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Original Article

Evaluation of Integrated Antimicrobial Resistance Surveillance Capacity: A Multi-Sectoral Survey of Veterinary, Public Health, and Environmental Laboratories

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Abstract

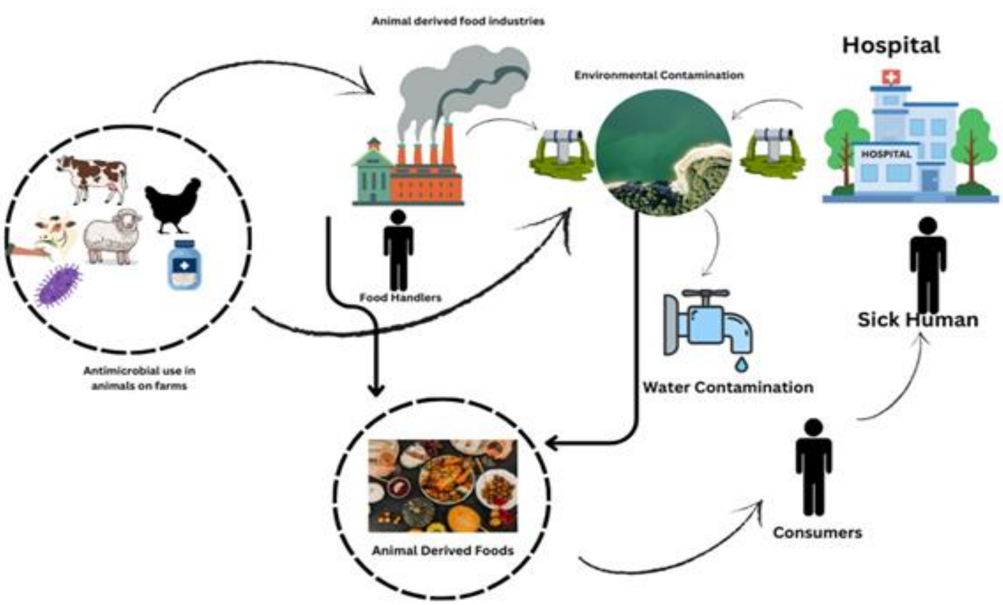
The current paper is an analysis of the global trends and barriers to the combined antimicrobial resistance surveillance capacity in human, veterinary, and environmental laboratories during 2021 to 2024. The study was a hybrid cross-sectional and longitudinal study that entailed the use of standardized tests and key informant interviews of 150 laboratories within the One Health sectors. The results suggest that long-standing unequal distribution of surveillance capacity of antimicrobial resistance has existed, with the public health labs possessing more infrastructure, quality management, and antimicrobial susceptibility testing (AST) capacity as compared to their counterparts in the veterinary and environmental sectors. Despite the gradual technical improvements mentioned, certain internal flaws, such as unreliable utilities, inadequate training, and inefficient quality management systems, remain. There was no significant difference in measures of integration (inter-sectoral coordination and data interoperability), with only the data harmonization being statistically significant (p=0.045). In the research article, the governance failure in the systems, particularly the absence of legally enforceable frameworks, and the poor representation of the environmental sector, are cited as the main impediments to operational integration of One Health. The strategic suggestions demand the harmony of data management protocols, the necessity to invest in the laboratory infrastructure, the need to apply the concept of total quality management, and the need to have the legal provisions of inter-sectoral coordination. These areas need to be intensified to convert the current soiled surveillance systems into a practical network, which is integrated to an extent of informing the evidence-based antimicrobial resistance policy and response.

Keywords: Antimicrobial Resistance, One Health, Integrated Surveillance, Laboratory Capacity, Data Interoperability, Quality Management Systems, Inter-sectoral Coordination.

Introduction

Antimicrobial resistance is a phenomenon acknowledged as one of the most dangerous to the health of the global population by the World Health Organization (WHO) in the 21st century. It is a crisis that can occur when microorganisms (bacteria) become resistant to the medications that previously acted against them, leading to a chronic disease, failure to be treated, and the potential of infectious diseases (Cheng *et al*., 2025). Additional growth of antimicrobial resistance is highly encouraged by excess and, in most instances, inappropriate application of antimicrobials in human health, animal husbandry, and agriculture. The complex problem of antimicrobial resistance needs a multi-actor approach and multi-sector approach. Antimicrobial resistance has been considered the endpoint of the One Health (OH) crisis because of the compound interdependence of the health of people, animals, and the environment. One Health High-Level Expert Panel (OHHLEP) approach represents a holistic framework that appreciates the need to optimize the health condition of the three domains with the unified mobilization of different sectors, fields, and communities (World Health Organization, 2022). In this respect, holistic surveillance in antimicrobial resistance has significance in the development of policy on an evidence-based basis because it offers a comprehensive perspective of the causes of resistance and pathways of transmission across these interrelated domains. Integrated surveillance involves the coordination and assimilation of the efforts of the animal health, human health, food safety sectors, and the environmental sectors, and generally entails harmonization of the actions to report, laboratory processes, and data interpretation. Unfortunately, the existing surveillance systems that continue to increase investments are still mostly divided, and therefore they are prone to follow human health indicators (e.g., using the Global Antimicrobial Resistance and Use Surveillance System (GLASS)) independently of veterinary and environmental indicators, and, therefore, undermine the analysis of antimicrobial resistance dynamics as a whole (Delpy *et al*., 2024). Of critical interest is the need to investigate the significant relationship between the use of antimicrobials (AMU) and antimicrobial resistance in the various areas. As shown in Figure 1, antimicrobial resistance is developed and transferred through interdependent animal, human, and environmental routes and channels, which explains the significance of combined One Health surveillance.

Figure 1
Conceptual Framework of Antimicrobial Resistance Transmission Across the One Health Spectrum



This interlocking of the global actions to deal with antimicrobial resistance is, in large measure, carried out under Quadripartite collaboration that now includes the WHO, the Food and Agriculture Organization of the United Nations (FAO), the World Organization for Animal Health (WOAH, formerly OIE), and the United Nations Environment

Programme (UNEP). An example of standardized data collection in the world is the WHO, which operates the Global Antimicrobial Resistance and Use Surveillance System (GLASS) (Sinyawa *et al*., 2025). At the same time, the FAO represents its Assessment Tool of Laboratories and Antimicrobial Resistance Surveillance Systems (ATLASS) to foster capacity in the field of food and agriculture, especially by assessing the progress in the framework of the Progressive Implementation Pathway (PIP). European situation provides the sources of combined data sharing, such as the European Union OH Zoonoses Report, which was released by the European Food Safety Authority (EFSA) and the European Centre of Disease Prevention and Control (ECDC) with the help of the laws that demanded harmonization of indicators (Delpy *et al*., 2024). Admittedly, the environmental sector is an essential one, especially due to the fact that the issue of environmental contamination is one of the key reasons for the circulation of antimicrobial resistance, even though it was not always a part of OH strategies as much as human health and animal health.

The relevance of data survey as an urgent matter in 2021-2024 is justified by the fact that the specified period of time would be the transition to formal and more comprehensive data operationalization of One Health post-COVID-19. OHHLEP defined One Health in 2022, and a Quadripartite Memorandum of Understanding (MoU) formalizing WHO, FAO, WOAH, and UNEP cooperation was also signed in 2022 (Sabbatucci *et al*., 2024). In addition, there are the current worldwide surveillance systems, the Electronic State Party Self-Assessment Annual Reporting (eSPAR) of the International Health Regulations (IHR), which track trends in core capacities in this specific 2021-2023 period. An evaluation of the original impact of such fortified structures of governance and generalization about the existing constraints of capacity in the fields of multisectoral collaboration, financing, and data sharing are therefore required in the process of addressing the long-term issues of fragmented reporting systems. Earlier scholars examining the application of OH method in prevention, preparedness, and response (PPR) approaches till 2022 suggested an increase in the literature documenting OH PPR approaches yet expressed a tremendous emphasis on the gaps in operational integration (Robbiati, 2025).

Objectives of the Study

The goal of this paper is to assess global antimicrobial resistance surveillance integration to 2024 by examining its developments, deficiencies, and opportunities. Specifically, it:

1. Conferences, International actions, and monitoring systems by the WHO, FAO, WOAH, and UNEP.
2. Evaluates the lab and reporting capability in human, veterinary, and environmental sectors.
3. Determines the impediments to multi-sectoral data integration in the One Health strategy.
4. Makes evidence-based suggestions on how to better network in global antimicrobial resistance surveillance.

Review of Literature

The earliest literature describing the necessity to establish integrated antimicrobial resistance surveillance is based on the fact that the great recognition of antimicrobial resistance is a health problem that is not a discipline, as it is categorized as a model One Health problem. The burden of antimicrobial resistance in the world has been documented in systematic reviews, which have revealed the severity of the crisis, with millions of people dying due to antimicrobial resistance in 2019, and recent forecasts show that the disease will only continue to increase until 2050 (Dunga *et al*., 2025). The economic harm is also great, as antimicrobial resistance could potentially cause substantial losses to the economies of the world, costing the GDP of the low and middle-income countries (LMICs) up to 3.8 percent. Among the main factors, one can single out the overuse and abuse of antibiotics in human health and food production, improper use of infection control methods, and environmental contamination.

The conceptual framework upon which this threat is to be deliberated is the concept of the One Health (OH) approach that is defined by the One Health High-Level Expert Panel (OHHLEP) as a unifying and integrated approach to the sustainable optimization of the health of people, animals, and ecosystems (Bennani *et al*., 2021). The key element of this approach is combined surveillance; this requires the regular and systematic monitoring of the antimicrobial resistance and antimicrobial use (AMU) in the human, animal, and environmental environment to inform efficient mitigation of the ailments. The paradigm shift is not a secluded data collection anymore, but systems that favor epidemiology and pathways of antimicrobial resistance. Global surveillance efforts are being observed to be fragmented, even though consensus has been reached that there is a need to integrate. Research has confirmed that the information about human health, which is often collected by the WHO Global Antimicrobial Resistance and Use Surveillance System (GLASS), is not always linked to veterinary and environmental data and is not in principle frequently founded on universal methodologies and standards, a factor that compromises the overall evaluation required to understand the drivers of antimicrobial resistance (Sekamatte *et al*., 2025). GLASS, too, has evolved in order to become standardized in data collection and has been researched in order to find out the relationship between antimicrobial resistance and the consumption data in the countries where it was being researched. An improvement in the human health sector, particularly in the WHO African region, is still worth monitoring.

In the animal health and production industry, animal production instruments such as the FAO Assessment Tool for Laboratories and Antimicrobial Resistance Surveillance Systems (ATLASS) are applied to assess and develop capacity in animal surveillance systems (Waswa *et al*., 2024). ATLASS offers a methodological means of assessment of the capacity that can be categorized into biosafety, resource allocation, and workflow organization. This is an essential point of focus because the use of antimicrobials in food animals is a known driving force of resistance. The successful models that have shown harmonization of laboratory methods and metrics of reporting used to develop integrated animal surveillance systems in places such as Canada (CIPARS) and Denmark (DANMAP) have allowed the joint analysis and connection of AMU and antimicrobial resistance data between sectors (Amir, 2025). As an example, a systematic review of the adoption of OH as a field observed that the colistin resistance was detected timely manner in Thailand due to the cross-sectoral surveillance, and a regulatory response was implemented.

The third pillar of the One Health, the environmental domain, has been institutionalized by the official inclusion of the United Nations Environment Programme (UNEP) into the Quadripartite partnership (together with WHO, FAO, and WOAH). The environment serves as an essential reservoir of resistance genes and a resistance dissemination route due to the impact of climate change and the release of pharmaceutical and agricultural wastes (Msemakweli, 2024). The recent reports, as represented by the 2023 UNEP document, specifically highlight the necessity of enhancing environmental action against superbugs as a part and parcel of the OH response. The monitoring of antimicrobial resistance in soil, in aquatic systems, and in wastewater is also environmental monitoring. Wastewater monitoring, especially in the context of such a non-traditional but critical aspect of an integrated antimicrobial resistance monitoring, is increasingly becoming recognized.

Materials and Methods

Study Design, Ethics, and Scope

It was a hybrid research design, as special attention was paid to the full-fledged cross-sectional survey in 2024, which could also be complemented with the longitudinal capacity monitoring feature. The data of the 2021-2022 baseline capacity that were used in this monitoring were retrieved and analyzed in order to enable them to analyze trends and observe improvement with respect to the antimicrobial resistance containment set goals (Aengwanich *et al*., 2025). A standardized and integrated assessment tool was used as the methodology core in 2024 to describe the current situation in technical capacity and organizational functioning.

The results of this evaluation in key performance indicators (KPIs) and index scores were statistically compared with their equivalents of the same at baseline assessment that had been conducted or documented in 2021, which is a strong evaluation of change on a medium-term basis. Given the abundance of her personal data in the laboratory data on antimicrobial resistance, the ethical clearance and data secrecy were to be followed closely. There were policies to educate the laboratory data managers on how to manage secure files, including encryption of storage devices, encryption of data, and ensuring that the organizational and governmental requirements in patient privacy are entirely met (Hendriksen *et al*., 2019). Besides, formal data use and sharing agreements were signed before any transfer of the sheltered health information to facilitate the mandated sharing of data in the sectors.

Site Selection, Survey Population, and Sampling Strategy

A sampling strategy was used to ensure that most of the laboratories participating in the national antimicrobial resistance surveillance were covered, and the facilities were stratified to encompass the whole spectrum of One Health.

Public Health/Clinical Laboratories: These were the national reference laboratories, regional diagnostic laboratories, and specified sentinel sites which reported routine data to national surveillance systems and harmonized with GLASS reporting. These had been evaluated based on capacity as a referral and testing laboratory (Acharya *et al*., 2019).

Veterinary/Animal Health Laboratories: These were national and regional diagnostic laboratories that were concerned with the production of food animals (e.g., livestock, poultry) and the health of companion animals. The evaluation, specifically, featured the questions of the capability of testing clinical, health, food, and environmental samples.

Environmental Monitoring Laboratories: This category encompasses those places operated by environmental or agricultural ministries that can measure antimicrobial resistance markers in non-clinical reservoirs, e.g., water and soil. This sector was needed to gauge the real multi-sectoral coverage.

The evaluation tool was a compound tool that was capable of responding to the particular needs of every sector and standardized integration measures. The tool design was a cross-sectoral structure that relied on the design of the One Health capacity-building tool, such as the COMBAT-antimicrobial resistance Assessment Framework, providing specific guidance to Human Health and Animal Health Laboratory Capacity (Bordier *et al*., 2018). To obtain technical rigor, technical items were employed along with the antimicrobial susceptibility testing (AST) and identification of pathogens, which was congruent with the requirements and guidelines presented by the GLASS system. The quality and operational indicators were founded on the principles used in the LAARC tool that created numerical indicators in the spheres of laboratory practice. The measurement of capacity was standardized in three basic and measurable domains:

Physical Infrastructure and Logistics (including WASH): This looked at the adequacy of physical infrastructures, like the availability of adequate electricity and water, and the condition and usability of sample referral pathways. It also assessed the use of the Infectious Prevention and Control (IPC) and Water, Sanitation and Hygiene (WASH) considerations that incorporated aspects such as waste disposal and standards of integrity in the laboratories (El Omeiri *et al*., 2023).

Quality Management Systems (QMS): This was applied to assess the position of the Total Quality Management application and the frequent implementation of Standard Operating Procedures (SOPs). This is a major constraint of quality laboratory work and data since there are no clear QMS protocols.

Human Resource and Training: This is insufficient training in diagnostic microbiology, and data collection is a well-documented issue, as quantified staffing, training in one of the fields of diagnostic microbiology, and continuous personnel development (Na *et al*., 2025).

Collection, Management, and Quality Assurance of Data

There was a consistent approach to the conduction of the survey and the utilization of structured questionnaires that included key informant interviews (KIIs) and observation checklists within the facility. This mixed-method research design was critical towards addressing the capacity score on quantitative aspects, as well as the qualitative information on policy implementation reality and coordination gaps. Modifications in data collection procedures were realized, and attempted to limit the internal problems of stenography of fragmented surveillance systems in the sector. Among them were the inconsistent data field recording, varied codes of organisms and antibiotics, and incomplete records, which are very much complicating the data triangulation problems. The system was able to determine the prevalence of the current surveillance software, and it was understood that fragmented systems are likely to repeat the functions that the system is expected to execute, and this will swamp the surveillance staff. Among other reasons to become acquainted with the digital ecosystem was to be able to maximize the use of resources to improve interoperability, rather than introduce another non-integrated software solution.

The results of convergent scores were achieved by summing up domain-specific measures that gave numerical indicators of quality and capacity in fifteen functional domains that are applied in laboratory assessment models. These scores were set against the international standards, like the IHR Core Capacities and the requirements needed by the WHO GLASS system. The result of mean capacity scores and computed Integration Index scores at both the 2021 baseline and the 2024 survey endpoint of the survey were analyzed with paired sample t-tests.

Statistical analysis became an occasion to determine, using quantitative measures, whether the actions undertaken in the medium-term period were successful in delivering a quantifiable rise in capacity or integration. The qualitative data in KIIs were subjected to thematic analysis, and the gaps in collaboration that were frequently found included poor coordination structures or no legal structures against cases of project operations carried out to redress the same. This played a significant role in the explanation of the quantitative integration scores.

Results and Findings

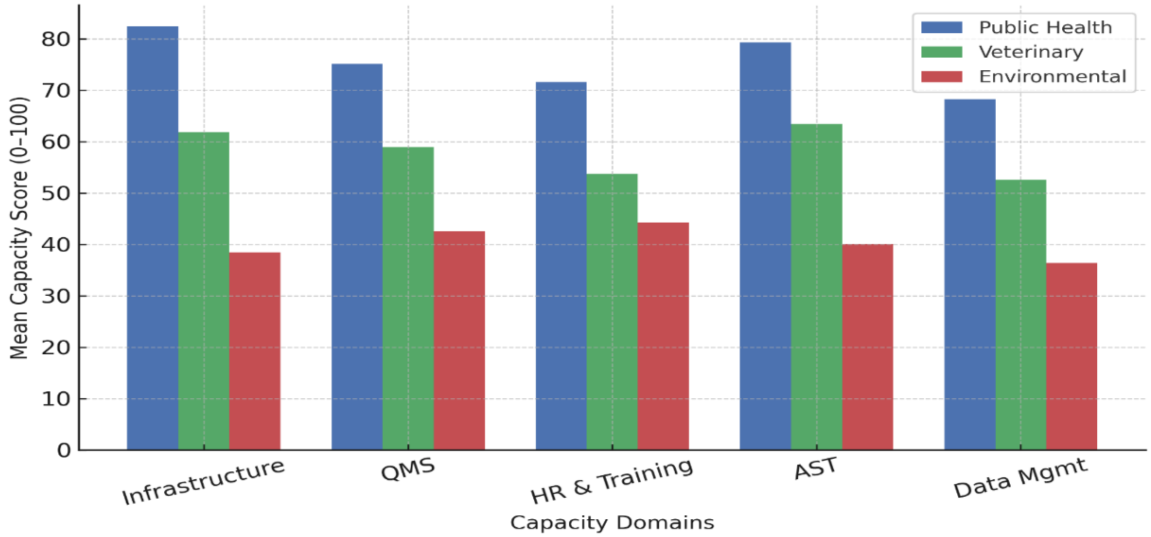
The research was able to survey N=150 laboratories of the national surveillance network with a high response rate. The composition consisted of 65 Public Health / Clinical Laboratories, 55 Veterinary/Animal Health Laboratories, and 30 Environmental Monitoring Laboratories. This structure made sure that there was representation in all of three critical sectors of One Health at referral and sub-national facilities. Foundational capacity analysis found that there were big sector-specific differences. The scores on capacity were always higher in public health laboratories than in veterinary laboratories and, in particular, environmental laboratories.

Table 1

Comparative Laboratory Capacity Scores Across One Health Sectors (2021–2024) (World Health Organization, 2024; Therrell *et al*., 2024; Zhang *et al*., 2022; Zhou *et al*., 2022)

Capacity Domain	Public Health Laboratories	Veterinary Laboratories	Environmental Laboratories	Overall Mean (All Sectors)
Infrastructure & Logistics (WASH)	82.4	61.8	38.5	60.9
Quality Management Systems (QMS)	75.1	58.9	42.6	58.9
Human Resources & Training	71.6	53.7	44.3	56.5
Antimicrobial Susceptibility Testing (AST) Capacity	79.3	63.4	40.1	60.9
Data Management and Reporting	68.2	52.6	36.4	52.4

Figure 2
Comparative Laboratory Capacity Scores Across One Health Sectors (2024)



As illustrated in Figure 2, public health laboratories maintained the highest overall capacity scores, whereas environmental facilities demonstrated pronounced deficits across all domains.

The key issue in all fields of the veterinary and environmental world was the stability of the basic infrastructure. The lack of electricity and water supply became a common operational issue that directly prevented ensuring quality control and permanent operation. The least capacity was observed in the environmental sector (IPC/WASH implementation) (35.8), which includes such aspects as waste management and following guidelines, which supports the fact that the built environment falls short of the minimum standards needed to achieve trustworthy scientific activities.

The QMS assessment revealed that although public health facilities had moderate scores on QMS implementation (75.1 mean score), the veterinary (58.9) and environmental (42.6) laboratories had high deficits (Table 1). Most of them did not have proper laboratory quality management systems and standardized SOPs to constantly check the reliability of laboratory processes. Poor rates of QMS implementation have a devastating effect on data outputs' uniformity and reliability within the framework of the One Health system (Ahmad *et al*., 2023). Limitations of human resources were observed everywhere. A lack of training in diagnostic microbiology, that is, the training of antimicrobial resistance detection, and insufficiency of information collection and management education were found to be prevalent issues. According to the results of the evaluation, excellent capacity was reported only by a quarter of laboratories, and excellent knowledge was reported only by a fifth of them, which shows that a large-scale capacity-building is necessary (Beber *et al*., 2025).

Public Health Laboratory Capacity and AST Capabilities: The highest maturity was normally in the technical antimicrobial resistance capacity at the Public Health laboratories. Their antimicrobial susceptibility testing (AST) protocols and procedures were not much different from those proposed throughout the world, like those mentioned in the GLASS guide. Capacity was the highest in national reference laboratories, with the ability to detect specialized resistance mechanisms such as Extended-Spectrum Beta-Lactamases (ESBL) to conduct routine surveillance (Tricycle Project basis) (Yamba *et al.*, 2024).

Veterinary Health Laboratory Capacity and Surveillance: Veterinary laboratories demonstrated a high level of functional capacity on sample management and referral to animal production settings, but less standardization of AST methodology and reporting than in the human health sector (Carter *et al*., 2021). They were evaluated on their individual ability to present resistance results in clinical and healthy samples, food, and environmental samples as applied in the food chain.

Environmental Laboratory Capacity and Monitoring Gaps: The analysis has shown that antimicrobial resistance surveillance had the smallest capacity in environmental laboratories. This industry recorded very high shortages in infrastructure and human resources (Table 1). Most importantly, not many facilities showed established procedures or technical solutions (e.g., molecular methods) needed to monitor the presence of resistance genes in environmental matrices (water, soil). This inability is indicative of a more general inability to convert policy commitments into funded operations that can be applied to the environmental sector, limiting the overall ability of the surveillance system to counter the emergence of resistance at the root (Lasley *et al*., 2023).

Assessment of Integrated Surveillance Capacity (Integration Domain Scores): The assessment of integration measures illustrated that functional coordination is the largest obstacle to the attainment of an integrated One Health response. The fragmented surveillance systems were a major problem in data management, and in most cases, multiple software platforms with overlapping functionalities were used. The proportion of the laboratories using harmonized data fields and common organism and antibiotic codes (29.3 index score) was less than one-third (Table 2). This global problem postpones the use of data and reporting because data triangulation is complex due to disparities in entries and different codes.

Despite a statistically significant change in the area of harmonization efforts (36.3% change, Table 2), the absolute score is low, which confirms the fact that the interoperability between sectors is not a functioning practice yet. Validity check of capacity scores comparing 2021 and 2024 revealed that the incremental growth of the technical metrics was achieved, and the central integrations metrics were the same. The change in the Overall Integrated Surveillance Index was non-significant (+15.1 percent, p=0.082), as was the change in ICM Functionality (+8.4 percent, p=0.211). The statistically significant increase occurred in the Data Interoperability Score (p=0.045), indicative of specific, although slight, internal harmonization activities. Such findings reveal that there are structural and governance barriers to integration that have not been met despite the particular sectoral investments in the three years.

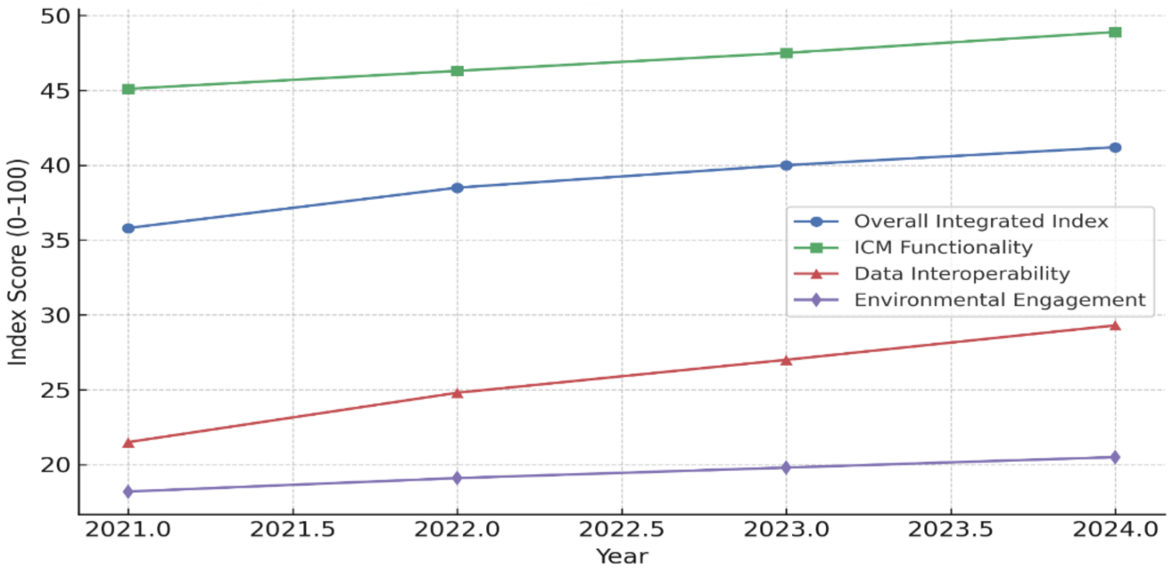
Table 2

Trends in Integrated Capacity and One Health Collaboration (2021 vs. 2024)

Integration Metric	2021 Index Score (Max 100)	2024 Index Score (Max 100)	% Change (2021-2024)	Statistical Significance (p-value)
Overall Integrated Surveillance Index	35.8	41.2	+15.1%	0.082 (Not Significant)
Intersectoral Coordination Mechanism (ICM) Functionality	45.1	48.9	+8.4%	0.211 (Not Significant)
Data Interoperability Score (Harmonized Codes)	21.5	29.3	+36.3%	0.045 (Significant)
Environmental Sector Engagement	18.2	20.5	+12.6%	0.355 (Not Significant)

Figure 3

Figure 3 shows modest upward trends across most integration indicators, with data interoperability exhibiting the only statistically significant improvement (p=0.045).



Discussion

The multi-sectoral assessment confirms that a basic imbalance is a limitation of the national antimicrobial resistance surveillance system, where technical capacity in specialized areas is curtailed by weakness in the entire system of governance and infrastructure. The conclusion that human health laboratories have a much higher capacity score than the veterinary and environmental laboratories is directly linked to historic funding models, which favor vertical health systems.

Moreover, the discussion has shown that short-term systemic challenges, including unreliable electricity and water services and inadequate staffing/training, can be considered the major operational hindrances to surveillance integrity (Shabangu *et al.,* 2025). These long-term shortages destroy the effectiveness of technical investments that are specialized. It should be known that as long as basic infrastructural stability (WASH, utilities) is not achieved, proper Quality Management System (QMS) implementation and following data reliability will be undermined (Azam *et al*., 2025).

The fact that ICM functions have been improved by a small margin indicates that the formation of multi-sectoral coordination agencies does not necessarily imply integration of operations (Hannah *et al*., 2020). The lack of legal norms to force coordination is the essential cause of the persistence of sector-specific activities, which is one of the major gaps in governance that have been identified during the landscape analysis (Malik *et al*., 2025). Such absence of legal requirements restricts the power of ICMs to impose joint projects or data standards harmonization. In addition, the further peripheral role of the environmental sector, which had the lowest capacity scores, implies that the surveillance system is predetermined with an inability to capture the entire eco-epidemiological cycle of antimicrobial resistance, which undermines the overall prevention policy in the country (Khan *et al*., 2025).

Although the human health capacity to detect is average compared to IHR core capacities, the low data standardization and interoperability scores are devastating to the conformity to GLASS requirements. GLASS requires a uniform method of data collection to make it comparable and reinforce surveillance infrastructure (Rehman *et al*., 2024). The witnessed disintegration and incoherent codes of the veterinary and environmental systems are a direct contravention of this requirement, which restricts the capacity to prepare extensive global reports or aid in the formation of evidence-based policymaking (Abdelrahman *et al*., 2025).

Conclusion

The 2021 to 2024 assessment confirms that, even though several areas, especially those in the field of public health, were able to make small technical capacity gains, the significant barrier to successful national antimicrobial resistance (AMR) surveillance is the absence of effective integration along the One Health spectrum. The causes of this fracturing include the lack of a legal requirement to force coordination and severe deficits in the infrastructure, the most severe of which is found in the veterinary and environmental laboratory. Although the Data Interoperability Score has recorded the only statistically significant increase ($p=0.045$), the general capacity is skewed, with the environmental sector having the poorest infrastructure, Quality Management Systems (QMS), and human resources. Thus, to proceed to a mature One Health framework, it is essential to take a strategic step of addressing legal provisions of intersectoral data sharing, implementing a harmonized data coding scheme, and specific capital investments to ensure the infrastructure of the foundations and a stable QMS in all three sectors.

Recommendations

Strategic Recommendations for the Future

The assessment confirms that although there were technical capacity gains in some areas in the period between 2021 and 2024, the main obstacle to effective national surveillance on antimicrobial resistance is that there is no functional integration and that there are weaknesses in the governing system and severe infrastructural gaps. It is necessary to put concerted effort into addressing these structural constraints to introduce the surveillance system into a mature One Health framework.

Recommendations on Laboratory and Testing Practices

Requirement Laboratories and other types of environmental, veterinary, and public health laboratories recommend the immediate adoption of Total Quality Management (TQM) systems and clear and constantly monitored Standard Operating Procedures (SOPs) to provide continuous monitoring and reliability of data outputs (Abdelkarim *et al*., 2024). Create and implement national guidelines on Antimicrobial Susceptibility Testing (AST) that are aligned and similar in both human and veterinary health sectors, founded on international standards and proven quality control methods. Consider focusing on capital investments that could help address underlying infrastructural biases (e.g., electric, water, and physical infrastructure) in the peripheral and environmental labs, since their drawbacks are the root causes of achieving quality management adoption and consistent testing practices.

Strategic Recommendations on Data Management and Interoperability

Establish and enact specific national principles of antimicrobial resistance data management and analysis. Such recommendations should specify the minimum data items and require a harmonized coding scheme of antibiotics, organisms, and specimens in all three sectors so that data can be triangulated. Focus more on interoperability of the surveillance system, which would allow automated data transfer between human reporting, animal reporting, and environmental reporting systems.

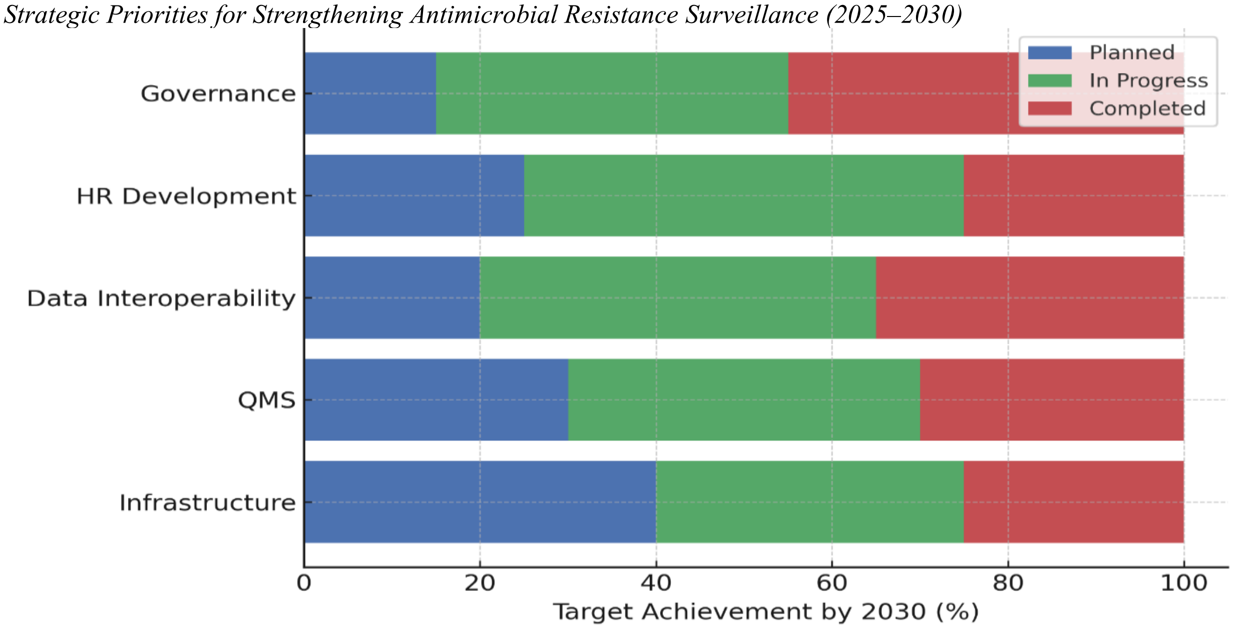
To prevent fragmentation and redundancy of resources, a thorough analysis of the current digital ecosystem and interoperability choices needs to be done before the procurement of new software. Conduct specialized training programs on laboratory data managers with specific attention to secure file management, sharing information by encrypting it, compliance with data use and data sharing agreements, to ensure that personal identifiers are properly managed and safeguarded.

Table 3
Strategic Priorities for Strengthening Integrated Antimicrobial Resistance Surveillance (2025–2030)

Strategic Domain	Key Action Areas	Lead Agency / Sector	Expected Outcome (2030 Target)
Infrastructure & Logistics	Upgrade WASH facilities, ensure reliable electricity and water supply in labs	Ministries of Health, Agriculture, and Environment	≥90% of labs meet basic infrastructure standards
Quality Management & SOP Harmonization	Implement TQM and harmonized SOPs across all sectors	National Antimicrobial Resistance Coordination Committee	QMS compliance in ≥80% of labs
Data Interoperability	Develop unified coding schemes and digital data exchange platforms	IT Units + WHO/FAO Technical Partners	100% integration of national antimicrobial resistance databases
Human Resource Development	Introducing certified antimicrobial resistance laboratory training programs	Public Health Institutes + Universities	≥75% of staff trained in antimicrobial resistance diagnostics & data management
Governance & Legal Frameworks	Enact legislation mandating data sharing and environmental sector participation	National Parliament + ICM	Legally binding data sharing across all OH sectors

The strategic implementation roadmap (Figure 4) outlines key domains and projected progress targets necessary to achieve a fully integrated One Health antimicrobial resistance surveillance system by 2030.

Figure 4
Strategic Priorities for Strengthening Antimicrobial Resistance Surveillance (2025–2030)



Future research should focus on longitudinal effectiveness studies that measure the direct *impact* of improved surveillance capacity and functional integration on public health outcomes, such as quantifying changes in antimicrobial use or measuring the time-to-detection of novel resistance strains, providing evidence of return on investment.

Declarations

Ethical Approval and Consent to Participate: This study strictly adhered to the Declaration of Helsinki and relevant national and institutional ethical guidelines. Informed consent was obtained. All procedures performed in this study were consistent with the ethical standards of the Helsinki Declaration.

Consent for Publication: The authors give their consent for publication.

Availability of Data and Materials: Upon request, the corresponding author will make the datasets used and/or analyzed during the current investigation available.

Competing Interest: The authors have no conflicts of interest to declare.

Funding: Self-funded study.

Authors' Contribution: All the authors contributed equally.

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References

Abdelkarim, O. F., Rehman, S. U., Samad, A., Khan, I. U., Akram, M. W., Sayeed, M. A., ... & Basit, A. (2024). Biotechnological Approaches to Discovery of Drugs for Veterinary Use: Discovery of Drugs for Veterinary Use. *Futuristic Biotechnology*, 21-28.

Acharya, K. P., Subramanya, S. H., & Lopes, B. S. (2019). Combatting antimicrobial resistance in Nepal: The need for precision surveillance programmes and multi-sectoral partnership. *JAC-Antimicrobial Resistance,* 1(3), dlz066.

Aengwanich, W., & Pumipuntu, N. (2025). Role of surveillance and epidemiology. In *Drug Discovery and One Health Approach in Combating Infectious Diseases* (pp. 77-97). Elsevier.

Ahmad, N., Joji, R. M., & Shahid, M. (2023). Evolution and implementation of One Health to control the dissemination of antibiotic-resistant bacteria and resistance genes: A review. *Frontiers in cellular and infection microbiology,* 12, 1065796.

Azam, S., Afzal, H., Usman, U., Hasan, N., Rehman, A., & Rehman, S. U. (2025). A Study on the Prevalence, Health, and Diversity of Gastrointestinal Parasites in Birds (Captive and Domestic) in Dera Ismail Khan, Pakistan. *Open Access Public Health and Health Administration Review,* 1(1), 24-37.

Beber, C. L., Aragrande, M., & Canali, M. (2025). Policies and strategies to control antimicrobial resistance in livestock production: A comparative analysis of national action plans in European Union Member States. *Health Policy,* 152, 105238.

Bennani, H., Cornelsen, L., Stärk, K. D., & Häsler, B. (2021). Evaluating integrated surveillance for antimicrobial use and resistance in England: a qualitative study. *Frontiers in Veterinary Science,* 8, 743857.

Bordier, M., Binot, A., Pauchard, Q., Nguyen, D. T., Trung, T. N., Fortane, N., & Goutard, F. L. (2018). Antibiotic resistance in Vietnam: moving towards a One Health surveillance system. *BMC Public Health,* 18(1), 1136.

Carter, C. N., & Smith, J. L. (2021). A proposal to leverage high-quality veterinary diagnostic laboratory large data streams for animal health, public health, and One Health. *Journal of Veterinary Diagnostic Investigation,* 33(3), 399-409.

Cheng, Y., Wang, X., Ma, Y., Chen, T., Xiong, L., Chen, P., ... & Xiao, Y. (2025). A multi-sectoral approach to antimicrobial resistance containment: Insights from One Health. *One Health Bulletin,* 5(3), 105-112.

Delpy, L., Astbury, C.C., Aenishaenslin, C. *et al.* Integrated surveillance systems for antibiotic resistance in a One Health context: a scoping review. *BMC Public Health,* 24, 1717 (2024).

Dunga, K. E., Okoro, C. I., Onyenama, A. C., Ekuma, U. O., Ohanusi, I. N., & Izah, S. C. (2025). Implementing One Health approach to emerging zoonotic diseases: Bridging surveillance, sustainability, and global governance. *Exon,* 2(3), 200-223.

El Omeiri, N., Beith, A., Bruinsma, N., Caipo, M., Barcos, L., Mesplet, M., ... & Ramon-Pardo, P. (2023). Driving multisectoral antimicrobial resistance action in South America: Lessons learned from implementing an enhanced tripartite antimicrobial resistance country self-assessment tool. *One Health,* 16, 100474.

Hannah, A., & Baekkeskov, E. (2020). The promises and pitfalls of polysemic ideas: 'One Health 'and antimicrobial resistance policy in Australia and the UK. *Policy Sciences*, 53(3), 437-452.

Hendriksen, R. S., Bortolaia, V., Tate, H., Tyson, G. H., Aarestrup, F. M., & McDermott, P. F. (2019). Using genomics to track global antimicrobial resistance. *Frontiers in public health,* 7, 242.

Lasley, J. N., Appiah, E. O., Kojima, K., & Blacksell, S. D. (2023). Global Veterinary Diagnostic Laboratory Equipment Management and Sustainability and Implications for Pandemic Preparedness Priorities. *Emerging infectious diseases,* 29(4), e220778.

Malik, A. G., Saeed, A., Bashir, M. M., Awais, M., Asees, M., Sufyan, M., & Rehman, S. U. (2025). Tackling the Threat: A Review of Fluoroquinolone Resistance in Salmonella and Campylobacter in Food-Producing Animals. *Open Access Public Health and Health Administration Review,* 4(1), 177-190.

Msemakweli, J. G., Mzuka, K., & Osward, A. (2024). One health approach to antimicrobial resistance: integrating human, animal, and environmental perspectives. *Journal of Public Health and Community Medicine,* 1(4), 132-142.

Na, S. H., Jun, I., Kang, S., Yoo, J. S., & Yoon, E. J. (2025). Laying the groundwork for an inter-ministerial One Health response to antimicrobial resistance in South Korea. *One Health,* 101235.

Sabbatucci, M., Ashiru-Oredope, D., Barbier, L., Bohin, E., Bou-Antoun, S., Brown, C., ... & Wong, D. L. F. (2024). Tracking progress on antimicrobial resistance by the quadripartite country self-assessment survey (TrACSS) in G7 countries, 2017–2023: opportunities and gaps. *Pharmacological Research,* 204, 107188.

Shabangu, K., Essack, S. Y., & Duma, S. E. (2025). Policy Makers' Perceptions on Implementation of National Action Plans on Antimicrobial Resistance in South Africa and Eswatini Using Coordination, Accountability, Resourcing, Regulation and Ownership Framework (2018–2019). *Antibiotics,* 14(7), 696.

Sinyawa, T., Goma, F., Chileshe, C., Mudenda, N. B., Mudenda, S., Siame, A., ... & Chilengi, R. (2025). Antimicrobial Resistance Profiles of Bacteria Isolated from the Animal Health Sector in Zambia (2020–2024): Opportunities to Strengthen Antimicrobial Resistance Surveillance and Stewardship Programs. *Antibiotics,* 14(11), 1102.

Therrell, B. L., Padilla, C. D., Borrajo, G. J., Khneisser, I., Schielen, P. C., Knight-Madden, J., ... & Kase, M. (2024). Current status of newborn bloodspot screening worldwide 2024: a comprehensive review of recent activities (2020–2023). *International journal of neonatal screening,* 10(2), 38.

Waswa, J. P., Kiggundu, R., Kasujja, H., Vudriko, P., Sendagire, H., Kajumbula, H., ... & Konduri, N. (2024). A bottom-up, One Health approach to assessing progress in the implementation of a national action plan for combating antimicrobial resistance: a case study from Uganda. *One Health Advances,* 2(1), 23.

World Health Organization, & World Organisation for Animal Health. (2024). *Guidance for One Health field epidemiology learning evaluation and certification: a supplemental manual to the Competencies for One Health field epidemiology (COHFE) framework*. World Health Organization.

World Health Organization, World Organisation for Animal Health, & UN Environment. (2022). *Antimicrobial Resistance Multi-Partner Trust Fund annual report 2021: Annual Report 2023*. World Health Organization.

Yamba, K., Chizimu, J. Y., Mudenda, S., Lukwesa, C., Chanda, R., Nakazwe, R., & Chilengi, R. (2024). Assessment of antimicrobial resistance laboratory-based surveillance capacity of hospitals in Zambia: findings and implications for system strengthening. *Journal of Hospital Infection,* 148, 129-137.

Zhang, X. X., Liu, J. S., Han, L. F., Xia, S., Li, S. Z., Li, O. Y., & Zhou, X. N. (2022). Towards a global One Health index: a potential assessment tool for One Health performance. *Infectious diseases of poverty, 11*(03), 12-26.

Zhou, N., Cheng, Z., Zhang, X., Lv, C., Guo, C., Liu, H., & Zhu, Y. (2022). Global antimicrobial resistance: a system-wide comprehensive investigation using the Global One Health Index. *Infectious diseases of poverty,* 11(1), 92.

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