of existing surveillance systems (e.g. CIPARS, DANMAP, MARAN) to include additional aspects of AMR and AMU or of other sectors, such as the environment or plants/crops;
- extending surveillance to sectors in which it is currently not conducted;
- sharing of data generated by systems and joint analyses and reports for integrated surveillance; and
- collaboration among existing surveillance coordinating groups to ensure the sustainability of the integrated system with no negative impact on current surveillance.

Fig. 4. Approach A. Use of existing surveillance systems



Approach B:
Building a new integrated surveillance system

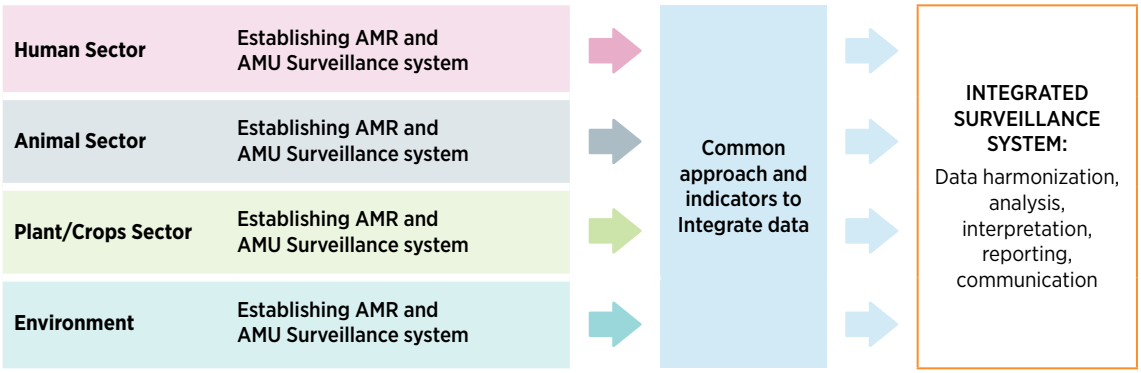
If there are no AMR or AMU sector-specific surveillance or multi-sectoral disease surveillance systems, an integrated surveillance system must be developed. For this approach, a choice must be made between two strategies: developing sector-specific systems or directly developing an integrated surveillance system.

The first approach requires creation of sector-specific AMR and AMU surveillance systems, with the integrated surveillance system in mind. Although this approach is time consuming, it ensures generation of comparable data from different sectors, providing strong evidence for both sector-specific and cross-sectoral interventions. This model will be useful in countries with no existing surveillance systems.

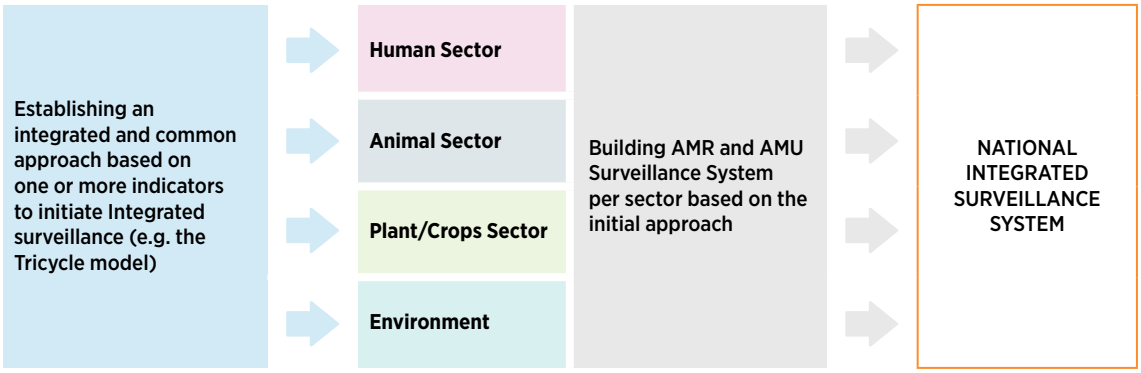
Developing an integrated surveillance system directly involves establishment of a cross-sectoral, integrated surveillance system. While this approach is potentially quicker, it can take as long as development of sector-specific systems if the scope of surveillance is broad. It usually involves conducting cross-sectoral surveys of a limited number of pathogens, such as in the Tricycle protocol *(44)*, which provides insights into AMR and AMU issues across sectors but limits the scope of evidence to sector-specific interventions. This approach can be used to understand the magnitude of AMR and AMU in a country and subsequently to invest in improving the capacity in the sectors involved. The approach allows countries to obtain data rapidly and thus allow national authorities to raise awareness of the problem and invest in building the integrated surveillance system.

Fig. 5. Approach B: building a new integrated surveillance system

Model 1



Model 2

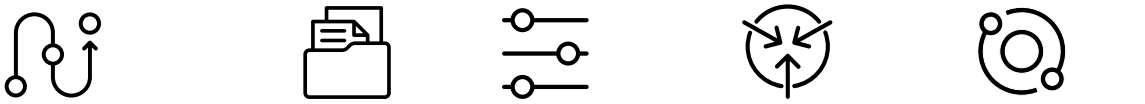


Whether leveraging existing systems or building a new one, the goal is to create a sustainable, comprehensive surveillance system that provides data to generate evidence-based policies for combatting AMR and optimizing AMU at the interfaces of One Health. The choice of approach depends on factors such as HR, costs and existing national bodies on surveillance and should be decided by each country.

Once the approach has been chosen, adapting, expanding or developing an integrated surveillance system should be initiated in the following stages:

- situation analysis, planning and resourcing:
  - Step 1: conducting the situation analysis, planning, resourcing and mapping stakeholders;
  - Step 2: setting priorities;
  - Step 3: epidemiological design of the system: and
  - Step 4: AMR and AMU data-sharing among sectors;
- sampling and data collection for AMR and for AMU;
- sample and specimen processing, laboratory analysis and quality control for AMR and antimicrobial compounds;
- data integration, analysis, reporting, interpretation and communication; and
- monitoring and evaluation.

Fig. 6. Stages and steps in establishing One Health integrated surveillance of AMR and AMU



STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5
Situation analysis, planning, and resourcing **Steps:** ● Step 1: Conducting the situation analysis, planning, resourcing, and stakeholder mapping ● Step 2: Priority setting ● Step 3: Epidemiological design of the system ● Step 4: AMR and AMU data sharing across sectors	**Sampling/data collection (AMR/AMU)**	**Sample/Specimen processing and laboratory analysis and quality control (AMR and antimicrobial compounds)**	**Data integration, analysis, reporting, interpretation and communication**	**Monitoring and Evaluation**

The success of integrated surveillance depends on synergistic alignment of existing surveillance infrastructure, governance and legislative, national health priorities and resources.

Surveillance of AMR, AMU and antimicrobial compounds can be conducted in parallel or at different paces even in the same sector. Countries should ensure continuous quality improvement in surveillance activities. While the following text outlines the stages, these represent what is fundamentally a continuous process, with some overlap between the stages.

3.5.1 | STAGE 1: Situation analysis, planning and resourcing

STEP 1

Conducting a situation analysis, planning, resourcing and stakeholder mapping

A situation analysis should be conducted to plan and identify the resources required to establish an integrated surveillance programme. Activities should be planned in consultation with the other sectors. A plan for a gradual phased approach for integrated surveillance by two or more sectors will ensure harmonization and comparable data. For countries in which some sectors already have integrated activities, the activities should be revised in collaboration with those sectors, with a plan for continuous improvement in key sectors and interfaces and to meet the desired purpose.

The situation analysis can include an analysis of strengths, weaknesses, opportunities and threats (SWOT) of existing surveillance activities and capacities in each sector and planning the resources required (financial, human and infrastructure). Considerations of the regulatory and legislative aspects of AMR and AMU is important, such as national legislation on the collection and sharing of data from AMR and AMU surveillance. This step should also include mapping any existing sector-specific surveillance activities for AMR, AMU, antimicrobial compounds and their metabolites and establishment of the synergies with the integrated surveillance system. The step should ensure that the planned integrated surveillance system is comprehensive, coordinated and sustainable.

Consideration of whether systems for communicable diseases and disease outbreaks could be used for monitoring or surveillance of AMU and AMR is essential. For example, there may already be programmes for passive surveillance of *Salmonella* outbreaks in humans and animals, national and subnational surveillance of notifiable diseases or food safety. For effective, efficient flow of information from local to national levels, collection of data on additional AMU and AMR components should be integrated into any existing routine surveillance systems if appropriate.

Elements to be included are listed below.

1. Define the scope and objectives to set clear objectives for the integrated surveillance system (see section 3.3).
2. Identify stakeholders, ensuring representation of all sectors and other relevant fields (e.g. water management and public policy). Determine the roles and responsibilities of each stakeholder in surveillance, data-sharing, reporting and action. Evaluate the ease of collaboration among stakeholders and competent authorities.
3. Review any existing national and local sector-specific or integrated AMR and AMU surveillance systems, and decide on the approach to be used (see section 3.5). Identify gaps and limitations, such as in coverage, presence of a coordination mechanism and data collection methods, data quality assessment, infrastructure and technical capacity.
4. Identify and define common indicators and targets for integrated surveillance of AMR and AMU, data to be collected and methods in each sector to ensure data comparability and quality. Identify sampling approaches.
5. Review relevant policies and regulations related to AMR and AMU in the human, animal, plants/crops and environmental sectors. This includes assessment of alignment with national action plans, especially in multisectoral coordination. Evaluate national and global data-sharing frameworks to ensure coordinated information exchange among sectors.
6. Evaluate existing capacity, and identify gaps in human, financial and infrastructural resources for sector-specific and integrated surveillance of AMR and AMU. Assess any requirement for capacity development, and identify relevant training programmes in AMR and AMU surveillance, data management and policy.
7. Identify surveillance data management system(s). Data flow mechanisms should be assessed,

such as how data are or should be collected, analysed and shared among sectors. Evaluate AMR and AMU surveillance databases, and assess how they could be integrated. Identify and use global platforms for standardized sector-specific and integrated surveillance data-sharing and data repositories for integrated analyses and reporting (see Tables 1 and 2). Ensure data confidentiality and security in the system to protect sensitive information.

8 Determine whether current funding mechanisms are sufficient or if new resources are required, and explore sustainable funding sources, such as national budgets, international grants or partnerships with nongovernmental organizations and the private sector.

9 Assess risk factors and barriers, and identify potential challenges to a multisectoral approach (e.g. resistance to collaboration, lack of political will, lack of data sharing and reporting standards, changes in agricultural practices, changes in health-care infrastructure, environmental challenges, insufficient coordination among sectors, lack of timely data).

10 Develop an action plan based on the situation analyses, which should include priorities for immediate action, recommendations for closing identified gaps, and a timeline for implementation of the proposed actions.

11 Establish monitoring and evaluation frameworks to monitor and evaluate progress by regular reviews of systems to adapt to emerging evidence, threats and challenges, and adjust the plan as necessary according to the results, feedback and evolving trends in AMR.

STEP 2

Setting priorities

Identify the priorities in each sector (Fig. 7):

- the populations of interest, including human, animal and plant/crop individuals and groups of interest;
- the microorganism species, ARGs and MGEs;
- the antimicrobials;
- sources for sampling in each sector;
- the antimicrobial compounds and metabolites;
- sampling strategy and sample sources;
- laboratory methods, including standards for interpretation of the results of antimicrobial susceptibility testing (AST);
- types of data analysis; and
- how, when and to whom to report.

Outlining priorities in integrating steps in surveillance or among different sectors and interfaces is the highest priority.

Fig. 7. Setting priorities for epidemiological design of a One Health integrated surveillance system

Epidemiological design: priority settings		Sampling strategy and sample sources	
Population of interest • **Human** (cases of disease) • **Animal** (poultry, cattle) • **Plant/crop** (vegetables, fruits) • **Environment** (river, human or animal wastewater)	**Location** • **Human** (hospital, PHC settings) • **Animal** (slaughterhouse, farms) Plant/crop (farms, market) • **Environment** (hospital, community, farms, rivers)	**Microorganisms** **Pathogens** • *Salmonella spp* • *Campylobacter spp* **Indicators** • *Escherichia coli*	**Resistance mechanisms and Antimicrobials** • Extended spectrum β-lactamases • Carbapenem-producing Enterobacterales **Antimicrobials** • 3rd and 4th Generation Cephalosporins • Carbapenems • Fluoroquinolones

STEP 3

Epidemiological design of the system

Determine the analytical capacity required and which and how data should be harmonized among sectors for integrated surveillance, including whether epidemiologists can analyse data from different sectors. Other considerations could be the possibility of joint reports of information from different sectors and interfaces.

In designing the epidemiological analysis, countries should consider the following aspects.

(i) AMR: Design for populations of interest

Humans

For AMR, the population under surveillance consists of patients attending health-care facilities with symptoms suggestive of infection. They could be surveyed by either prospective AMR surveillance GLASS-AMR surveys or prevalence surveys *(56).* In surveillance conducted by routine clinical patient testing (referred to as routine AMR surveillance), the population being surveyed includes all patients from whom clinical samples are collected for routine microbiological investigations, including species identification and AST.

In GLASS-AMR prevalence surveys, the population surveyed includes all patients seeking care at health-care facilities who meet the definition of a case of infection and for whom clinical samples are collected for quality-assured microbiological investigations, including species identification and AST.

For AMU, the population under surveillance is the whole population who can use antimicrobial medicines. The population could be disaggregated by geographical area (country, state, province) or by socio-economic parameters (e.g. insured population, indigent population). As AMU data are reported at national level, the population is usually the entire population of a country.

Animals and food

For AMR, the population under surveillance depends on the primary objective of the monitoring programme. Broadly, AMR surveillance of animals and food serves two main purposes:

- protecting public health, by identifying and monitoring transmission of zoonotic and foodborne resistant bacteria from animals and food to humans; and
- protecting animal health, by tracking AMR in diseased animals to guide decisions on antimicrobial treatment.

AMR surveillance therefore covers five main population groups in different programmes. The InFARM system provides a framework for harmonized collection of AMR data from these programmes *(46).* The main purpose of three of the programmes is to inform policies and interventions in public health. These are usually programmes for active surveillance, with systematic, scheduled sample collection to ensure statistical representativeness. The populations surveyed are:

- healthy terrestrial animals, representing the general population of food-producing animals, with potential extension to their production environment;
- healthy aquatic animals, either farmed or wild, with potential extension to their production environments; and
- food of animal and plant origin at the level of processing and/or point of sale, to determine the prevalence of AMR in food products before human consumption.

These programmes indicate the movement of resistant bacteria from animals to humans through direct contact, environmental exposure and food consumption.

The purpose of two further programmes is to protect animal health by tracking AMR in bacterial pathogens isolated from clinically affected animals, primarily as a basis for veterinary treatment. Surveillance is usually passive, based on diagnostic samples, which introduces selection bias, reducing statistical representativeness. The populations surveyed are:

- diseased terrestrial animals, comprising livestock, poultry and companion animals with diagnosed bacterial infections; and
- diseased farmed and wild aquatic species undergoing veterinary diagnosis for bacterial infections.

By structuring AMR surveillance according to the target population, InFARM accommodates data for both public health and animal health, ensuring comprehensive monitoring in diverse surveillance settings.

(ii) AMU

For AMU, data on quantities of use should be collected from all available data sources (e.g. imports, sales, prescriptions). ANIMUSE collects data on AMU annually, reported as quantities disaggregated by class and type of use (veterinary versus non-veterinary) alone, for animal groups or for animal groups and routes of administration.

To compare quantitative data on antimicrobial agents intended for use in animals among sectors and over time, a rate is used to evaluate the data in the context of the associated animal populations, which vary in size and composition. To analyse the quantities of antimicrobials reported, the denominator is the animal biomass. In ANIMUSE, the animal biomass is calculated as the total weight of live domestic animals in a given population and year, used as a proxy for those likely to be exposed to the quantities of antimicrobial agents reported.

Plants and crops

The selection of plants and crops should be based on risk and/or guided by any relevant standard-setting body and the food and feed production environment. Samples may be collected from farms before or after harvesting, the immediate environment of the plants or crops, processing plants, wholesale facilities or retail outlets *(53).*

The amount of antibiotics used in plant protection is commonly considered to be lower than that used in human and animal health. An increasing number of studies and reports show, however, that the quantities effectively applied to crops are difficult to assess due to lack of monitoring throughout the world, and it has been suggested that AMU for plant health is more widespread than previously thought *(57).* FAO is conducting several initiatives on this topic, including surveys of antibiotic and fungicide use by the International Plant Protection Convention, an intergovernmental treaty for the development, adoption and promotion of application of International Phytosanitary Measures. Additionally, the FAO statistical data website FAOSTAT collects and provides access to data on food and agriculture from

245 countries and territories, including on the quantities of antibiotics and fungicides used, reported as "fungicides". Currently, FAO is optimizing a mechanism for collecting data on AMU in plants, which will be added to the InFARM system. The information will include the types of antibiotics authorized in each participating country, the crops on which they are used, for which diseases, the quantities applied, the surface of application and the method of application.

Environment

Testing for antimicrobial agents and compounds and their metabolites in wastewater treatment plants, food production environments and rivers yields data for evaluating baselines and trends in the frequencies and levels of antimicrobial compounds from effluents of pharmaceutical manufacture in waterways, which are one of the interfaces between humans and the environment.

The surveillance system (in particular for AMR and antimicrobial compounds) may be based on a sampling framework that can robustly detect a certain percentage change in microbial AMR indicators or compounds over time in comparison with known frequencies of AMR or of residues.

The Tricycle approach *(44)* can be used as a starting point. The environmental component of Tricycle can be used to detect and quantify selected microbial targets in hotspot sources and in rivers that receive wastewater from such sources. Hotspot sources include human sewage, effluent from wastewater treatment plants and wastewater with animal waste from wet markets or slaughterhouses. Rivers should be sampled both upstream and downstream of cities and communities. The downstream sample is intended to represent the presence and concentrations of microbial targets resulting from inputs from the community, such as sewage discharges and waste from wet markets. The upstream site does not necessarily represent a site with no human or animal influent but serves for comparison with the results of the downstream sample. It is proposed that total bacteria (microbial target) in samples also be detected and quantified *(44).*

Table 3 lists the proposed epidemiological requirements for AMU data.

Table 3. Suggested epidemiological data requirements for AMU

Type of data	Type of variable	Description
AMU medicines	Contextual	Data source Setting (health-care or community; clinic, farm, greenhouse or field) Private or public sector Intended targeted population
	AMU	Name of antimicrobial agent Active ingredients ATC code or ATC in Animal Medicine code Type of formulation or intended route of administration Whether the antimicrobial is a pro-drug Strength Package size Number of packages used
	Denominator	Number of individuals (humans, animals) treated Weight of individuals (to calculate biomass) Biomass of plants and crops For plants and crops, surface area cultivated or leaf area

Type of data	Type of variable	Description
Individual data	Contextual	Data source Setting (type of facility) Private or public sector
	AMU	Name of antimicrobial agent Active ingredients ATC code or ATC in Animal Medicine code Type of formulation or intended route of administration Whether the antimicrobial is a pro-drug Package size Dosing regimen (dose, frequency of dosing, route and duration of treatment)
	Individual data	Epidemiological data on the individual or group treated (mainly for animals and humans but may be applicable to plants and crops) Risk factors for use, if available
	Indication	Reason for use (e.g. diagnosis, indication) applicable for analyses Prescriber

(iii) Epidemiological data requirements for integrated AMU and AMR surveillance

Integrated AMU and AMR surveillance requires epidemiological and other relevant data for meaningful analysis of surveillance data from all sectors. Currently, a major barrier to making inferences to inform AMU and AMR policies and interventions is lack of harmonized data, due to differences in measurement units and in information on time, place and source among sectors *(58).*

Format for data collection: Data from all sectors and interfaces should be reported in similar metrics that can easily be compared, combined and analysed together *(59).* Epidemiological data on AMR and AMU differ according to the approach used for data collection and the objective and design of the surveillance programme. A review of available formats indicates that, at a minimum, the following core data should be included and a data dictionary always be provided to ensure clear understanding during data analyses and reporting. Table 4 lists the proposed epidemiological and microbiological data requirements for reporting data and pathogen identification for isolates.

Table 4. Suggested core epidemiological and microbiological data requirements for reporting data and pathogen identification in isolates

Data	Description	Humans	Animals	Plants and crops	Environment
Bacterial isolate identification	Unique number or code assigned to an isolate (might have to be encrypted before reporting to the next level of the surveillance system to respect privacy requirements (e.g. EU general data protection regulation)	Yes	Yes	Yes	Yes
Specimen identification	Unique number or code assigned to the specimen	Yes	Yes	Yes	Yes

Data	Description	Humans	Animals	Plants and crops	Environment
Specimen type	Nature of specimens or samples from patients, animals, food type or crops	For example, faeces, blood, swabs from infection sites, urine, sputum	For example, faeces, animal feed, water, carcass swabs, caecal contents, lymph nodes, organs	For example, pre-harvest or post-harvest (to be risk-based and/or guided by any relevant standard-setting bodies)	For example, soil, water, litter and bedding, organic fertilizers, sewage, slurry or manure, abattoir waste
Specimen collection date	Date of collection and whether specimens are pooled or individual samples	Yes	Yes	Yes	Yes
Origin of the specimen	Place or location at which specimens were collected	For example, infection sites, patient location, such as hospital or outpatient clinic	For example, on-farm, at slaughter, food processing plant, wholesale facility, retail outlet	For example, on-farm, processing plant, wholesale facility or retail outlet	For example, river sites (upstream and downstream), wastewater (community and wet markets), food production environment, wastewater from farms
Method of isolation	Bacterial recovery or reference to a standard operating procedure (SOP). Should be maintained in a separate "recovery" or "isolation" file, which records positive and negative results for each bacterium in a sample	Yes	Yes	Yes	Yes
Identification of isolate	Bacterial species, serotype or strain and method of confirmation (e.g. polymerase chain reaction [PCR] or immunoassay)	Yes	Yes	Yes	Yes
Phenotypic data	Antimicrobial agent(s), antibiotic disc concentrations, range of minimum inhibitory concentrations (MIC) tested Quantitative (MIC distribution, inhibition zone) and qualitative or interpretative (susceptible, intermediate or resistant, wild-type or non wild-type) Methods and criteria of AST, including version and year Information on standards or cut-offs used to assess AMR and application of clinical or epidemiological breakpoints	Yes	Yes	Yes	Yes

For laboratories that use molecular-based methods and generate genotypic data, the following additional information may be included to complement phenotypic surveillance methods:

- DNA and RNA extraction methods;
- method used and reference to a SOP or protocol: specific PCR, genomic or metagenomic;
- data analysis methods used;
- resistance gene profile (single or entire resistome [set of genes in a bacterium that confer resistance to antibiotics]);
- mobilome (entire set of mobile genetic elements in a genome);
- virulome (set of genes that contribute to the virulence of a bacterium);
- phylogeny, with working definitions; and
- Bioproject or other designation for locating genomic sequences submitted to public databases.

Other common epidemiological variables that can facilitate comparisons among sectors are:

- geographical distribution of AMR bacterial species;
- types of infection, e.g. urinary tract, respiratory;
- demographic data, e.g. age, sex, social class, geographical location;
- antimicrobial stewardship programme (guidelines followed, adherence);
- clinical outcome such as cure rate, complications (not relevant when the environment is included); and
- transmission to humans: zoonotic risk or transfer of AMR pathogens from animals to humans.

Sampling design

The term "sampling" is used here to denote the selection of individuals or objects from whom or from which samples or specimens are taken in such a way as to infer information about a whole population. Both probability sampling and non-probability sampling can be used, although non-probability sampling, such as relatively common convenience sampling, are prone to significant bias.

For the purposes of this Guidance, the term "sample" refers to biological specimens collected from humans, animals and animal-derived products, plants, crops and products, and/or natural and built environments to test for the presence and characteristics of antimicrobial-resistant microorganisms, ARGs or MGEs. The term "data" covers both microbiological and epidemiological data, including demographic and clinical patient information from hospitals and clinics, surveillance laboratory databases, food chains, farms and the environment.

AMR

For AMR, it is important to obtain a statistically calculated sample size to ensure the representativeness of the data *(60,61).* Variations in sample size between sectors (e.g. numbers of animals and areas treated for plants) are to be expected, as the type and methods of collection of samples and data differ for each sector *(62).* If integrated surveillance is longitudinal and covers several periods, representative samples for each period should be collected *(63,64).* In some cases, large sample sizes may be required for specific subgroups or expected rare events to ensure that they are adequately identifiable. Resource mobilization considerations, such as the budget and availability of infrastructure, are vital *(65).*

AMU

Usually, the most readily available data at national level are antimicrobial sales and imports, which can be used as a proxy if data on use in animals, humans or plants are not available. The supply chain of medicines can be used to estimate AMU in different sectors.

Data can be collected from high-level sources that manage antimicrobial medicines, such as manufacturers' data on production batches, import records, distribution, sales and purchase. These sources, however, generally provide information only on medicines, such as the antimicrobial agent and its content, the formulation and the number of packages of medicines used. These data are referred as medicine-level data.

AMU data can also be collected from end-users where the medicines are used, such as health-care facilities, general medical or veterinary practices, households and farms. These sources may also provide additional information on patients or animals, the reason for use and information on treatment, such as dosage prescribed or administered to a patient or animal. These data are referred to as individual-level data.

Each source of data provides different information, often in different formats. The availability of each source of data may differ, for example by country, sector or sectors. In addition, the possibility of accessing and extracting data from different sources varies, depending on data ownership, data protection issues or because of the format or software package with which the data are collated and stored. It is important to understand the advantages and disadvantages of each data source.

Other data sources are those on sales and distribution, import records and purchase information. In rare instances, actual AMU in animals may be available in clinical records. In humans, although patient-level data are more common, they are usually local and not national. Most countries use data on imports and sales, as they are the easiest to collect and may even be mandated by law. It is often not, however, possible to translate such high-level information into actual use. For instance, it is difficult to distinguish sales data by animal species, particularly for veterinary products authorized for use for in several species. It is important to understand the advantages and disadvantages of each data source and the limitations of using market information to infer use in animals or people. For the purpose of this Guidance, individual-level data on AMU are those that include information on individual humans, animals, groups of animals or humans, farm(s), ponds(s) or crops or fields treated with antimicrobials. The other data types are referred to as sales and/or import data, as appropriate. All of these data sources are encompassed in the term AMU.

Individual-level data

Information on AMU reported by individual or groups of individual end users, such as:

- by people (e.g. patient, sick child in household);
- by veterinarians for an individual animal (e.g. horse, dog);
- on a group of animals (e.g. chicken flock, cattle herd, aquaculture operation); or
- on plants or crops (e.g. fields, trees, orchards, greenhouses).

Individual-level data may provide information on dose regimen, frequency of dosing and route of administration, indication and clinical outcome, allowing assessment of the quality of use of antimicrobials and understanding of the behaviour of practitioners.

Individual AMU data are usually collected by sampling at sentinel surveillance sites (hospitals, practices, farms). In many settings, the data are collected manually or semi-automatically. Local databases can be used when available. Data collection is top–down when there is a central electronic database (e.g. medical records) that captures the required information.

In human health, individual-level data on AMU are collected frequently, generally for research or for local stewardship programmes. The data are accessed from individual-level databases at surveillance sites (hospitals, general practices, pharmacies), usually from patient records or questionnaires completed by prescribers, dispensers or users through surveys or audits. A very few countries have national databases of individual AMU data, often for research purposes.

Individual data are seldom collected outside the human sector. Collection of data on individual animals is difficult, although it may be achieved for companion animals and as part of surveillance programmes with centralized collection of AMU data from veterinary practices for both non-food- and food-producing animals (e.g. DANMAP). In husbandry and agriculture, possible data sources are farm or the veterinary treatment records. In the environment sector, the data sources would be records of analysis

of environmental samples for antimicrobial compounds in laboratories or facilities that conduct internal surveillance of the environment or water (e.g. pharmaceutical plants). No source is yet available for the plants/crops sector.

Such data represent small numbers of individuals in a limited number of settings (hospitals, practices, households, farms) and may not be representative of the whole country.

It is important to anticipate that the presentation of data in treatment records is in different formats, which must be harmonized, which is a challenge to valid evaluation of AMU in different settings.

Medicine-level data

In their lifecycle, antimicrobial products move from manufacturers to the final user. Most participants in the supply chain have their own databases to track the flow of medicines at their level, especially in human health. In addition, many countries have national regulatory authorities that oversee and regulate products, although the process may differ by sector. For, example, there is no regulation of AMU in the plant health sector.

Medicine-level AMU data can be obtained at three stages of the supply chain.

Manufacturing/import: Data at this level provide complete information on the types and quantities of medicines entering a country to be sold on the national market. Because of production or import cycles, the data may not reflect actual use, but they can be used as a proxy for AMU when individual data are not available. These data nevertheless provide information on the availability of products on the national market.

Distribution/wholesale: Data on distribution or wholesale quantities from manufacturers, distributors or wholesalers provide information on the distribution of the medicines in a country. They could be used to track antimicrobials to subnational level or specific supply chains, such as distinguishing AMU in humans in public or private practice and in hospitals or communities.

Facility: Facility-level data consist in general of data extracted from in/out stock management systems and should not be confused with individual-level data obtained from prescribing or dispensing databases. The data are generally from pharmacies, health-care facilities, veterinary clinics, feed mills, retailers or agricultural shops. The number of facilities to be monitored may thus be very large, and, in general, obtaining data at this level requires expensive IT solutions.

The flow of antimicrobials along the three levels of the supply chain could be to estimate use, with consideration of the known limits of this approach. All the medicines identified in the supply chain might not be used, such as expired medicines removed from stocks, or the final user cannot be assessed; for example, veterinary antimicrobial products may be authorized for use in several species, making it difficult to determine the species in which it was used from sales or imports data alone. Medicine-level data contain basic information, such as the name of the product or molecule, strength, package size and dosage form. Most national databases do not, however, have information on the end user or the specific reasons for antibiotic use.

These data are often easier to collect than individual AMU data, as they are already monitored by participants in the supply chain, and they can be used for routine surveillance. In many cases (particularly in the human sector), the data are already in electronic format. The challenge of this approach is to obtain access to the different databases in the supply chain. Some may already share their data with authorities. For instance, importers in many countries must declare the volume of medicines imported for taxation purposes. In this case, the national authority must ensure that every imported product is linked to information on the antimicrobial concentration and package size.

Efforts should be made to avoid counting the same antimicrobial medicines twice when collecting data from different sources. In general, the more supply chain participants there are in a country, the more difficult it becomes to map products.

In most national and global surveillance systems, the medicine-level approach is used. For instance, in the WHO GLASS-AMU and WOAH ANIMUSE systems, data on sales, imports, distribution and wholesale or, for humans, health facility and health insurance records are used.

STEP 4

AMR and AMU data-sharing among sectors

Determine how data can be shared among sectors according to the data types and owners. Data-sharing agreements should be established, maintaining confidentiality and privacy when applicable. It is also important to identify the entity or committee in a country that is responsible for data analysis within and among sectors for the purposes of integration.

Countries should decide on how the system will be established and whether the institutions, entities or competent authorities that collect data from different sectors and components (AMR and AMU) will collaborate in analysing, interpreting and reporting an integrated analysis of the data, or whether the government will create a new entity to collect the data from different sectors, conduct the analysis and report the findings (Fig. 8 and 9).

Fig. 8. Joint integration and coordination of an integrated surveillance system

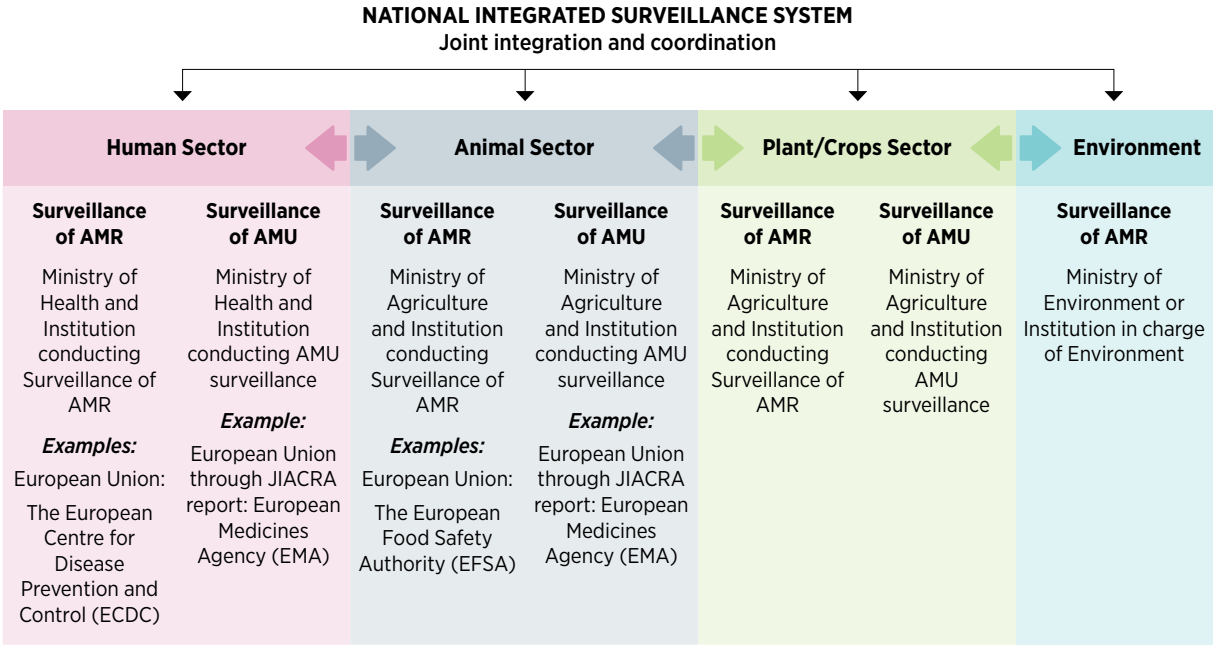
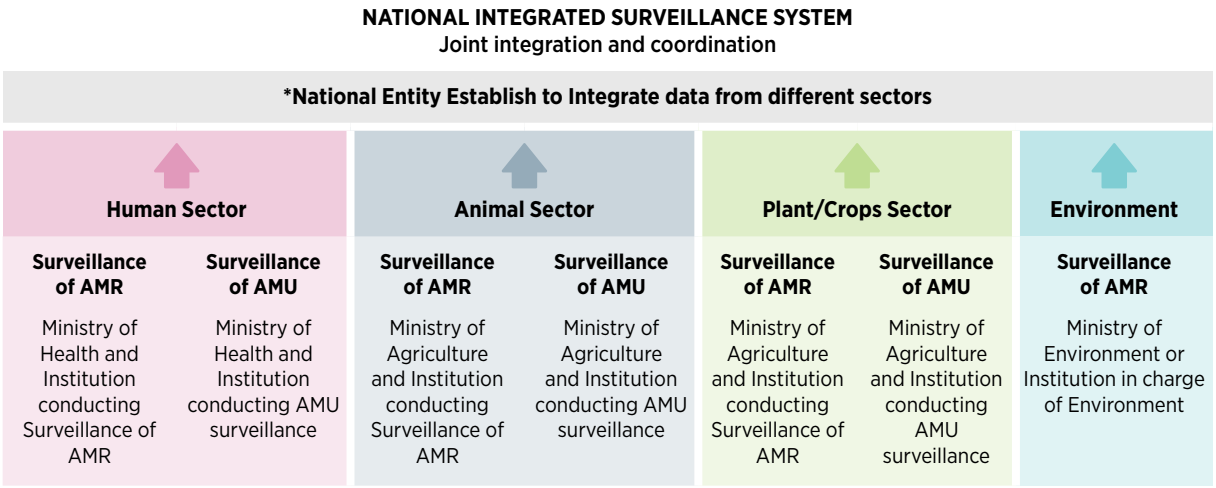


Fig. 9. National entity to coordinate, integrate and analyse data on AMR and AMU collected by entities or institutions in each sector



* Example: the Public Health Agency of Canada coordinate CIPARS

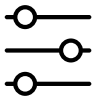
3.5.2 | STAGE 2: Sampling and data collection

In Stage 2, implementation is based on the priorities identified in Stage 1, with allocation of the necessary financial, technical, technological and HR. This stage starts with ensuring data confidentiality and data-sharing agreements. Data management and storage systems should be in place.

At this stage, all relevant sector-specific and cross-sectoral experts must work together, including epidemiologists, microbiologists, clinicians and policymakers, to ensure harmonization of sample processing, data collection, data sharing and data analysis for comparisons among sectors. Stage 2 also involves broadening the collection of samples and/or data (AMU) in two or more sectors or at an interface that can provide insights into AMR as it relates to AMU.

For AMR, this stage requires that each sector adopt standardized methods for sample collection, Epidemiological data should also be collected.

For AMU, this stage involves adoption of harmonized, standardized methods for collecting data, such as on sales, use, imports and storage, with comparable metrics among sectors, on humans, animals and plants/crops, as appropriate. Quality control of medicines to identify substandard and falsified products or pharmacovigilance notifications should be considered by consulting programmes such the WHO Member State Mechanism for Substandard and Falsified Medical Products *(66–68)* and the WOAH Global Information & Alert System for Substandard & Falsified Veterinary Products *(68)*.



3.5.3 | STAGE 3: Sample and specimen processing, laboratory analysis and quality control

This stage involves the analysis of samples, procedures for isolating, identifying and characterizing (serotyping) microorganisms by AST methods and applying interpretative criteria, with or without additional characterization of AMR by molecular methods, including whole genomic sequencing if available and necessary (for surveillance of ARGs/MGEs). When available, metagenomic sequencing can be used to determine ARG diversity in a collected specimen. All relevant SOPs for laboratory analyses recommended in manuals for the sector-specific systems ANIMUSE, GLASS and InFARM should be available.

Antimicrobial panels for AST are used to evaluate the susceptibility of microorganisms to various antimicrobial agents *(69,70)*. Recommendations for selecting antimicrobial panels for AST and recommended interpretative criteria (epidemiological or clinical) are listed below.

1. During planning, consensus should be achieved among sectors on the antimicrobials to be tested to achieve the objectives of integrated surveillance and to harmonize analyses for comparability. Panels of compounds should be representative of commonly used antimicrobial classes on limited or essential lists and specific shared-class antimicrobials to represent actual use *(71,72)*. National and international guidance on antimicrobials important for human and animal health should be consulted, including the AWaRe antibiotic book *(73)*, the WHO list of medically important antimicrobials *(74)*, the WOAH List of Antimicrobial Agents of Veterinary Importance *(75)* and the WHO List of Essential Medicines and treatment guidelines *(76)*. Panels should reflect the prevalent resistance profiles in a region or setting *(59,77–79)*. Table 5 lists recommended antimicrobial classes and agents to be considered for inclusion.
2. The panel should cover a comprehensive range of antimicrobial classes according to applicable international standards and guidelines in diverse categories *(59,80–82)*. Panels should be reviewed and updated periodically to meet international standards and recommendations. Countries should use current, up-to-date international standards and recommendations
3. Established guidelines for AST and standards for quality control should be used to ensure

accurate data, such as the consensus standards of organizations such as the Clinical and Laboratory Standards Institute in the USA and the European Committee on Antimicrobial Susceptibility Testing *(83).*

4 Determine which microorganisms to investigate and then which AST to use on those pathogens. National consensus guidelines and standards should be followed, if available, or GLASS recommendations *(3).* For animals, national guidance documents can be used or recommendations of the International FAO Antimicrobial Resistance Monitoring System *(46)*, the WOAH Terrestrial and Aquatic Animal Health Codes *(5,6)* and the WOAH Manual of Diagnostic Tests and Vaccines for Terrestrial Animals *(84)*. Sources of specimen and samples to be tested should be considered in selecting the panel. The antimicrobial concentrations used in susceptibility testing for different species may differ by sector. For greater sensitivity, AST panels can be designed with a drug dilution range that covers both susceptible (including microorganisms used as controls in susceptibility testing) and wild-type populations and those for which the MIC is at or above the epidemiological cut-off value and/or the clinical breakpoint to detect the full range of changes in susceptibility and emerging resistance. Disc diffusion methods and zone diameter are also good parameters to be used initially if MIC testing is not available. Countries should base the choice of panels on their suitability for integrated surveillance, including the target microorganisms, priority pathogens and context-specific priorities for the sector and used according to international guidelines.

5 Regular communication among stakeholders in all sectors should be ensured so that the selected panels are aligned with local sector practices for integration, including use of priority microbe–drug combinations.

Table 5. Antimicrobial classes and subclasses proposed for an antimicrobial panel for testing bacteria in an integrated surveillance system

Antimicrobial class	*Salmonella, E. coli*	*Campylobacter*[a]	*Enterococcus*	*Staphylococcus*
Aminoglycosides	Gentamicin	Gentamicin Streptomycin	Gentamicin Streptomycin	Gentamicin
Amphenicols	Chloramphenicol		Chloramphenicol	Chloramphenicol
Carbapenems	Imipenem Meropenem			
Cephalosporins II	Cefoxitin			Cefoxitin
Cephalosporins III	Cefatoxime (or Ceftriaxone) Ceftazidime			
Cephalosporins IV	Cefepime[b]			
Glycopeptides			Vancomycin *Teicoplanin*	Vancomycin
Glycylcyclines	*Tigecycline*		Tigecycline	
Lincosamides		*Clindamycin*[c]		Clindamycin
Lipopeptides			Daptomycin	
Macrolides	Azithromycin	Erythromycin[d]	Erythromycin	Erythromycin
Nitrofurans	*Nitrofurantoin*[e]		*Nitrofurantoin*[f]	
Oxazolidinones				Linezolid

Antimicrobial class	*Salmonella, E. coli*	*Campylobacter*[a]	*Enterococcus*	*Staphylococcus*
Penicillins	Ampicillin Amoxicillin *Temocillin*[g]	Ampicillin	Ampicillin	Penicillin, Oxacillin
Polymyxins	Colistin			
Quinolones	Ciprofloxacin Nalidixic acid *Pefloxacin*[h]	Ciprofloxacin *Nalidixic acid*[i]	Ciprofloxacin	Ciprofloxacin
Rifamycins				Rifampicin
Streptogramins			Quinupristin-dalfopristin	Quinupristin-dalfopristin
Sulfonamides[j]	Sulfisoxazole[j]			Sulfisoxazole
Tetracyclines	Tetracycline	Tetracycline[k]	Tetracycline	Tetracycline
Trimethoprim[j]	Trimethoprim			Trimethoprim

Antimicrobials shown in italics are of secondary priority.

a Recommended antimicrobials used for surveillance of *Campylobacter jejuni* and *E. coli*.

b Cefepime is used in the EU to distinguish between AmpC and ESBL.

c Lincosamides are used in treatment of some infections caused by *Campylobacter*.

d Resistance to erythromycin reflects resistance to azithromycin.

e Nitrofurantoin is used in the USA for testing Gram-positive bacteria.

f Testing of Enterococcus for resistance to nitrofurantoin is optional.

g Temocillin is included as a marker of the blaOXA-48 genotype.

h Used to screen for ciprofloxacin resistance in *Salmonella* spp. in disc diffusion.

i Nalidixic acid is used in *Campylobacter* to identify rare mutations.

j Trimethoprim-sulfamethoxazole can be used instead of sulfisoxazole or trimethoprim alone.

k Doxycycline may be used instead of tetracycline

3.5.4 | STAGE 4: Data integration, analysis, reporting and communication

Data on AMR, AMU and antimicrobial compounds from two or more sectors or interfaces could be collated, analysed, interpreted and communicated together. Such data should be chosen at an early stage, as not all sector-specific data are relevant for integrated surveillance. National adaptation of the modelling approaches used in the EU JIACRA reports could be considered *(55).* In these approaches, integrated analyses include defining the relations between AMU and AMR in the human and non-human sectors in a series of univariate and multivariate analyses.

Analysis of data from integrated monitoring and surveillance programmes may include assessment within or between sectors on the One Health spectrum of temporal or geographical trends over time, among host species, bacterial species or antimicrobial classes. Other contextual information, such as epidemiological data, should be considered.

A plan for analysing data should be developed according to the objectives of the integrated surveillance systems adopted. Experts from different sectors must be involved in the analysis and interpretation of the data to generate pertinent recommendations. Recommendations derived from findings of surveillance to be communicated to policymakers in countries or regions should be prioritized according to whether interventions are to be implemented in the short, medium or long term. Surveillance data will indicate to countries the range of interventions available and who would implement them (e.g. national policies or regulations or sector-specific interventions).

To ensure that epidemiological conclusions can be drawn, the data should be linked to the demographic, geographical, clinical or veterinary individual or group of animals, plants, crop and environment tested. Depending on the local surveillance protocol adopted, additional clinical data, such as patient outcomes, diagnoses, specific symptoms, underlying diseases and antimicrobial treatment, should also be included. Interpretation of epidemiological findings should include consideration of the national, regional and multisectoral context for policymaking.

3.5.5 | STAGE 5: Monitoring and evaluation

Most guidelines in the literature for evaluation of surveillance systems are based on their attributes. The following questions guided the approach used to monitor the quality of data and of the surveillance system *(85).*

- What are the components of a surveillance system, and how do they interact?
- What triggers evaluation of a surveillance system?
- Which evaluation methods are appropriate?
- Which components should be evaluated?
- What do the results of the evaluation tell us?
- What are the possible interventions?

The goal of monitoring the quality of data is to detect problems and take corrective measures. Evaluation of surveillance systems involves comprehensive measurements of relevant attributes (once or over time) to determine whether the system is still "fit for purpose" or to recommend improvements. Each type of surveillance system will require specific evaluation (for example, for specific attributes) according to the objectives of the surveillance system.

The following steps should be considered in evaluating a surveillance system.

STEP 1

Describe the system and each element.

STEP 2

Plan the evaluation in detail, including an overview of possible triggers for an evaluation in a decision tree. Planning should ensure full engagement of the team and participating stakeholders.

STEP 3

Conduct the two main components of the evaluation: performance and costs for HR and infrastructure.

STEP 4

Propose an action plan, providing recommendations for addressing the results of the evaluation.

Those who evaluate surveillance systems should remember that an evaluation is not complete until its results have been disseminated to appropriate stakeholders and the stakeholders have responded to the results.

3.6

Data access, confidentiality and sharing

Access to data is critical for effective integrated surveillance of AMU and AMR *(86).* The first step is to establish who will use the data. SOPs and data-sharing agreements should be established between relevant ministries and stakeholders.

Web-based tools can be developed for both data collection and reporting, and data can be published on interactive interfaces that allow users to query and visualize the data. Simple data visualization, with tables and figures that are easy to interpret and have enough context to understand them is important. Rigorous authentication and encryption should be in place to safeguard against unauthorized access and data breaches *(87,88).*

Access controls and secure data-sharing agreements should be established to maintain confidentiality. Countries should determine with whom the data can be shared, what data can be shared and under what conditions *(89–91).* We encourage countries to overcome barriers to accessing data, to ensure a timely response to emerging AMR *(90).*

Once SOPs, memoranda of understanding and agreements for data interoperability are established, national legislation should be in place to oblige public and private entities involved in integrated surveillance to collect and share data, as, in some countries, surveillance may not be legislated. Once agreements are in place, budgets should be allocated to ensure sustainability.

Sharing of data from integrated surveillance of AMU and AMR depends on the structure of the surveillance system. When skills for data analyses and interpretation are available, data should generally be shared at two levels: between the data sources and the surveillance department of local competent authorities and between the local surveillance department and the surveillance units in national competent authorities under relevant ministries to inform policy and action. Countries should leverage, integrate or adapt any existing data-sharing platforms for AMR. For example, if a country already reports on AMU and AMR in humans to WHO's GLASS, AMR in animals and food to FAO's InFARM, and AMU in animals to WOAH's ANIMUSE integrated surveillance, reporting across sectors or interfaces could be added to national reports. A multisectoral coordinated surveillance and information-sharing system *(92)* originally developed for zoonotic diseases could be adapted and extended to integrated surveillance of AMU and AMR.

Ethical considerations *(93,94)*, data ownership and legal compliance should be considered, particularly regarding the privacy of patients and/or animal owners *(93–98).* Such considerations include de-identification and data anonymization to protect sensitive information. In some countries, legal compliance with medicines regulation and mandatory reporting is highly relevant for pharmaceutical companies.

Transparent informed consent processes should be used as necessary *(91,99).* A balance between facilitating data access and use and protecting sensitive and confidential information *(91)* is critical for the success and credibility of integrated AMR and AMU surveillance. Compliance with data protection regulations and transparent communication with all stakeholders about surveillance initiatives will build trust and reinforce commitments to safeguard sensitive information *(69,91,100,101).*

3.7

Data repositories

Repositories of AMU and AMR data ensure the effectiveness of national, regional and global integrated surveillance programmes. For example, WHO's GLASS *(3)* is a comprehensive framework for standardizing AMR and AMU surveillance among countries. GLASS has created a repository of data on AMR and AMU with a coordinated, standardized approach to data collection, reporting and sharing. Thus, countries collect and report data on AST, antimicrobial sales and other relevant information according to standardized protocols established by GLASS.

In the animal sector, WOAH has been publishing annual reports on antimicrobials intended for use regionally and globally reported by its members since 2015. Recently, WOAH launched ANIMUSE, an interactive interface that Members are encouraged to use to upload and analyse data on AMU in non-food and food-producing aquatic and terrestrial animals and to provide national reports *(47,102).* FAO has begun to implement InFARM, and its web application will serve as a repository for data on AMR in priority bacterial species of interest to human and animal health, isolated from animals, their production environment and food commodities *(46).*

Other programmes, such as the European Antimicrobial Resistance Surveillance Network also maintain centralized databases of data on AMR in humans from member countries *(103).* The EARS-Vet initiative for veterinary medicine and surveillance of zoonotic resistance is coordinated by the European Food Safety Authority, which provides efficient storage, retrieval and analysis of information from different countries. NARMS *(41)* and the CIPARS also maintain centralized databases in which data from different sectors are stored and analysed *(43).* NARMS data on isolates and genomic sequences are updated continuously and are freely available for downloading and use in any multinational reporting system *(41).*

The National Center for Biotechnology Information, also in the USA, serves as a repository of whole genome sequences. It includes software tools for annotating genomes for ARGs, biocides, virulence genes and some serotypes. The European Nucleotide Archive provides free access and comprehensive online records of nucleotide sequences collected globally, including raw sequencing data, sequence assembly information and functional annotation.

4 Priority microbial targets, metrics and indicators

4.1 Introduction

Integrated surveillance of AMU and AMR requires identification, prioritization and monitoring of process and outcome indicators in One Health domains and at One Health interfaces. These include microbial targets (e.g. antimicrobial-resistant microorganisms, ARGs, MGEs, AMU indicators and metrics, residue concentrations in water, food and other sources, and monitoring and evaluation indicators *(104–117).* This section of the Guidance provides criteria for choosing priority antimicrobial indicators and metrics and microbial targets for use in different sectors for integrated surveillance of AMU and AMR. It also proposes core global and national indicators for monitoring and evaluating integrated surveillance programmes.

4.2 Characteristics of microbial targets for AMR surveillance at the interface between two or more sectors

4.2.1 Priority microorganisms and antimicrobial agents to be considered as biological and antimicrobial targets and indicators

Priority microorganisms and antimicrobial agents for use as biological and antimicrobial targets and indicators should serve at least one of the objectives of integrated surveillance, with the following characteristics:

- be relevant to One Health: to highlight the interconnectedness of two or more sectors (e.g. human and animal, animal and environment) *(118,119)*;
- be accurately detectable and/or quantifiable with reliable, harmonized laboratory methods;
- provide insights into the patterns and trends of AMR or emerging forms of resistance (for objective 3);
- inform the development and use of interventions to manage AMR in one or more sectors (for objective 4); and
- identify genetic and genomic microbial targets (e.g. ARGs) that can be used in tandem with phenotypic data for comparisons among sectors.

The following considerations are also important.

- Relevance to policy: Consider whether monitoring and measuring the chosen target, indicator or metric will guide critical decisions and policy issues on AMR for more than one sector.
- Clinical, veterinary or agricultural relevance: The indicator should be related to human, animal health and plant/crop health and/or productivity.
- Global and regional relevance: Countries should consider global indicators that are aligned with their priorities and initiatives to facilitate collaboration and data-sharing on AMR and AMU.
- Economic relevance: The indicator should provide information on the human workforce, the effect on animal and crops/plants productivity and on significant costs for animal health and health care.
- Regulation of data privacy and ethical considerations: The indicator should comply with data privacy regulations and ethical considerations.
- Implementation: The required data should be feasible to collect. Resources, information systems and infrastructure should be available for data collection. Responsibilities for data collection should be explicitly defined and assigned. The periodicity of collecting and reporting data should also be defined.

Table 6 lists microbial targets for One Health integrated surveillance according to evidence for transmission of AMR among sectors.

Table 6. Microbial targets for One Health integrated surveillance by evidence for transmission of AMR among sectors

Sectors and Interface (see Section 4.2/ Table 1 for the basis for prioritization)	**Interface of interest**	**Proposed populations for sampling**	**Specimen to be collected from sampled populations**	**Microbial Targets**	**ARGs targets**	**Key microorganism–drug combination**	**Antimicrobial agents to be monitored**
Sectors: human, animal, environment **(Tricycle)**	Human–animal–environment	Humans: People with bloodstream infections Healthy people, including pregnant women Food-producing animals: Chickens Environment: River sites: upstream and downstream Wastewater: community and wet markets	Humans in hospital: Blood cultures Health-care facilities: Stools or faecal swab Food-producing animals: chicken caeca Environment: rivers: surface water Wastewater: human and animal	*E. coli*	ESBL genes Optional: carbapenemase-encoding genes; other classes of resistance genes depending on country context (e.g. *gyrAB/parCE* mutations and *qnr* acquisition)	*E. coli* – third-generation cephalosporins; Optional: carbapenems, fluoroquinolones, others	Cefotaxime/ceftriaxone, ceftazidime Optional: meropenem, ciprofloxacin, enrofloxacin, tetracyclines
Animals, plants/crops, environment **(Codex)**	Animals and food at various stages of the food chain Food production environment Wastewater from farms	Food-producing animals and their products Plants/crops on farms Wastewater from farms Feed and feed ingredients Food production environment; wastewater from farms	Healthy animals: faeces, animal feed, water, carcass swabs, cecal contents, or lymph nodes collected on a farm or at slaughter. Plants/crops: farms, pre-harvest or post-harvest (should be risk-based and/or guided by relevant standard setting bodies where available) Environment: Soil, water, litter and bedding, organic fertilizers, sewage, slurry or manure collected from the immediate environment of food-producing animals and plants/crops, processing plants, wholesale facilities or retail outlets	*Salmonella, Campylobacter* Commensal bacteria: *E. coli* and enterococci (e.g. *Enterococcus faecium* and *E. faecalis*) Target microorganisms from aquatic animals and food of non-animal origin based on scientific evidence and/or relevance to public health.	Depending on target bacteria, clinical and epidemiological relevance of the antimicrobials		Fluoroquinolones. Third- and higher- generation cephalosporins, carbapenems, other β-lactams Trimethoprim-sulfamethoxazole Macrolide Tetracyclines Vancomycin

Sectors and Interface (see Section 4.2/ Table 1 for the basis for prioritization)	**Interface of interest**	**Proposed populations for sampling**	**Specimen to be collected from sampled populations**	**Microbial Targets**	**ARGs targets**	**Key microorganism–drug combination**	**Antimicrobial agents to be monitored**
Sectors: Humans and food animals **(CIPARS)**	Animal-derived products; direct contact with animals and/or their waste	Infected humans Healthy food-producing animals Animal-derived food products (e.g. fresh meat) obtained from retail stores	Humans: faeces/stool samples Healthy animals: faeces/ stool samples Faecal material from fresh faecal pats, boot swabs collected on a farm and/or caecum at a slaughterhouse. Fresh meat, milk, eggs, fish, vegetables or processed foods obtained at processing and/or point of sale	Invasive non-typhoidal *Salmonella spp*. (non-typhoidal), *Campylobacter* Methicillin-resistant *S. aureus* Commensal bacteria: *E. coli, Enterococcus faecium* and *E. faecalis*	Fluoroquinolone-resistant genes (*gyrA/E* and *parCE* mutations and *qnr* acquisition) Genes encoding β-lactamases and ESBL Carbapenemase-encoding genes *mecA* gene Other classes of resistance genes to be selected, depending on the country	*E. coli*, third- and fourth-generation cephalosporins, carbapenems, fluoroquinolones Non-typhoidal *Salmonella*–fluoroquinolones, third/fourth generation cephalosporins MRSA *Campylobacter*-macrolides, fluoroquinolones	Third- and fourth-generation cephalosporins Carbapenems Fluoroquinolones Macrolides Tetracyclines Methicillin and other β-lactams Trimethoprim sulfamethoxazole
Sectors: Food animals (aquatic) and food derived from animals **(WOAH Aquatic Animal Health Code)**	Animal-derived products	Aquatic animals Animal-derived food products obtained from retail stores	Animals: e.g, fish, crustaceans, molluscs Food: seafood products to be consumed raw or undercooked	Foodborne pathogens: *Salmonella* spp.; *Vibrio parahaemolyticus; Listeria monocytogenes*	Not stated	Not stated	Major antimicrobial classes used to treat disease in aquatic animals
Sectors: Food animals (terrestrial) and food derived from animals **(WOAH Terrestrial Animal Health Code)**	Animal-derived products at different steps of the food chain (slaughterhouse, packaging, retail) Animal-related environment Animal feed	Healthy terrestrial animals Animal feed Animal-derived foods (at different stages of the food chain: slaughterhouse; packaging facility; retail)	Animals: faeces, caeca, carcass Food product: e.g. meat, milk, eggs Animal feed Animal-related environment: e.g. slurry, manure	Foodborne bacteria: *Campylobacter* spp.; *Salmonella* spp. Commensal bacteria: *E. coli; Enterococcus* spp.	Not stated	Not stated	Colistin, fluoroquinolones, third and fourth-generation cephalosporins, phosphonic acid derivatives.

4.2.2 Metrics for One Health integrated surveillance of AMR

Various metrics have been proposed for use in the surveillance of AMR. Absolute numbers can be used, especially in reporting emerging resistance or in outbreaks for a rapid overview of infections with specific resistance profiles.

Resistance proportions are the most frequently used measures for reporting AMR surveillance data:

Metric	Numerator	Denominator
Resistance proportion	Number of bacterial isolates in a specific bacterial species resistant to an antimicrobial agent or class (i.e. ATC subgroup*(120)*) per specimen type	Total number of isolates of a specific bacterial species with interpretable AST results (both susceptible and resistant) for an antimicrobial agent or class (ATC subgroup), per specimen type

Example:

$$\frac{\text{Number of patients with bloodstream infection caused by } \textit{E. coli} \text{ resistant to cefotaxime}}{\text{Number of patients with bloodstream infection caused by } \textit{E. coli} \text{ resistant, with AST results for cefotaxime}} * 100$$

Example:

$$\frac{\text{Number of faecal isolates from pigs infected with } \textit{E. coli} \text{ resistant to carbapenems}}{\text{Number of faecal isolates from pigs with } \textit{E. coli} \text{ with AST results for carbapenems}} * 100$$

Frequency of infection with drug-resistant pathogens is a useful measure for estimating the relative burden of AMR due to resistant pathogens when data for calculating incidence rates are not available.

Metric	Numerator	Denominator
Frequency of infection with drug-resistant bacterial species	Number of infections in a defined population caused by a bacterial species resistant to an antimicrobial agent or class (e.g. ATC subgroup *(120)*), per specimen type	Population tested during the reporting period, per specimen type

Example:

$$\frac{\text{Number of patients with bloodstream infection caused by } \textit{E. coli} \text{ resistant to cefotaxime}}{\text{Number of patients with suspected infections from whom a blood sample was taken}} * 100\text{^n}$$

Example:

$$\frac{\text{Number of cows with mastitis caused by } \textit{Staphylococcus aureus} \text{ resistant to penicillin}}{\text{Total number of cows with clinical mastitis from whom a milk sample was taken for bacteriological culture and AST}} * 100\text{^n}$$

4.2.3 Characteristics of indicators for AMU surveillance in two or more sectors

The WOAH Terrestrial *(121)* and Aquatic *(121)* Animal Health Codes should be considered as sources of AMU surveillance. They are included in WOAH's annual report template *(47)*. The Codex Guidelines on integrated monitoring and surveillance of foodborne antimicrobial resistance [CXG 94-2021] also provides guidance on AMU surveillance in food-producing animals *(54)*. In the human sector, the GLASS method for surveillance of national AMU provides guidance for establishing AMU surveillance, a list of data sources, variables on AMU to be collected and information to contextualize AMU, such as coverage, collection and methodological limitations. ANIMUSE and GLASS, on their respective interactive dashboards, provide examples of the display of AMU indicators and contextual information for interpretation.

AMU metrics and indicators can be calculated from various data types (Table 7). Some examples of AMU metrics that can be used for surveillance in different sectors are:

- quantity of active ingredients: reported in kilograms and tonnes; a common comparative metric for use in various sectors *(122–131)*;
- prescribing rates: the number of antimicrobial prescriptions per unit population (e.g. per 1000 inhabitants or animals) *(132,133)*, or, for crops, amount per hectare or square kilometre of agricultural land, a particular crop, or amount per tonne of harvest;
- milligrams of antimicrobial agents reported per animal biomass in kilograms is a relevant indicator for comparison over time and between regions to account for variations in animal populations, with the WOAH approach for AMU in animals; and
- kilograms per square kilometre, which represents the density of use per surface; important when comparing high-density countries or areas with low-density countries or areas.

Table 7. AMU metrics for One Health integrated surveillance

AMU metric	Description	Data requirements
Quantities of active ingredients	Reported in kilograms and tonnes	Population tested during the reporting period, per specimen type
Prescribing rates	Humans and animals: number of antimicrobial prescriptions per unit population (e.g. per 1000 inhabitants or animals). Crops: amount per ha or km^2 of agricultural land or a particular crop; or amount per tonne of harvest.	AMU prescription data (e.g. health care, veterinary practice or farm) Population data (Table 4)
Antimicrobial agents reported (mg)/animal biomass (kg)	Volume of antimicrobials adjusted by biomass of animal population in a given country Allows comparison of AMU over time and among regions while accounting for variations in animal populations	AMU sales or imports Animal population (requires further calculation of total animal biomass and by animal species according to population size). Standardized method should be used for calculating this indicator *(122,134)*

Considerations for selecting an AMU metric will depend on the metrics available, the sector/interface, the purpose of surveillance and the sustainability. Other considerations include:

- the availability, harmonization and quality of data from different sources;
- the population at risk, such as a specific patient group, community, animal or plant/crop population, and type of production system; and
- metrics to categorize AMU and antimicrobial compounds by class or type, dose and duration of treatment for a comprehensive view of patterns in specific categories of antimicrobials.

Metrics and indicators for One Health integrated AMU surveillance

Metrics for AMU

Various metrics can be used, such as those based on:

- counts,
- weight (quantity of active ingredients in mg or kg) or
- dose.

Other metrics include price or number of medicines or substances. Such commercial information may be difficult to obtain.

Indicators for AMU

Indicators that can be used for integrated AMU surveillance are based on counts or weights; e.g.

- total use of antimicrobials, total and relative use of antimicrobials per pharmacological group; or
- total and relative use of antimicrobials on the medically important antimicrobials list *(74)* and/or the AWaRe classification *(73).* An equivalent Aware list for the animal sector (VetAWaRe) will be developed in the near future, overseen by WOAH *(135).*

Such indicators can be used to compare use over time and sectors. Use should be adjusted per sector and country size by expressing it as density of use.

Density of use

In order to compare AMU among systems, sectors and countries, density of use is expressed with a common denominator to adjust for the actual size of the population under surveillance; e.g.:

- number of individuals (humans or animals) in a population potentially exposed to antimicrobials;
- weight or biomass (e.g. overall weight of human population, animal biomass or harvest); and
- area (e.g. km^2 or ha).

Indicators for density of use:

Based on count:

- animals: number of animals treated/total number of animals at risk
- humans: number of humans treated/ total number of humans at risk

Based on weight:

- animals:[4] weight (mg) of active ingredient used/ animal biomass (kg) (WOAH) or weight (mg) of active ingredient used/population corrected unit[5]
- kg/km^2 or kg/ha

Based on dose:

- animals: number of defined daily doses[6] used/number of animals in the population
- number of defined daily doses used/animal–time.[7]

4 For national integrated surveillance, countries should use their own denominator, as it differs from country to country. WOAH is used primarily at global level.

5 Population corrected unit = population x average weight at treatment (European Medicines Agency European Surveillance of Veterinary Antimicrobial Consumption)

6 Defined daily dose (animals) is the assumed average dose of antimicrobial per kilogram of animal per species per day.

7 Animal–time: time during which a population of animals was at risk of exposure to the antimicrobial agent.

4.3

Data analysis and interpretation

Analysis of data from an integrated surveillance programme may include assessment within or among sectors in the One Health spectrum to evaluate temporal or geographical trends over time, among host species, bacterial species or antimicrobial classes, to explore associations between AMU and AMR and to quantify risk. Different data sources may have to be considered, depending on the purpose of the data analysis.

When available, other contextual information, such as epidemiological data, may be considered, if available, which may be at population level (e.g. age group, gender, type of production system). When data are available, pathways of exposure of people, food-producing animals, plants/crops and the environment to resident bacterial populations could be included in the analysis. When data are derived from different surveillance systems, the metrics selected for measuring AMU and AMR among sectors should allow harmonization and comparability of data among systems and sectors.

The choice of analytical approaches should allow investigation of relations between AMU and AMR within or among food-producing animals, plants/crops and human populations, provided that the data are representative of the target population; for instance, by use of advanced statistical analytical methods such as multivariate logistic regression models. An example is co-analysis and reporting of the EU JIACRA reports of data from different sectors and EU agencies in which the relations between AMU and AMR in both human and food-producing animal populations were investigated in a series of univariate and multivariate analyses of combinations of selected antimicrobial groups and bacteria.

Integrated surveillance AMR should be harmonized, when possible, among the One Health sectors to aid understanding of the relations between AMR and AMU, including factors that may influence the emergence and spread of AMR. Integration of data from surveillance of human clinical isolates should facilitate identification of trends in resistance to specific antimicrobials important for use in human medicine and also of trends in the occurrence of resistance in humans, food-producing animals, plants/crops and/or food. Statistical analysis should be used to ensure proper interpretation of results.

AMU and AMR surveillance data can also be used to estimate trends in AMU and AMR over time in a given country, which is important for assessing variations in AMU and in the antimicrobial susceptibility of bacteria of interest over time as result of interventions and changes in legal frameworks (e.g. ban on use of colistin as a growth promoter in animal production systems). Various advanced statistical methods, such as longitudinal mixed model comparative analysis of temporal trends, are available.

The combined report of an integrated surveillance system should include estimates of the annual prevalence of resistance by bacterial species and sub-species, antimicrobial and bacterial sources (with other relevant epidemiological information such as geographical area, animal species and type of production system). The prevalence of resistance can be reported as MIC range, MIC50 or MIC90. Comparison of such summary statistics by source and year can be displayed graphically. Other presentation options include the zone diameter, MIC measurement distributions and explorations of cross-resistance and multidrug resistance. Data on AMU, including population-corrected data, can be presented in tabular form with comparisons by year displayed graphically. Within- and/or between-country comparisons for “benchmarking” purposes is facilitated by using statistical and derivable endpoints such as those generated by many countries as part of the EU AMU and AMR surveillance programmes. Box illustrations of integrated surveillance of AMU and AMR in humans and animals over time can be used to illustrate important, relevant resistance and AMU patterns. Such illustrations, with the findings of statistical analyses, can be used to demonstrate relations between AMU and AMR on an immediate scale and be used to raise awareness about AMR, communicate risk to relevant stakeholders and contribute to evidence-based policies by policy-makers

In addition to the qualitative analyses described above, additional information should be recorded for AMU and AMR policies *(125,126,136).* These include genotypic, whole genome and metadata *(137).* Such data sets (including phenotypic and epidemiological data) may be analysed statistically by modelling, including predictive and machine learning, and artificial intelligence protocols to derive quantitative data *(51,102,136–139)*, which may also include gender, equity and human rights issues pertaining to AMR and/or AMU.

4.4

Communication and reporting

Various types of reporting are used to communicate the results of a programme of integrated surveillance of AMR. The variety reflects international differences in resource availability, national priorities such as issues of concern and the maturity of the systems. In many countries, regulatory structures, jurisdictional matters and resources require that separate reports be issued for each component of the programme (e.g. human, food, animal, plant/crop, environment). This is the case in countries with integrated surveillance in the food chain, such as the US NARMS. In other countries (e.g. CIPARS in Canada), a combined report is issued. In programmes with the most comprehensive analysis and reporting, such as in Denmark (DANMAP) and in Netherlands (Kingdom of the) (NethMAP and MARAN), each major public health or agri-food agency provides separate sections and textboxes on human, food and animal end-points for both AMU and AMR, especially for non-zoonotic infectious agents.

This Guidance does not prescribe specific reporting requirements. When the data are sufficiently robust or when a particular concern dictates an analysis, such as presented in the JIACRA report, statistical approaches to inference as opposed to simple graphical and tabular descriptive approaches can be used. Approaches such as multivariate regression are less accessible to non-technical readers, and their interpretation by lay people and policy-makers should be considered. Further, there is some risk of over-reliance on statistically derived results, especially if underlying limitations of the data and analysis are overlooked. Simple yet carefully designed tabular and graphical displays are likely to be the most effective forms of communication for the foreseeable future.

A programme of integrated surveillance of AMR will provide information of interest to many stakeholders, including government risk managers, physicians, veterinarians, farmers, food manufacturers, retailers and consumers. For example, food producers may be concerned about public disclosure of information about their production practices, including use of antimicrobials in animal husbandry, as they may risk loss of reputation and of trade. Consumers may be concerned that food is contaminated by resistant pathogens. Preliminary research and context analysis should be conducted to identify stakeholders and develop effective messages. A plan for implementation and leadership should be drawn up. Continuous evaluation will allow timely improvements to the strategy. The timing of communication is another important consideration, as each stage of the programme will have different objectives, such as:

- raising support for the programme and educating groups. In the early stages, a major part of risk communication is encouraging support for and participation in the programme and identifying and educating groups of stakeholders.
- ensuring smooth operation. Once the programme is running, open communications must be maintained with the primary stakeholders, participants and those involved in day-to-day operations, including regularly asking about problems or concerns and responding to them in a timely manner.
- keeping communication channels open. While data are being analysed, communication must be kept open and stakeholders helped to understand the analysis and the timeline for dissemination of results.
- keeping all stakeholder groups informed about the results. Information must be released to all stakeholder groups, with consideration of the issues of concern for each group. Each stakeholder will want access to details that are critical to them. Ideally, this should be done at a meeting, so that all stakeholder groups hear, question and respond to the information at the same time. This will provide the best opportunity for stakeholder groups to assess the importance of the information, as they can also hear the questions and comments of other stakeholders. An open forum can provide an opportunity for balanced media coverage of the different views likely to be expressed.
- continuously reviewing and evaluating communication materials and approaches. The effectiveness of the communications strategy should be reviewed regularly. Changes should be made to materials, spokespeople or outreach methods as necessary. Many stakeholders are

involved in integrated surveillance programmes, and, as the programmes mature, the size of the annual report will probably increase, which may complicate sharing of materials with stakeholders. Alternative forms of presentation and distribution of results should be considered.

- preparing for adverse events. The team should be prepared for any adverse events reported in the media, so that they can respond rapidly.

Countries should decide the frequency of communication, such as weekly, monthly or annually, depending on the purpose of surveillance and the requirements of the target audience and stakeholders. The objective is to ensure that relevant stakeholders are well informed about evolving patterns and trends in AMU and AMR so that they can take timely action appropriate to the purpose of integrated surveillance. Continuous communication may be necessary in order to respond swiftly to emerging threats *(140).* Periodic in-depth reporting and communication should be conducted to assess long-term trends and make informed policy decisions. Countries should choose or nominate a competent authority responsible for communication of surveillance reports appropriate to the target audience.

Communication should be multi-faceted and tailored to stakeholders in different sectors.

- Regular, standardized reports delivered at predetermined intervals (e.g. quarterly or annually) to all sectors will provide a structured overview of the results of surveillance, facilitating analysis of long-term trends and strategic planning *(141).*
- Interactive dashboards and data visualization tools will enable rapid, dynamic visualization and assessment of data by personnel involved in early identification and monitoring of emerging and ongoing AMR trends. Frequent uploading and posting of the data will allow prompt intervention and containment *(142).* Updates should also be conducted frequently.
- The communication strategy should comprise various formats, such as written technical reports, presentations and infographics and lay summaries and briefings, to meet the needs of different stakeholders.
- During communication and reporting, it is essential to ensure dissemination of the findings to all sectors in meaningful ways for policy-making and the necessary action(s) to ensure a One Health approach.

5 Resources and requirements

5.1 Introduction

This section addresses the resources required for implementing integrated AMR and AMU surveillance at interfaces and among two or more sectors, and approaches for optimizing and strengthening them. Mapping the available resources and infrastructure should be among the first steps taken *(143,144)*. Determination of the availability of resources is essential for costing the system, allocating a budget and deciding on the appropriate scale for design and implementation *(4,143,144)*. Resources should first be discussed for the entire system and subsequently detailed for the laboratory equipment required for specific microorganisms and laboratory analytical methods. The necessary epidemiological data and resources for assessment of AMU should also be discussed. The resource requirements listed below were determined in a consultation of the Quadripartite Technical Group and after a review of the published literature on One Health integrated AMR and AMU surveillance systems and relevant implementation guidance.

Resources in a One Health integrated surveillance system are understood to consist of the input that the system requires to function in two or more sectors *(143,145)*. The three categories are HR, infrastructure and consumables, with the one-time capital investment and recurring maintenance costs *(145,146)* (see Table 4).

HR are defined as all the people in different sectors involved and engaged in actions whose primary intent is to conduct and enhance One-Health-integrated AMR and AMU surveillance *(147)*. Examples include the required workforce, expertise and disciplines.

Infrastructure refers to the physical resources and nonphysical systems that require maintenance. Infrastructure takes three distinct forms:

- institutional infrastructure, such as laboratory space and facilities;
- equipment, such as laboratory equipment that requires maintenance, such as a PCR machine, and vehicles; and
- supporting systems, such as utilities systems, information and communication technology systems, transport and logistics.

Consumables are single-use or disposable materials or equipment. Examples include antimicrobial panels, discs, culture media, AST media, laboratory reagents, supplies and equipment that does not require maintenance.

Capital investments are the funds or available budget, and maintenance expenditure refers to the recurrent costs for sustaining the usefulness of other resources. Each category of resources takes many forms (Table 4) *(4,7,143,144)*.

5.2

Potential points of integration

Section 3 (see sections 3.5 and 3.6) introduced five steps for integrating AMU and AMR surveillance activities across One Health sectors throughout the surveillance process. The present section highlights a few resource considerations for specific points of integration. It is followed by a list of the core resources required for One Health integrated surveillance of AMU and AMR in Table 4 and laboratory requirements for specific methods.

5.2.1 Human resources

Countries should assess and outline the capacity and expertise required for sampling and data collection; sample and specimen analysis, interpretation and reporting; and data analysis, interpretation and reporting.

Sampling and data collection: The number of personnel should reflect the amount of labour and the level of expertise required to conduct the work. Larger samples (e.g. a large number of facilities or establishments such as health-care facilities, farms, slaughter plants, markets) require more HR, especially when data must be entered or retrieved and analysed manually *(4,146).*

Sample analysis, interpretation and reporting: Microbiology staff should have the required expertise to analyse, interpret and accurately report results and participate in multidisciplinary and multisectoral analysis and discussion of the results of surveillance.

Data analysis, reporting, interpretation and communication: There may be no subject matter expert in a specific One Health sector. For example, formal education in laboratory and epidemiological approaches to disease control is more limited in some subsectors (e.g. aquaculture) than in others (e.g. livestock), as is expertise in certain advanced techniques (e.g. whole genome sequencing) than in routine laboratory testing (e.g. AST) especially in low- and middle-income countries *(146,147).* Workforce competence and skills should be considered to identify whether capacity-building is necessary in surveillance programmes.

5.2.2 Infrastructure

Ideally, countries should establish and work with a laboratory network in each sector. National reference laboratories in each sector should conduct complementary analyses of isolates that require special characterization of the pathogen and determine whether susceptibility testing or confirmation of the resistance mechanisms is required, with technologies adapted to the degree of complexity (e.g. whole genome sequencing). Routine laboratories are established in each sector according to the available resources to perform the first analysis of a sample or specimen and provide the information locally.

In some countries, the national reference laboratory can analyse samples and specimens. For example, surveillance of foodborne diseases requires laboratory capacity in primary health care, and lack of such laboratories requires a national laboratory to analyse samples or specimens to identify and characterize the pathogens.

Sampling, data collection and data analysis: Electronic data entry and collation systems allow handling of larger sample sizes, whereas manual data entry systems make data collation more resource-intensive and prone to errors. Decisions on infrastructure for sampling and data collection should be based on stakeholders' priorities. Electronic laboratory information systems facilitate the workload, transmission of locally generated data (in peripheral laboratories) to national databases and analysis, interpretation and reporting of results locally and nationally.

Laboratory analysis and test methods: Bacteriology laboratories must have the capacity to analyse samples, including culture, isolation, identification and AST. The disc diffusion method is a reliable and the cheapest method, but it is time consuming and requires well-trained staff. In laboratories that have more advanced technology, such as automated AST and whole genome DNA sequencing, the equipment is costly, and a reliable supply of materials and consumables is necessary to operate them *(138,148).*

Centralization of resources at a national or regional reference laboratory is recommended in countries with resource constraints and limited technical expertise for advanced technologies such as whole genome sequencing to complement routine surveillance. Laboratory networks coordinated by national reference laboratories ensure that SOPs and quality controls are adhered to. In low-resource settings, countries can consider a centralized system, which will reduce costs and facilitate the distribution, maintenance and sustainability of surveillance.

Data analysis, reporting, interpretation and communication: SOPs and resources are necessary for analysing medicines, laboratory and epidemiological data to support harmonization. A reporting and communication plan and SOPs ensure that results are available for each stakeholder group and other interested parties.

5.2.3 Consumables

Sampling and data collection: The quantity of consumables procured should be based on the number of target populations, estimated sample sizes and sampling intervals *(132,136,144,146).* Uninterrupted supply chains to prevent stockouts is an important consideration in procurement. Countries should consider only registered or accredited providers to ensure the quality of consumables. Mechanisms should be in place in the procurement process to ensure an interrupted supply of consumables.

5.2.4 Capital investment and expenditure for maintenance

Sampling and data collection: Resource generation entails procuring and making available the resources that the system requires to function *(145).* Considerations of capital investment and maintenance costs must include not only finances and a budget but also time, with longer timelines allocated to accommodate the different starting points in different sectors in countries and also to accommodate the gradual formation and roll out of the surveillance system within and among sectors. Optimal distribution of resources for a One Health integrated AMR and AMU surveillance system can be assessed by several possible methods, including:

- a productivity analysis to determine how efficiently resources are used to achieve integrated surveillance *(149)*; and
- comparative analysis of the use of resources and the impacts of the intervention (e.g. in a cost-benefit, cost-effectiveness or cost-utility evaluation or investment case) *(148).*

Laboratory analysis and test methods: Sustainable investment in human, infrastructure and material resources for laboratories for One Health Integrated AMR and AMU surveillance begins with the core resources identified in Table 8.

Data analysis, reporting, interpretation and communication: Sustainable capital investment is required to effectively support human and infrastructural resources for data collation, analysis, reporting, interpretation and communication, such as a national body or competent authority responsible for the oversight, coordination and implementation of these activities.

Table 8. Suggested core requirements and resources for undertaking One Health integrated surveillance of AMR and AMU

Resource type	Specific examples	Capital	Maintenance
Human Resources	Well-defined roles and responsibilities of staff, including epidemiological, data analysis and laboratory expertise, e.g. pharmacists, epidemiologists, bioinformaticians, data analysts, statisticians, laboratory technicians, microbiologists *(56,148,150–151)*; AMR and AMU surveillance officers *(4)*, logistics specialists *(143,146)*, network management specialists *(143)*, IT managers *(4,143,145,152)*, field sample collectors and accessioning staff *(56,151)*	Human capital (e.g. funded salaries, scholarships); contingency budgets for signal verification and response *(143)* Time	HR time and financial expenditure for continuing education and on-the-job training to maintain skills. Wages, stipends, salaries, benefits, payment, according to national or local employment guidance
Equipment infrastructure	Laboratory equipment for phenotypic and genomic analyses	Capital funds for purchase of equipment	HR time and financial expenditure for upkeep and repair of equipment and vehicles
Institutional infrastructure	Interdisciplinary collaborative agreements, data-sharing resources *(143,147,152,153)*; data repository infrastructure or access to a data repository; legal and regulatory framework *(143,151,153)*; digitized and electronic records systems *(4,151)* IT tools for data collection and analysis (e.g. ANIMUSE Calculation Tool *(151)*, WHO AMU tool) Reference gene data sets *(148)* National laboratory network *(147)* Dedicated physical structures for laboratory work	Capital funds for purchase of real estate and equipment	HR time and financial expenditure for upkeep of buildings
Supporting systems infrastructure	Basic utilities such as constant electricity, potable water supply, cold chain, access to computers and Internet, analytical weighing balance, light microscopes. Back-up or emergency utilities (i.e. back-up power generator and water reservoir) Safe biological waste disposal *(145)* Biosafety infrastructure Information and communication technology infrastructure *(145)*	Physical capital (e.g. capital funds for purchase or development of systems)	HR time and financial expenditure for maintenance, support and archiving of databases or cyberinfrastructure
Consumable resources	AST reagents and consumables Laboratory reagents and materials Personal protective equipment	Physical capital (e.g. funds or budget for purchase of inventory)	HR time and financial expenditure for sustaining or strengthening the supply chain
Capital expenditure	Contingency budgets for signal verification and response *(143)* Time Intersectoral funding (e.g. intersectoral calls for proposals for obtaining resources *(152)*)		

5.3

Benefits, enablers and challenges in resource allocation in a One Health context

One Health collaboration among sectors for integrated surveillance of AMR and AMU allows maximized use of data and resources, providing many benefits to sector-specific surveillance programmes, the integrated system and stakeholders, contributing to the generation of scientific information about AMR and AMU to ensure more targeted prevention and control strategies *(149,152).* Furthermore, sharing of resources among sectoral surveillance programmes leads to greater efficiency, cost-effectiveness and sustainability in the use of those resources. Resource pooling approaches, such as peer-to-peer sharing of expertise among sectors (e.g. through communities of practice) strengthen and sustain relationships, knowledge and the reputation of professional networks *(7,59,149,152).*

Inconsistent or inequitable distribution of funding among sectors poses a challenge to One Health integrated AMR and AMU surveillance *(143).* Surveillance is often not conducted in the areas of plants/crop and the environment, or, if it is, it is inadequately resourced *(154).* The amounts of resources vary widely among and within regions, countries and sectors *(143).* In some subsectors, such as wild animals and aquaculture, inadequate and inequitable resource allocation poses a barrier to their participation in integrated surveillance *(146).* Disparity in funding and resource allocation among sectors often mirrors the priorities of certain institutions with specific mandates. It indicates weak governance and coordination among institutions, limiting effective supplementation or synergy of each other's mandates. Stronger One Health governance to foster collaboration among institutions is important for creating more equitable, efficient distribution of resources.

When insufficient resources have been allocated for collaboration in a surveillance programmes, it may be addressed as an afterthought *(152,155).* Collaboration with other sectors is essential to meet the obligations of individual and collective sectors in a timely fashion. National budgets should allocate time and funding to ensure the sustainability of integrated surveillance programmes.

Prioritization of multisectoral collaboration on AMR requires both awareness of the benefits of resource sharing and formalization of collaboration as a priority in the objectives of each surveillance programme. Dedication of human, financial and technical resources to collaboration (e.g. a dedicated budget and a multisectoral operational team) is an important part of the solution to these challenges. Surveillance programmes should take into account the available resources and infrastructure, and countries should allocate finances to further increase them by investing in infrastructure and in building a sufficient workforce with the expertise to implement the surveillance activities as planned. In low-resource settings, a targeted analysis of priorities and effective use of available resources to strengthen capacity and infrastructure for AMR and AMU surveillance is essential for establishing and sustaining a system.

References[8]

1. Guidelines for designing animal disease surveillance plans. Rome: Food and Agriculture Organization of the United Nations; 2021 (https://openknowledge.fao.org/handle/20.500.14283/cb3252en).
2. World AMR Awareness Week: Key Messages. Food and Agriculture Organization of the United Nations, United Nations Environment Programme, World Health Organization, World Organisation for Animal Health (https://www.qjsamr.org/technical-work/world-amr-awareness-week).
3. Global Antimicrobial Resistance and Use Surveillance System (GLASS). Geneva: World Health Organization (https://www.who.int/initiatives/glass).
4. GLASS methodology for surveillance of national antimicrobial consumption. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/336215).
5. Chapter 6.4. Development and harmonization of national antimicrobial resistance surveillance and monitoring programmes for aquatic animals. In: Aquatic Animal Health Code. 22nd edition. Paris: World Organisation for Animal Health; 2019 (https://www.woah.org/fileadmin/Home/eng/Health_standards/aahc/2010/en_chapitre_antibio_development_harmonisation.htm).
6. Chapter 6.8. Harmonisation of national antimicrobial resistance surveillance and monitoring programmes. In: Terrestrial Animal Health Code. Paris: World Organisation for Animal Health; 2018 (https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/en_chapitre_antibio_harmonisation.htm).
7. FAO, WHO. Foodborne antimicrobial resistance. Compendium of Codex standards. First revision. Rome: Codex Alimentarius Commission; 2023. (https://doi.org/10.4060/cb8554en).
8. Technical brief on water, sanitation, hygiene (WASH) and wastewater management to prevent infections and reduce the spread of antimicrobial resistance (AMR). Geneva: World Health Organization; 2020. (https://iris.who.int/handle/10665/332243). License: CC BY-NC-SA 3.0 IGO.
9. Bracing for Superbugs. Strengthening environmental action in the One Health response to antimicrobial resistance. Nairobi: United Nations Environment Programme; 2023 (https://wedocs.unep.org/bitstream/handle/20.500.11822/38444/antimicrobial_Report.pdf?sequence=1&isAllowed=y).
10. Antimicrobial resistance terms. Rome: Food and Agriculture Organization of the United Nations; undated (https://openknowledge.fao.org/server/api/core/bitstreams/db8272f6-0b18-4af3-8e33-54e742df4eee/content).
11. Murray CJL, Ikuta KS, Sharara F, Swetschinski L, Aguilar GR, Gray A et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet 2022;399(10325):629–55. (https://doi.org/10.1016/S0140-6736(21)02724-0).
12. Ten threats to global health in 2019 [website]. Geneva: World Health Organization; 2019 (https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019).
13. Karp BE, Tate H, Plumblee JR, Dessai U, Whichard JM, Thacker EL et al. National antimicrobial resistance monitoring system: two decades of advancing public health through integrated surveillance of antimicrobial resistance. Foodborne Pathog Dis. 2017;14(10):545–57. (https://doi.org/10.1089/fpd.2017.2283).
14. Islam T, Haque MA, Barai HR, Istiaq A, Kim JJ. Antibiotic resistance in plant pathogenic bacteria: recent data and environmental impact of unchecked use and the potential of biocontrol agents as an eco-friendly alternative. Plants (Basel). 2024;13(8):1135. (https://doi.org/10.3390/plants13081135).
15. Miller SA, Ferreira JP, Lejeune JT. Antimicrobial use and resistance in plant agriculture: a One Health perspective. Agriculture. 2022;12(282):1–27. (https://doi.org/https://doi.org/10.3390/agriculture12020289).
16. Taylor P, Reeder R. Antibiotic use on crops in low and middle-income countries based on recommendations made by agricultural advisors. CABI Agric Biosci. 2020;1(1):1. (https://doi.org/10.1186/s43170-020-00001-y).
17. Mshana SE, Matee M, Rweyemamu M. Antimicrobial resistance in human and animal pathogens in Zambia, Democratic Republic of Congo, Mozambique and Tanzania: An urgent need of a sustainable surveillance system. Ann Clin Microbiol Antimicrob. 2013;12(1):28. (https://doi.org/10.1186/1476-0711-12-28).
18. Kipkorir KC, Ang'ienda PO, Onyango DM, Onyango PO. Antibiotic resistance of Escherichia coli from humans and black rhinoceroses in Kenya. Ecohealth. 2020;17(1):41–51. (https://doi.org/10.1007/s10393-019-01461-z).
19. Marco-Fuertes A, Marin C, Lorenzo-Rebenaque L, Vega S, Montoro-Dasi L. Antimicrobial resistance in companion animals: a new challenge for the One Health approach in the European Union. Vet Sci. 2022;9(5):208. (https://doi.org/10.3390/vetsci9050208).
20. Nieto-Claudin A, Deem SL, Rodríguez C, Cano S, Moity N, Cabrera F et al. Antimicrobial resistance in Galapagos tortoises as an indicator of the growing human footprint. Environ Pollut. 2021;284:117453. (https://doi.org/10.1016/j.envpol.2021.117453).
21. Barour D, Berghiche A, Boulebda N. Antimicrobial resistance of Escherichia coli isolates from cattle in Eastern Algeria. Vet World. 2019;12(8):1195–203. (https://doi.org/10.14202/vetworld.2019.1195-1203).

8 All references were accessed on 11 February 2026.

22. Pissetti C, Kich JD, Allen HK, Navarrete C, de Freitas Costa E, Morés N et al. Antimicrobial resistance in commensal Escherichia coli and Enterococcus spp. isolated from pigs subjected to different antimicrobial administration protocols. Res Vet Sci. 2021;137:174–85. (https://doi.org/10.1016/j.rvsc.2021.05.001).
23. Brunn AA, Roustit M, Kadri-Alabi Z, Guardabassi L, Waage J. A meta-analysis to estimate prevalence of resistance to tetracyclines and third generation cephalosporins in Enterobacteriaceae isolated from food crops. Antibiotics (Basel). 2022;11(10):1424. (https://doi.org/10.3390/antibiotics11101424).
24. Pärnänen KMM, Narciso-da-Rocha C, Kneis D, Berendonk TU, Cacace D, Do TT et al. Antibiotic resistance in European wastewater treatment plants mirrors the pattern of clinical antibiotic resistance prevalence. Sci Adv. 2019;5(3):eaau9124. (https://doi.org/10.1126/sciadv.aau9124).
25. Tiedje JM, Wang F, Manaia CM, Virta M, Sheng H, Ma L et al. Antibiotic resistance genes in the human-impacted environment: A One Health perspective. Pedosphere. 2019;29(3):273–82. (https://doi.org/10.1016/S1002-0160(18)60062-1).
26. Haenni M, Lupo A, Madec JY. Antimicrobial resistance in Streptococcus spp. Microbiol Spectr. 2018;6(2):10.1128/microbiolspect.arba-0008-2017. (https://doi.org/10.1128/microbiolspec.ARBA-0008-2017).
27. Smalla K, Cook K, Djordjevic SP, Klümper U, Gillings M. Environmental dimensions of antibiotic resistance: assessment of basic science gaps. FEMS Microbiol Ecol. 2018;94(12). (https://doi.org/10.1093/femsec/fiy195)
28. Drug-resistant infections: a threat to our economic future. Washington DC: World Bank; 2017. (https://documents1.worldbank.org/curated/en/323311493396993758/pdf/final-report.pdf?_gl=1*1yqv46e*_gcl_au*MjA5OTg3NDI1NC4xNzIzMjI2OTAw).
29. GLG report: Towards specific commitments and action in the response to antimicrobial resistance. Recommendations for consideration by UN Member States in the outcome document of the High-level Meeting on Antimicrobial Resistance. Geneva: Global Leaders Group on Antimicrobial Resistance; 2024 (https://www.amrleaders.org/resources/m/item/glg-report).
30. Political Declaration of the High-level Meeting on Antimicrobial Resistance. Geneva: Global Leaders Group on Antimicrobial Resistance; 2024 (https://www.un.org/pga/wp-content/uploads/sites/108/2024/09/FINAL-Text-AMR-to-PGA.pdf).
31. Majumder MAA, Rahman S, Cohall D, Bharatha A, Singh K, Haque M et al. Antimicrobial stewardship: fighting antimicrobial resistance and protecting global public health. Infect Drug Resist. 2020;13:4713–38. (https://doi.org/10.2147/IDR.S290835).
32. Mettenleiter TC, Markotter W, Charron DF, Adisasmito WB, Almuhairi S, Behravesh CB et al. The One Health High-level Expert Panel (OHHLEP). One Health Outlook. 2023;5:18. (https://doi.org/10.1186/s42522-023-00085-2).
33. Cars O, Xiao Y, Stålsby Lundborg C, Nilsson LE, Shen J, Sun Q et al. Building bridges to operationalise one health – a Sino-Swedish collaboration to tackle antibiotic resistance. One Health. 2016;2:139–43. (https://doi.org/10.1016/j.onehlt.2016.09.002).
34. Mwatondo A, Rahman-Shepherd A, Hollmann L, Chiossi S, Maina J, Kurup KK et al. A global analysis of One Health networks and the proliferation of One Health collaborations. Lancet. 2023;401(10376):605–16. (https://doi.org/10.1016/S0140-6736(22)01596-3).
35. Corning S. World Organisation for Animal Health: strengthening veterinary services for effective One Health collaboration. Rev Sci Tech. 2014;33(2):639–50. (https://doi.org/10.20506/rst.33.2.2305).
36. A One Health priority research agenda for antimicrobial resistance. Geneva: FAO, UNEP, WHO, WOAH; 2023 (https://iris.who.int/handle/10665/370279).
37. M'Ikanatha NM, Kline KE, Boktor SW, Yin X, Dettinger L, Tewari D et al. Integrated surveillance for antimicrobial-resistance in *Salmonella* from clinical and retail meat sources – Pennsylvania, 2015–2017. Open Forum Infect Dis. 2019;6:S291–2. (https://doi.org/10.1093/ofid/ofz360.696).
38. Otto SJG, Haworth-Brockman M, Miazga-Rodriguez M, Wierzbowski A, Saxinger LM. Integrated surveillance of antimicrobial resistance and antimicrobial use: evaluation of the status in Canada (2014–2019). Can Vet J. 2022;63(2):161–70. (https://doi.org/10.17269/s41997-021-00600-w).
39. Global Leaders Group on Antimicrobial Resistance [website]. Geneva (https://www.amrleaders.org/#tab=tab_1).
40. DANMAP. The Danish Integrated Antimicrobial Resistance Monitoring and Research Programme [website]. Copenhagen: Statens Serum Institut (https://www.danmap.org).
41. National Antimicrobial Resistance Monitoring System (NARMS) [website]. Washington DC: Food Safety and Inspection Service, US Department of Agriculture [website]. (https://www.fsis.usda.gov/science-data/national-antimicrobial-resistance-monitoring-system-narms).
42. SWAB. Stichting Werkgroep Antibioticabeleid [Working Party on Antibiotic Policy] [website]. (Dutch acronym is SWAB) - NethMap [website]. Leiden (https://swab.nl/en/nethmap-pvid369).
43. Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) [website]. Ottawa: Centre for Food-borne, Environmental and Zoonotic Infectious Diseases and National Microbiology Laboratory, Public Health Agency of Canada (https://www.canada.ca/en/public-health/services/surveillance/canadian-integrated-program-antimicrobial-resistance-surveillance-cipars.html).
44. Global Tricycle Surveillance ESBL *E. coli*. WHO integrated global surveillance on ESBL-producing *E. coli* using a "One Health" approach: implementation and opportunities. Geneva: World Health Organization; 2021. (https://iris.who.int/handle/10665/340079). License: CC BY-NC-SA 3.0 IGO.

45. International FAO Antimicrobial Resistance Monitoring (InFARM) system [website]. Rome: Food and Agriculture Organization of the United Nations (https://www.fao.org/antimicrobial-resistance/resources/infarm-system/en/).
46. International FAO Antimicrobial Resistance Monitoring (InFARM) system – Manual for implementation. Rome: Food and Agriculture Organization of the United Nations; 2024 (https://doi.org/https://doi.org/10.4060/cd0805en).
47. ANIMUSE [website]. Paris: World Organisation for Animal Health (https://amu.woah.org/amu-system-portal/home).
48. Kirchhelle C, Atkinson P, Broom A, Chuengsatiansup K, Ferreira JP, Fortané N et al. Setting the standard: multidisciplinary hallmarks for structural, equitable and tracked antibiotic policy. BMJ Glob Health. 2020;5(9):e003091. (https://doi.org/10.1136/bmjgh-2020-003091).
49. Waśko I, Kozińska A, Kotlarska E, Baraniak A. Clinically relevant β-lactam resistance genes in wastewater treatment plants. Int J Environ Res Public Health. 2022;19(21):13829. (https://doi.org/10.3390/ijerph192113829).
50. Iskandar K, Molinier L, Hallit S, Sartelli M, Hardcastle TC, Haque M et al. Surveillance of antimicrobial resistance in low- and middle-income countries: a scattered picture. Antimicrob Resist Infect Control. 2021;10(1):63. (https://doi.org/10.1186/s13756-021-00931-w).
51. Chen C, Li SL, Xu YY, Liu J, Graham DW, Zhu YG. Characterising global antimicrobial resistance research explains why One Health solutions are slow in development: An application of AI-based gap analysis. Environ Int. 2024;187:108680. (https://doi.org/https://doi.org/10.1016/j.envint.2024.108680).
52. Integrated surveillance of antimicrobial resistance in foodborne bacteria: application of a one health approach: guidance from the WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR). Geneva: World Health Organization; 2017 (https://iris.who.int/handle/10665/255747).
53. Guidelines on integrated monitoring and surveillance of foodborne antimicrobial resistance (CXG 94-2021). Rome: Codex Alimentarius; 2021 (https://www.fao.org/fao-who-codexalimentarius/sh-proxy/de/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXG%2B94-2021%252FCXG_94e.pdf).
54. Analysis of antimicrobial consumption and resistance ('JIACRA' reports) [website]. Amsterdam: European Medicines Agency (https://www.ema.europa.eu/en/veterinary-regulatory-overview/antimicrobial-resistance-veterinary-medicine/analysis-antimicrobial-consumption-resistance-jiacra-reports).
55. European Centre for Disease Prevention and Control (ECDC), European Food Safety Authority (EFSA), European Medicines Agency (EMA). Antimicrobial consumption and resistance in bacteria from humans and food-producing animals. Fourth joint inter-agency report on integrated analysis of antimicrobial agent consumption and occurrence of antimicrobial resistance in bacteria from humans and food-producing animals in the EU/EEA JIACRA IV – 2019–2021. EFSA J. 2024. (https://doi.org/https://doi.org/10.2903/j.efsa.2024.8589).
56. GLASS guide for national surveillance systems for monitoring antimicrobial consumption in hospitals. Geneva: World Health Organization; 2020 (https://iris.who.int/handle/10665/336182).
57. IPPC survey on antimicrobial products used in phytosanitary context. In: 18th Session of the Commission on Phytosanitary Measures. Rome: Food and Agriculture Organization; 2024 (https://assets.ippc.int/static/media/files/publication/en/2024/03/43_CPM_2024_IPPC_AMR_survey_2024-03-08.pdf).
58. Pettengill JB, Beal J, Balkey M, Allard M, Rand H, Timme R. Interpretative labor and the bane of nonstandardized metadata in public health surveillance and food safety. Clin Infect Dis. 2021;73(8):1537–9. (https://doi.org/10.1093/cid/ciab615).
59. Varona OM, Chaintarli K, Muller-Pebody B, Anjum MF, Eckmanns T, Norström M et al. Monitoring antimicrobial resistance and drug usage in the human and livestock sector and foodborne antimicrobial resistance in six European countries. Infect Drug Resist. 2020;13:957–93. (https://doi.org/10.2147/IDR.S237038).
60. Hyde RM, Remnant JG, Bradley AJ, Breen JE, Hudson CD, Davies PL et al. Quantitative analysis of antimicrobial use on British dairy farms. Vet Rec. 2017;181(25):683. (https://doi.org/10.1136/vr.104614).
61. Kalanxhi E, Osena G, Kapoor G, Klein E. Confidence interval methods for antimicrobial resistance surveillance data. Antimicrob Resist Infect Control. 2021;10(1):91. (https://doi.org/10.1186/s13756-021-00960-5).
62. Booton RD, Meeyai A, Alhusein N, Buller H, Feil E, Lambert H et al. One Health drivers of antibacterial resistance: Quantifying the relative impacts of human, animal and environmental use and transmission. One Health. 2021;12:100220. (https://doi.org/10.1016/j.onehlt.2021.100220).
63. Schrijver R, Stijntjes M, Rodríguez-Baño J, Tacconelli E, Babu Rajendran N, Voss A. Review of antimicrobial resistance surveillance programmes in livestock and meat in EU with focus on humans. Clin Microbiol Infect. 2018;24(6):577–90. (https://doi.org/10.1016/j.cmi.2017.09.013).
64. Peñalva G, Crespo-Robled P, Molvik M, López-Nava A, Kacelnik O, Cisneros JM et al. A step forward in antibiotic use and resistance monitoring: A quarterly surveillance system pilot in 11 European Union/European Economic Area countries, September 2017 to May 2020. Eurosurveillance. 2022;27(46):2200082. (https://doi.org/10.2807/1560-7917.ES.2022.27.46.2200082).
65. Raboisson D, Ferchiou A, Sans P, Lhermie G, Dervillé M. The economics of antimicrobial resistance in veterinary medicine: Optimizing societal benefits through mesoeconomic approaches from public and private perspectives. One Health. 2020;10:100145. (https://doi.org/https://doi.org/10.1016/j.onehlt.2020.100145).
66. The WHO Member State mechanism on substandard and falsified medical products: how WHO Member States work together to increase access to safe, effective and quality medicines, vaccines and other medical products. Geneva: World Health Organization; 2023 (https://iris.who.int/handle/10665/332635). License: CC BY-NC-SA 3.0 IGO).

67. Global surveillance and monitoring system for substandard and falsified medical products: activity report, August 2017–December 2021. Geneva: World Health Organization; 2024 (https://iris.who.int/handle/10665/379645). License: CC BY-NC-SA 3.0 IGO.

68. Update on substandard & falsified veterinary products (SFVPs) activities and relevant WOAH standards. Paris: World Organisation for Animal Health; 2024 (https://rr-asia.woah.org/app/uploads/2024/11/S6.01_TPW_AMU_Aqua_Singapore.pdf).

69. Humphries RM, Ambler J, Mitchell SL, Castanheira M, Dingle T, Hindler JA et al. CLSI Methods Development and Standardization Working Group best practices for evaluation of antimicrobial susceptibility tests. J Clin Microbiol. 2018;56(4):e01934-17. (https://doi.org/10.1128/jcm.01934-17).

70. Karlowsky JA, Richter SS. Antimicrobial susceptibility testing systems. In: Jorgensen JH, Carroll KC, Funke G, Pfaller MA, Landry ML, Richter SS et al., editors. Manual of Clinical Microbiology. Washington DC: ASM Press; 2015:1274–85. (https://doi.org/https://doi.org/10.1128/9781555817381.ch72).

71. Yu Z, Zhang X, Zhao Q, Yan X, Wu C, Qing L et al. Urolithin B alleviates Helicobacter pylori-induced inflammation and oxidative stress in mice. Helicobacter. 2023; 28(6):e13016. (https://doi.org/10.1111/hel.13016).

72. Strohaeker J, Aschke V, Koenigsrainer A, Nadalin S, Bachmann R. Urinary tract infections in kidney transplant recipients — Is there a need for antibiotic stewardship? J Clin Med. 2021;11(1):226. (https://doi.org/10.3390/jcm11010226).

73. The selection and use of essential medicines 2023. Web Annex C. WHO AWaRe (access, watch, reserve) classification of antibiotics for evaluation and monitoring of use, 2023. Geneva: World Health Organization; 2023 (https://iris.who.int/handle/10665/371093). License: CC BY-NC-SA 3.0 IGO.

74. WHO list of medically important antimicrobials: a risk management tool for mitigating antimicrobial resistance due to non-human use. Geneva: World Health Organization; 2024 (https://cdn.who.int/media/docs/default-source/gcp/who-mia-list-2024-lv.pdf?sfvrsn=3320dd3d_2).

75. WOAH List of Antimicrobial Agents of Veterinary Importance. Paris: World Organisation for Animal Health; 2024 (https://www.woah.org/app/uploads/2021/06/amended-91gs-tech-03-amr-working-group-report-en.pdf).

76. 23rd Essential Medicines List [online database]. Geneva: World Health Organization; 2023 (https://list.essentialmeds.org/).

77. Cei M, Pardelli R, Sani S, Mumoli N. Local resistance patterns to antimicrobials in internal medicine: a focused report from the REGIMEN (REGistro Infezioni in MEdicina INterna) study. Clin Exp Med. 2014;14(1):778–82. (https://doi.org/10.1007/s10238-012-0219-0).

78. Jones RN. Resistance patterns among nosocomial pathogens: trends over the past few years. Chest. 2001;119(2 Suppl): 397S–404S. (https://doi.org/10.1378/chest.119.2_suppl.397s).

79. Mogasale VV, Saldanha P, Pai V, Rekha PD, Mogasale V. A descriptive analysis of antimicrobial resistance patterns of WHO priority pathogens isolated in children from a tertiary care hospital in India. Sci Rep. 2021;11(1):5116. (https://doi.org/10.1038/s41598-021-84293-8).

80. Tyson GH, Sabo JL, Hoffmann M, Hsu CH, Mukherjee S, Hernandez J et al. Novel linezolid resistance plasmids in Enterococcus from food animals in the USA. J Antimicrob Chemother. 2018;73(12):3254–8. (https://doi.org/10.1093/jac/dky369).

81. Xiao M, Fan X, Chen SCA, Wang H, Sun ZY, Liao K et al. Antifungal susceptibilities of Candida glabrata species complex, Candida krusei, Candida parapsilosis species complex and Candida tropicalis causing invasive candidiasis in China: 3 year national surveillance. J Antimicrob Chemother. 2015;70(3):802–10. (https://doi.org/10.1093/jac/dku460).

82. Wetzker W, Pfeifer Y, Wolke S, Haselbeck A, Leistner R, Kola A et al. Extended-spectrum beta-lactamase (ESBL)-producing Escherichia coli isolated from flies in the urban center of Berlin, Germany. Int J Environ Res Public Health. 2019;16(9):1530. (https://doi.org/10.3390/ijerph16091530).

83. Kovačević Z, Vidović J, Erdeljan M, Cincović M, Ružić Z, Galić I et al. Veterinary practitioners' standpoints and comprehension towards antimicrobial use – Are there opportunities for antimicrobial stewardship improvement? Antibiotics (Basel). 2022;11(7):867. (https://doi.org/10.3390/antibiotics11070867).

84. Manual of diagnostic tests and vaccines for terrestrial animals. Thirteenth edition. Paris: World Organisation for Animal Health; (https://www.woah.org/en/what-we-do/standards/codes-and-manuals/terrestrial-manual-online-access/).

85. Data quality monitoring and surveillance system evaluation – a handbook of methods and applications. Stockholm: European Centre for Disease Prevention and Control; 2014 (https://www.ecdc.europa.eu/en/publications-data/data-quality-monitoring-and-surveillance-system-evaluation-handbook-methods-and).

86. Acharya KR, Brankston G, Soucy JPR, Cohen A, Hulth A, Löfmark S et al. Evaluation of an OPEN Stewardship generated feedback intervention to improve antibiotic prescribing among primary care veterinarians in Ontario, Canada and Israel: Protocol for evaluating usability and an interrupted time-series analysis. BMJ Open. 2021;11(1):e039760. (https://doi.org/10.1136/bmjopen-2020-039760).

87. Coombes CE, Gregory ME. The current and future use of telemedicine in infectious diseases practice. Curr Infect Dis Rep. 2019;21(11):41. (https://doi.org/10.1007/s11908-019-0697-2).

88. Rasheed H, Höllein L, Holzgrabe U. Future information technology tools for fighting substandard and falsified medicines in low- and middle-income countries. Front Pharmacol. 2018;9:995. (https://doi.org/10.3389/fphar.2018.00995).

89. Patil R, Gopal I. The importance of data sharing in managing public health crises. In: Shaw R, Gurtoo A, editors. Global Pandemic and Human Security. Singapore: Springer; 2022:393–412. (https://doi.org/10.1007/978-981-16-5074-1_21).

90. Wirth FN, Meurers T, Johns M, Prasser F. Privacy-preserving data sharing infrastructures for medical research: systematization and comparison. BMC Med Inform Decis Mak. 2021;21(1):242. (https://doi.org/10.1186/s12911-021-01602-x).

91. Xiang D, Cai W. Privacy protection and secondary use of health data: strategies and methods. Biomed Res Int. 2021;6967166. (https://doi.org/10.1155/2021/6967166).

92. FAO, WHO, WOAH. Surveillance and Information Sharing Operational Tool [website]. Geneva: World Health Organization; 2022 (https://www.who.int/initiatives/tripartite-zoonosis-guide/surveillance-and-information-sharing-operational-tool).

93. Santos RP, Mayo TW, Siegel JD. Active surveillance cultures and contact precautions for control of multidrug-resistant organisms: ethical considerations. Clin Infect Dis. 2008;47(1):110–6. (https://doi.org/10.1086/588789).

94. Griffith MM, Patel JA, Sutton SH, Bolon MK, Esterly JS, Gross AE et al. Prospective approach to managing antimicrobial drug shortages. Infect Control Hosp Epidemiol. 2012;33(7):745–52 (https://doi.org/10.1086/666332).

95. Fasina FO, Fasanmi OG, Makonnen YJ, Bebay C, Bett B, Roesel K. The one health landscape in sub-Saharan African countries. One Health. 2021;13:100325. (https://doi.org/10.1016/j.onehlt.2021.100325).

96. Etkind SC. The role of the public health department in tuberculosis. Med Clin North Am. 1993;77(6):1303–14. (https://doi.org/10.1016/s0025-7125(16)30195-x).

97. Falchi A, Lasserre A, Gallay A, Blanchon T, Sednaoui P, Lassau F et al. A survey of primary care physician practices in antibiotic prescribing for the treatment of uncomplicated male gonoccocal urethritis. BMC Fam Pract. 2011;12:35. (https://doi.org/10.1186/1471-2296-12-35).

98. Odoi A, Samuels R, Carter CN, Smith J. Antibiotic prescription practices and opinions regarding antimicrobial resistance among veterinarians in Kentucky, USA. PLoS One. 2021;16(4):e0249653. (https://doi.org/10.1371/journal.pone.0249653).

99. Oh SR, Seo YD, Lee E, Kim YG. A comprehensive survey on security and privacy for electronic health data. Int J Environ Res Public Health. 2021;18(18):9668. (https://doi.org/10.3390/ijerph18189668).

100. Yigzaw KY, Olabarriaga S, Michalas A, Marco-Ruiz L, Hillen C, Verginadis Y et al. Health data security and privacy: challenges and solutions for the future. In: Hovenga E, Grain H, editors. Roadmap to successful digital health ecosystems. A global perspective. Amsterdam: Elsevier; 2022:335–62. (https://doi.org/10.1016/B978-0-12-823413-6.00014-8).

101. Zarour M, Alenezi M, Ansari MTJ, Pandey AK, Ahmad M, Agrawal A et al. Ensuring data integrity of healthcare information in the era of digital health. Healthc Technol Lett. 2021;8(3):66–77. (https://doi.org/10.1049/htl2.12008).

102. Gutiérrez-Sacristán A, De Niz C, Kothari C, Kong SW, Mandl KD, Avillach P. GenoPheno: cataloging large-scale phenotypic and next-generation sequencing data within human datasets. Briefings Bioinformatics. 2020;22(1):55–65. (https://doi.org/10.1093/bib/bbaa033).

103. European Antimicrobial Resistance Surveillance Network (EARS-Net) [website]. Stockholm: European Centre for Disease Prevention and Control (https://www.ecdc.europa.eu/en/about-us/networks/disease-networks-and-laboratory-networks/ears-net-data).

104. Kula C, Arga KY. Systems biomarkers, artificial intelligence, and One Health vision can help fight antimicrobial resistance. Omics. 2023;27(4):191–2. (https://doi.org/10.1089/omi.2023.0021).

105. Berman TS, Barnett-Itzhaki Z, Berman T, Marom E. Antimicrobial resistance in food-producing animals: towards implementing a one health based national action plan in Israel. Isr J Health Policy Res. 2023;12(1):18. (https://doi.org/10.1186/s13584-023-00562-z).

106. Hoteit M, Yaghi J, El Khoury A, Daou R, Hindieh P, Assaf JC et al. Prevalence and antibiotic resistance of *Staphylococcus aureus* and Escherichia coli isolated from bovine raw milk in Lebanon: a study on antibiotic usage, antibiotic residues, and assessment of human health risk using the One Health approach. Antibiotics (Basel). 2022;11(12):1815. (https://doi.org/10.3390/antibiotics11121815).

107. Meroni G, Sora VM, Martino PA, Sbernini A, Laterza G, Zaghen F et al. Epidemiology of antimicrobial resistance genes in Streptococcus agalactiae sequences from a public database in a One Health perspective. Antibiotics (Basel). 2022;11(9):1236. (https://doi.org/10.3390/antibiotics11091236).

108. Gomes B, Dias M, Cervantes R, Pena P, Santos J, Vasconcelos Pinto M et al. One Health approach to tackle microbial contamination on poultries – a systematic review. Toxics. 2023;11(4):374. (https://doi.org/10.3390/toxics11040374).

109. Hailat E, Amiri M, Debnath N, Rahman M, Nurul Islam M, Fatima Z et al. Strengthening the One Health approach in the Eastern Mediterranean Region. Interact J Med Res. 2023;12:e41190. (https://doi.org/10.2196/41190).

110. Ramai D, Noorani A, Ofosu A, Ofori E, Reddy M, Gasperino J. Practice measures for controlling and preventing hospital associated Clostridium difficile infections. Hosp Pract (1995). 2019;47(3):123–9. (https://doi.org/10.1080/21548331.2019.1627851).

111. Kruse EB, Dettenkofer M. Epidemiologie von und Präventionsmaßnahmen bei multiresistenten Erregern [Epidemiology of and preventive measures for multiresistant pathogens (in German)]. Ophthalmologe. 2010;107(4):313–7. (https://doi.org/10.1007/s00347-009-2074-2).

112. Flanagan M, Ramanujam R, Sutherland J, Vaughn T, Diekema D, Doebbeling BN. Development and validation of measures to assess prevention and control of AMR in hospitals. Med Care. 2007;45(6):537–44. (https://doi.org/10.1097/MLR.0b013e31803bb48b).

113. Khamadi SA, Mavere C, Bahemana E, Lwilla A, Mizinduko M, Bwigane S et al. Early warning indicators of HIV drug resistance in the southern highlands region of Tanzania: Lessons from a cross-sectional surveillance study. PLOS Glob Public Health. 2023;3(3):e0000929. (https://doi.org/10.1371/journal.pgph.0000929).

114. Macía-Rivas L, Calzón Blanco C, Fernández Laguna CL, Álvarez Asteinza C, Maray Mateos I, Fernández Lastras S et al. 4CPS-186 2020 antimicrobial consumption indicators: analysis compared with previous years. Eur J Hosp Pharm. 2022;29(Suppl_1):A90–1. (https://doi.org/10.1136/ejhpharm-2022-eahp.189).

115. Giorgi Rossi P, Mantovani J, Ferroni E, Forcina A, Stanghellini E, Curtale F et al. Incidence of bacterial meningitis (2001–2005) in Lazio, Italy: the results of a integrated surveillance system. BMC Infect Dis. 2009;9:13. (https://doi.org/10.1186/1471-2334-9-13).

116. Alban L, Bordier M, Häsler B, Collineau L, Tomassone L, Bennani H et al. Capturing systematically users' experience of evaluation tools for integrated AMU and AMR surveillance. Front Vet Sci. 2023;10:1107122. (https://doi.org/10.3389/fvets.2023.1107122).

117. Baldovin T, Lazzari R, Cocchio S, Furlan P, Bertoncello C, Saia M et al. Invasive meningococcal disease in the Veneto region of Italy: a capture–recapture analysis for assessing the effectiveness of an integrated surveillance system. BMJ Open. 2017;7(4):e012478. (https://doi.org/10.1136/bmjopen-2016-012478).

118. Barroso P, Acevedo P, Vicente J. The importance of long-term studies on wildlife diseases and their interfaces with humans and domestic animals: a review. Transbound Emerg Dis. 2021;68(4):1895–909. (https://doi.org/10.1111/tbed.13916).

119. Jones DC, LaMartina EL, Lewis JR, Dahl AJ, Nadig N, Szabo A et al. One Health and Global Health View of Antimicrobial Susceptibility through the "Eye" of Aeromonas: Systematic Review and Meta-Analysis. Int J Antimicrob Agents. 2023;62(2):106848. (https://doi.org/10.1016/j.ijantimicag.2023.106848).

120. Anatomical Therapeutic Chemical (ATC) classification system and the Defined Daily Dose (DDD) [website]. Geneva: World Health Organization (https://www.who.int/teams/health-product-and-policy-standards/inn/atc-ddd).

121. Terrestrial and Aquatic Animal Health Code (2024) [website]. Paris: World Organisation for Animal Health; 2024 (https://www.woah.org/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/).

122. Bansal D, Mangla S, Undela K, Gudala K, D'Cruz S, Sachdev A et al. Measurement of adult antimicrobial drug use in tertiary care hospital using defined daily dose and days of therapy. Indian J Pharm Sci. 2014;76(3):211–7. PMCID: PMC4090828.

123. Guillot J, Roy H, Ovetchkine P, Lebel D, Bussières JF. Exploration of defined daily dose and days of therapy in paediatrics and ob-gyn-a descriptive analysis of antifungals. Pharmacoepidemiol Drug Saf. 2013;22:330. (https://doi.org/10.1002/pds.3512).

124. Lee HY, Liu PY, Liu CH, Chang WK, Chiang MC, Li CY et al. Decreased antibiotic resistance and defined daily doses after implementation of a clinical culture-guided antimicrobial stewardship program in a local hospital in Taiwan. J Microbiol Immunol Infect. 2015;48(2):S51–2

125. Montecatine-Alonso E, Gil-Navarro MV, Fernández-Llamazares CM, Fernández-Polo A, Soler-Palacín P, Llorente-Gutiérrez J et al. Antimicrobial defined daily dose adjusted by weight: a proposal for antibiotic consumption measurement in children. Enferm Infecc Microbiol Clin (Engl Ed). 2019;37(5):301–6. (https://doi.org/10.1016/j.eimc.2018.07.011).

126. Nunes PHC, Moreira JPDL, Thompson ADF, Machado TLDS, Cerbino-Neto J, Bozza FA. Antibiotic consumption and deviation of prescribed daily dose from the defined daily dose in critical care patients: a point-prevalence study. Front Pharmacol. 2022;13:913568. (https://doi.org/10.3389/fphar.2022.913568).

127. Szewczyk B, Campion M, Bylsma T, Vazquez GA, Doron S, Wurcel AG. Application of defined daily dose to antibiotic prescribing in Massachusetts jails. Open Forum Infect Dis. 2022;9:S683–4. (https://doi.org/10.1093/ofid/ofac492.1396).

128. Villanueva-Bueno C, Montecatine-Alonso E, Jiménez-Parrilla F, Fernández-Llamazares CM, Manrique-Rodríguez S, Zamora-Flores E et al. Antimicrobial defined daily dose in neonatal population. Enferm Infecc Microbiol Clin. 2022;40(2):59–65. (https://doi.org/10.1016/j.eimc.2021.05.007).

129. Dalton BR, MacTavish SJ, Bresee LC, Rajapakse N, Vanderkooi O, Vayalumkal J et al. Antimicrobial use over a four-year period using days of therapy measurement at a Canadian pediatric acute care hospital. Can J Infect Dis Med Microbiol. 2015;26(5):253–8. (https://doi.org/10.1155/2015/835209).

130. Redding LE, Grunwald H, Melofchik C, Meily P, Henry A, Stefanovski D. Comparison of animal daily doses and days of therapy for antimicrobials in species of veterinary importance. Prev Vet Med. 2020;176:104942. (https://doi.org/10.1016/j.prevetmed.2020.104942).

131. Suzuki H, Heintz BH, Livorsi DJ, Perencevich EN, Goto M. Tracking antimicrobial stewardship activities beyond days of therapy (DOT): Comparison of days of antibiotic spectrum coverage (DASC) and DOT at a single center. Infect Control Hosp Epidemiol. 2023;44(6):934–7. (https://doi.org/10.1017/ice.2022.312).

132. Hansen MJ, Carson PJ, Leedahl DD, Leedahl ND. Failure of a best practice alert to reduce antibiotic prescribing rates for acute sinusitis across an integrated health system in the Midwest. J Manag Care Spec Pharm. 2018;24(2):154–9. (https://doi.org/10.18553/jmcp.2018.24.2.154).

133. Weichman B, Bushman A, Rosa RM. Impact of fluoroquinolone cascade reporting of urine samples on antibiotic prescribing rates in a network of urgent care clinics. Open Forum Infect Dis. 2021;8(Suppl 1):S95–6. (https://doi.org/10.1093/ofid/ofab466.158).

134. Góchez D, Raicek M, Pinto Ferreira J, Jeannin M, Moulin G, Erlacher-Vindel E. OIE annual report on antimicrobial agents intended for use in animals: methods used. Front Vet Sci. 2019;6:317. (https://doi.org/10.3389/fvets.2019.00317).

135. Global ministers and partners pledge action with new Jeddah Commitments on AMR [news release]. Geneva: World Health Organization; 2024 (https://www.who.int/news/item/21-11-2024-global-ministers-and-partners-pledge-action-with-new-jeddah-commitments-on-amr).

136. Rüegg SR, Antoine-Moussiaux N, Aenishaenslin C, Alban L, Bordier M, Bennani H et al. Guidance for evaluating integrated surveillance of antimicrobial use and resistance. CABI One Health. 2022;ohcs20220007. (https://doi.org/10.1079/cabionehealth.2022.0007).

137. Hendriksen RS, Munk P, Njage P, van Bunnik B, McNally L, Lukjancenko O et al. Global monitoring of antimicrobial resistance based on metagenomics analyses of urban sewage. Nat Commun. 2019;10(1):1124. (https://doi.org/10.1038/s41467-019-08853-3).

138. Bonomi L, Huang Y, Ohno-Machado L. Privacy challenges and research opportunities for genomic data sharing. Nat Genet. 2020;52(7):646–54. (https://doi.org/10.1038/s41588-020-0651-0).

139. Brookes AJ, Robinson PN. Human genotype–phenotype databases: aims, challenges and opportunities. Nat Rev Genet. 2015;16(12):702–15. (https://doi.org/10.1038/nrg3932).

140. Sims N, Kasprzyk-Hordern B. Future perspectives of wastewater-based epidemiology: monitoring infectious disease spread and resistance to the community level. Environ Int. 2020;139:105689. (https://doi.org/10.1016/j.envint.2020.105689).

141. Pandey RP, Mukherjee R, Chang CM. Antimicrobial resistance surveillance system mapping in different countries. Drug Target Insights. 2022;16:36–48. (https://doi.org/10.33393/dti.2022.2482).

142. AMR data platforms [website]. Stockholm: JPIAMR; undated (https://www.jpiamr.eu/resources/amr-knowledge-hub/amr-data-platforms/).

143. Hayman DTS, Adisasmito WB, Almuhairi S, Behravesh CB, Bilivogui P, Bukachi SA et al. Developing One Health surveillance systems. One Health. 2023;17:100617. (https://doi.org/https://doi.org/10.1016/j.onehlt.2023.100617).

144. Monitoring and surveillance of antimicrobial resistance in bacteria from healthy food animals intended for consumption. Regional antimicrobial resistance monitoring and surveillance – Volume 1. Guidelines. Rome: Food and Agriculture Organization of the United Nations; 2019: 72 (https://www.fao.org/documents/card/en/c/ca6897en/).

145. Papanicolas I, Rajan D, Karanikolos M, Soucat A, Figueras J, editors. Health system performance assessment: a framework for policy analysis. Health Policy Series 57. Copenhagen: European Observatory on Health Systems and Policies; 2022. (https://iris.who.int/handle/10665/352686). License: CC BY-NC-SA 3.0 IGO.

146. Bondad-Reantaso MG, Fejzic N, Mackinnon B, Huchzermeyer D, Seric-Haracic S, Mardones FO et al. A 12-point checklist for surveillance of diseases of aquatic organisms: a novel approach to assist multidisciplinary teams in developing countries. Rev Aquacult. 2021;13(3):1469–87. (https://doi.org/10.1111/raq.12530).

147. Mudenda S, Chabalenge B, Daka V, Mfune RL, Salachi KI, Mohamed S et al. Global strategies to combat antimicrobial resistance: A One Health perspective. Pharmacol Pharm. 2023;14(08):271–328. (https://doi.org/10.4236/pp.2023.148020).

148. Buckley GJ, Palmer GH, editors. Combating antimicrobial resistance and protecting the miracle of modern medicine. Washington DC: National Academies of Sciences Engineering and Medicine; 2022. (https://doi.org/10.17226/26350).

149. Delesalle L, Sadoine ML, Mediouni S, Denis-Robichaud J, Zinszer K, Zarowsky C et al. How are large-scale One Health initiatives targeting infectious diseases and antimicrobial resistance evaluated? A scoping review. One Health. 2022;14:100380. (https://doi.org/10.1016/j.onehlt.2022.100380).

150. Antimicrobial stewardship programmes in health-care facilities in low- and middle-income countries: a WHO practical toolkit. JAC Antimicrob Resist. 2019;1(3):dlz072. (https://doi.org/10.1093/jacamr/dlz072).

151. Annual report on antimicrobial agents intended for use in animals. 8th report. Paris: World Organization for Animal Health; 2024 (https://www.woah.org/app/uploads/2023/05/a-seventh-annual-report-amu-final.pdf).

152. Bourély C, Rousset L, Colomb-Cotinat M, Collineau L. How to move towards One Health surveillance? A qualitative study exploring the factors influencing collaborations between antimicrobial resistance surveillance programmes in France. Front Public Health. 2023;1111:1123189. (https://doi.org/10.3389/fpubh.2023.1123189).

153. World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme and World Organisation for Animal Health. Antimicrobial Resistance Multi-Partner Trust Fund: annual report 2021. Geneva: World Health Organization; 2022. (https://iris.who.int/handle/10665/354584). License: CC BY-NC-SA 3.0 IGO.

154. Klümper U, Leonard A, Stanton I, Anjum M, Antonio M, Balkhy H et al. Towards developing an international environmental AMR surveillance strategy. Stockholm: Joint Programming Initiative on Antimicrobial Resistance; 2022 (https://www.jpiamr.eu/app/uploads/2022/08/Towards-developing-an-international-environmental-AMR-surveillance-strategy_report-2022-08-04.pdf).

155. Klaucke DN, Buehler JW, Thacker SB, Parrish RG, Trowbridge FL, Berkelman RL et al. Guidelines for evaluating surveillance systems. Morbid Mortal Wkly Rep. 1988:37(S-5);1–18 (https://www.cdc.gov/mmwr/preview/mmwrhtml/00001769.htm).

156. World Health Organization. Guidance on wastewater and solid waste management for manufacturing of antibiotics. Geneva: World Health Organization; 2024. (https://iris.who.int/handle/10665/378471). License: CC BY-NC-SA 3.0 IGO

Annex 1.
Considerations for implementation and operationalization of integrated surveillance

Certain considerations are necessary for implementation of this Guidance. Implementation teams are advised to coordinate with the competent authorities responsible for planning and AMU and AMR monitoring and surveillance (sector-specific or at different levels of integration) in following this Guidance. Implementation teams consist of government authorities, development partners, local organizations and other national bodies, such as a national AMR multisectoral coordination mechanism responsible for surveillance of AMR and AMU in the national action plan. The checklist below should guide implementation.

- Map and engage stakeholders to establish the governance structure of the system.
- Conduct a strategic and situational analysis to fully understand SWOT.
- Identify the scope and objectives of the integrated surveillance system.
- Select the data requirements and microbial and antimicrobial indicators.
- Map available resources.
- Prioritize resources.
- Design and plan the surveillance system according to the available infrastructure and resources.
- Plan and mobilize resources to ensure the sustainability of the surveillance system.
- Conduct pilot exercises, evaluate performance, improve quality continuously, and analyse risks.

A1.1
Stakeholder mapping and engagement

Map and engage stakeholders, from national coordinators to field workers who collect samples and final processing and communication of the results to users (health-care services, veterinary services, policymakers and budget holders), who must be engaged from the beginning for buy-in and ownership of integrated surveillance, depending on the purpose. Stakeholders can co-develop, implement, monitor and evaluate the integrated surveillance system to fit the selected purpose(s).

A1.2
Strategic and situational analysis

Identify the current governance mechanism for AMR. Contact the multisectoral coordination mechanism responsible for developing, implementing, monitoring and evaluating the national action plan on AMR, and request participation in its meetings or the meetings of its designated subgroup for AMR and AMU surveillance. Present a proposal to undertake a situational and a SWOT analysis, if one has not already been done. If there is no multisectoral coordination mechanism, assemble a working group of stakeholders in AMR and AMU surveillance who represent all sectors to conduct a situational and SWOT analysis to ascertain the maturity of any sector-specific and One Health integrated AMR and AMU surveillance systems in the country. Such frameworks include:

- the International Health Regulations Capacity and Joint External Evaluation Tool, the International Health Regulations Benchmarks Tool, with five capacity levels in progressing towards “Effective multisectoral coordination on AMR”, AMR and AMU surveillance, the country’s priority pathogens and optimized use of antimicrobials;
- the Global Database for Tracking AMR Country Self-assessment Survey (five grades for collaboration);

- WHO progress towards strengthening biological indicator-based surveillance of and response to foodborne diseases (three stages);
- WOAH Performance of Veterinary Services Pathway; and
- the FAO Progressive Management Pathway for AMR.

Analyse the SWOT to establish a well-functioning integrated system or to enhance an existing one.

A1.3
Identify the purpose and scope of the system.

Section 3 details the purposes and scope of integrated surveillance. Section 3 also guides the choice of purpose(s) according to the priorities outlined in the national action plan. Progress in sector-specific and/or integrated AMR surveillance frameworks is determined during the situational analysis. The expectations of each sector's role in the purpose and scope should be in line with the next feasible stage of progress for each sector in its capacity-strengthening framework.

A1.4
Select data requirements and microbial and antimicrobial indicators.

Sections 3 and 4 provide guidance for defining priority interfaces, microbial targets, epidemiological indicators, programme monitoring indicators and other data. With key stakeholders, those that are the most appropriate for national priorities are chosen according to the country's epidemiological and socioeconomic context. Examples are bacteria–antimicrobial combinations with a strong impact on human health and also cause clinical disease in animals (e.g., drug-resistant *Salmonella* spp. in pigs), leading to high burden of disease in both humans and animals alike and also food insecurity and economic losses. The data analysis and reporting and data-sharing methods should be chosen.

A1.5
Map resources

Map resources to identify the available HR, equipment, institutional infrastructure, supporting system infrastructure, consumables, capital investment resources and maintenance resources *(1–7)*. The exercise will include consideration of whether resources are organized centrally at national level or decentralized to sub-national levels. Consideration of different sectors is important, as they might be organized differently. Such consideration will identify possibilities for resource pooling and infrastructure leveraging within and among sectors for integrated surveillance. References to resources are provided.

A1.6
Prioritize resources.

Determine what resources are required and should be prioritized, using the lists of resources in section 5. Countries should plan gradual implementation of integrated surveillance of AMR and AMU within and among sectors, with clear timescales and deliverables and mapping of resources for proper allocation in national AMR programmes.

A1.7
Design and plan the surveillance system.

Design and plan the surveillance system, identifying opportunities for integration of existing data sources and developing the governance, strategy, protocols and implementation of the integrated surveillance system. Section 3 outlines the components of the system and the steps in surveillance. With these components, map the flow of activities and information, from sample collection to reporting (e.g. publication of national surveillance reports, policy decision-making and alert response points). Chart the data to show all sources of input, including populations, data types, resources and integration points. The activities and information flow in each sector could be mapped to visualize their alignment and opportunities for integration.

A1.8
Plan resources and mobilization

Plan resources, including use of existing and acquiring new financial and HR, and allocate budgets to the plan. This exercise should be conducted under the remit of the competent authorities in each sector.

A1.9
Conduct pilot exercises, evaluate performance, and ensure continuous quality improvement

Evaluate performance within a continuous quality improvement paradigm, which can include multisectoral and multidisciplinary simulation exercises to simulate detection of alert signal events, verification and response capacity, test indicators and metrics and engaging the community. This should be conducted within a framework that is either to be developed or adapted from another framework, such as the Guidelines for evaluating surveillance systems of the US Centers for Disease Control and Prevention *(7).* The latter is especially useful for strengthening community-based surveillance, perhaps through implementation research or science. Publication of national surveillance reports should be a key deliverable and a key performance indicator.

Annex 2.
Detailed methodology

Three evidence streams were used to collect and synthesize information that supported the development of sections of the Quadripartite guidance on One Health integrated surveillance of AMR and AMU. The evidence was collected between May and October 2023, following a series of consultations with the QTG-AIS. The evidence review request included definitions, existing approaches, guidance, guidelines, protocols, standards, frameworks, systems, and technologies, and legal framework for integrated surveillance across the One Health spectrum, in different income settings, and at national, regional, and global levels.

1. Results from a scoping review of academic peer-reviewed literature conducted in May 2023 with the Library & Digital Information Networks, World Health Organization. This review searched literature published from January 1949 to May 2023
2. Results from a review of grey literature conducted between May and October 2023, using the same search strategy as the scoping review. Relevant updates and revisions for normative documents and data reports were scanned for and included.
3. Supplementary search and screening of the "AMR Database": This database is an archive of 254,738 existing peer-reviewed manuscripts indexed in Scopus as previously described *(8)* and made available by the authors.

Scoping review of academic peer-reviewed literature

The Quadripartite Joint Secretariat of AMR (QJS) completed a scoping review of academic peer-reviewed literature published between January 1949 and May 2023. English-language original articles, reviews and meta-analyses were identified through searches conducted in two databases on May 1, 2023, using the following search terms:

PubMed:

1 Population Surveillance[Mesh] OR "Public Health Surveillance"[Mesh] OR "Sentinel Surveillance"[Mesh] OR bioSurveill*[ti] OR Surveill*[ti] OR "Antimicrobial Stewardship"[Mesh] OR stewardship[ti] OR "resistance monitoring"[ti:~10] OR "investigation resistance"[ti:~10] OR one-health[tiab] OR Global-surveillance[tiab] OR Global-monitoring[tiab] OR Public-Health-Surveillance*[tiab] OR Sentinel-Surveillance*[tiab] OR Syndromic-Surveillance*[tiab] OR Bio-surveillance*[tiab] OR Sentinel-Health-Event*[tiab] OR Population-Surveillance*[tiab] OR integrated-surveillance*[tiab]

2 "Bacteria"[Mesh] OR bacter*[tw] OR bacillus[tw] OR antibacter*[tw] OR Eubacteria* [tiab] OR Acidobacteria*[tiab] OR Chlorobi*[tiab] OR Chloroflexi*[tiab] OR Herpetosiphon*[tiab] OR Chloroflexaceae*[tiab] OR Cyanobacteria*[tiab] OR Algae*[tiab] OR cyanophyceae*[tiab] OR Endospore-Forming*[tiab] OR Firmicute*[tiab] OR Fusobacteria*[tiab] OR Gram-Negative*[tiab] OR Gram-Positive[tiab] OR Proteobacteria*[tiab] OR Spirochaetales[tiab] OR Spirochete*[tiab]

3 anti-biotic*[tiab] OR antibiotic*[tiab] OR antibacterial*[tiab] OR anti-bacterial*[tiab] OR anti-bacterium*[tiab] OR antimicrobial[tiab] OR anti-microbial*[tiab]

4 "Drug Resistance, Bacterial"[Mesh] OR "Drug Resistance, Multiple, Bacterial"[Mesh] OR resistan*[tiab] OR non-susceptib*[tiab] OR nonsusceptib*[tiab] OR AMR[ti]

5 #2 Or #3 OR #4

6 #1 AND #6

Embase:

1 population surveillance'/exp OR 'public health surveillance'/exp OR 'sentinel surveillance'/exp OR 'active surveillance'/exp OR 'biosurveillance'/exp OR 'passive surveillance'/exp OR 'environmental surveillance'/exp OR 'wastewater-based epidemiology'/exp OR 'one health'/exp OR bioSurveill*:ti OR Surveill*:ti OR Antimicrobial-Stewardship:ti,ab OR stewardship:ti OR (resistance NEAR/10 monitoring) OR (investigation NEAR/10 resistance) OR (Global-surveillance OR Global-monitoring OR Public-Health-Surveillance* OR Sentinel-Surveillance* OR Syndromic-Surveillance* OR Bio-surveillance* OR Sentinel-Health-Event* OR Population-Surveillance* OR integrated-surveillance*):ti,ab

2 bacterium'/exp OR (bacter*:ti,ab) OR (bacillus:ti,ab) OR (antibacter*:ti,ab) OR (eubacteria*:ti,ab) OR (acidobacteria*:ti,ab) OR (chlorobi*:ti,ab) OR (chloroflexi*:ti,ab) OR (herpetosiphon*:ti,ab) OR (chloroflexaceae*:ti,ab) OR (cyanobacteria*:ti,ab) OR (algae*:ti,ab) OR (cyanophyceae*:ti,ab) OR (endospore-forming*:ti,ab) OR (firmicute*:ti,ab) OR (fusobacteria*:ti,ab) OR (gram-negative*:ti,ab) OR (gram-positive*:ti,ab) OR (proteobacteria*:ti,ab) OR (spirochaetales:ti,ab) OR (spirochete*:ti,ab)

3 antibiotic agent'/exp OR (anti-biotic* OR antibiotic* OR antibacterial* OR anti-bacterial* OR anti-bacterium* OR antimicrobial OR anti-microbial*):ti,ab

4 antibiotic resistance'/exp OR 'multidrug resistance'/exp OR resistan*:ti,ab OR 'non susceptib*':ti,ab OR nonsusceptib*:ti,ab OR amr:ti

6 #3 OR #4

7 #2 OR #3 OR #4

8 #1 AND #6

Review of grey literature

A review of the grey literature was conducted from May to October 2023. The same search approach used in the academic literature review was applied here. Additionally, suggestions from internal experts within the Quadripartite organizations were incorporated.

Supplementary search and screening of the "AMR Database"

This was conducted using the same search terms applied in the scoping review of academic peer-reviewed literature from PubMed and Embase. The AMR database search returned results similar to those from the PubMed and Embase databases. Articles retrieved from PubMed and EMBASE were cross-checked with the AMR database to prevent duplication.

Inclusion and exclusion criteria for academic peer-reviewed and grey literature

Articles that met the following criteria according to the PICoS framework *(9)* were used to populate the Guidance sections.

	Inclusion criteria	Exclusion criteria
Population (P)	ALL sectors	Articles not written in English.
Interest (I)	Surveillance components for antimicrobial resistance and antimicrobial use	
Context (Co)	One health across 2 or more interfaces	
Study type (S)	ALL study types, including reports from grey literature	

From the original scoping reviews of academic literature, 46,216 articles were identified, along with 82 additional articles provided by the Quadripartite organizations. Following deduplication, these articles were included for evidence synthesis to support the development of the sections of the Guidance.

Information collation, extraction and synthesis for drafting sections of the Guidance

Consultations with the Quadripartite Technical Group for AMR and AMU Integrated Surveillance (QTG-AIS) and the Quadripartite focal persons informed the outline and sections of the Guidance. To populate each section, a combination of keywords and Boolean operators was used to refine article selection. This was followed by title, abstract, and full-text screening of the articles. Synthesis was done following the Preferred Reporting Items for Systematic Reviews extension for Scoping Reviews (PRISMA-ScR) guideline *(10)*. All files in the grey literature repository were reviewed to establish a baseline of existing works conducted by the Quadripartite organizations.

References[9]

1. Suzuki H, Heintz BH, Livorsi DJ, Perencevich EN, Goto M. Tracking antimicrobial stewardship activities beyond days of therapy (DOT): Comparison of days of antibiotic spectrum coverage (DASC) and DOT at a single center. Infect Control Hosp Epidemiol. 2023;44(6):934–7. (https://doi.org/10.1017/ice.2022.312).
2. Global ministers and partners pledge action with new Jeddah Commitments on AMR [news release]. Geneva: World Health Organization; 2024 (https://www.who.int/news/item/21-11-2024-global-ministers-and-partners-pledge-action-with-new-jeddah-commitments-on-amr).
3. Sims N, Kasprzyk-Hordern B. Future perspectives of wastewater-based epidemiology: monitoring infectious disease spread and resistance to the community level. Environ Int. 2020;139:105689. (https://doi.org/10.1016/j.envint.2020.105689).
4. Papanicolas I, Rajan D, Karanikolos M, Soucat A, Figueras J, editors. Health system performance assessment: a framework for policy analysis. Health Policy Series 57. Copenhagen: European Observatory on Health Systems and Policies; 2022. (https://iris.who.int/handle/10665/352686). License: CC BY-NC-SA 3.0 IGO.
5. Hayman DTS, Adisasmito WB, Almuhairi S, Behravesh CB, Bilivogui P, Bukachi SA et al. Developing One Health surveillance systems. One Health. 2023;17:100617. (https://doi.org/https://doi.org/10.1016/j.onehlt.2023.100617).
6. Antimicrobial stewardship programmes in health-care facilities in low- and middle-income countries: a WHO practical toolkit. JAC Antimicrob Resist. 2019;1(3):dlz072. (https://doi.org/10.1093/jacamr/dlz072).
7. Klaucke DN, Buehler JW, Thacker SB, Parrish RG, Trowbridge FL, Berkelman RL et al. Guidelines for evaluating surveillance systems. Morbid Mortal Wkly Rep. 1988:37(S-5);1–18 (https://www.cdc.gov/mmwr/preview/mmwrhtml/00001769.htm).
8. Chen C, Li SL, Xu YY, Liu J, Graham DW, Zhu YG. Characterising global antimicrobial resistance research explains why One Health solutions are slow in development: An application of AI-based gap analysis. Environ Int. 2024;187:108680. (https://doi.org/https://doi.org/10.1016/j.envint.2024.108680).
9. Amir-Behghadami M, Janati A. Population, Intervention, Comparison, Outcomes and Study (PICOS) design as a framework to formulate eligibility criteria in systematic reviews. Emerg Med J. 2020;37(6):387. (https://doi.org/10.1136/emermed-2020-209567).
10. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. 2018;169(7):467-473. (https://doi.org/10.7326/m18-0850).

9 All references were accessed on 11 February 2026.

For more information, please visit our websites:

FAO: www.fao.org

UNEP: www.unep.org

WHO: www.who.int

WOAH: www.woah.org