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Citation for published version:
Redman-White, C, Loosli, K, Qarkaxhija, V, Lee, T, Mboowa, G, Wee, BA & Muwonge, A 2023, 'A Digital One Health framework to integrate data for public health decision-making', *The International Journal of Infectious Diseases- One Health*, pp. 1-6. https://doi.org/10.1016/j.ijidoh.2023.100012

Digital Object Identifier (DOI):
10.1016/j.ijidoh.2023.100012

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
The International Journal of Infectious Diseases- One Health

A Digital One Health framework to integrate data for public health decision-making

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Keywords: Digital One Health, data integration, legal, ethics, sociological, boundaries

Abstract

The current implementation of One Health primarily focuses on multi-sectoral collaboration but often overlooks opportunities to integrate contextual and pathogen-related data into a unified data resource. This lack of integration hampers effective, data-driven decision-making in One Health activities. In this perspective, we examine the existing strategies for data sharing and identify gaps and barriers to integration. To overcome these challenges, we propose the Digital One Health (DOH) framework for data integration, which consolidates data sharing principles within five pillars for the One Health community of practice:

a) Harmonization of standards to establish trust,

b) Automation of data capture to enhance quality and efficiency,

c) Integration of data at point of capture to limit bureaucracy,

d) Onboard data analysis to articulate utility, and

e) Archiving and governance to safeguard the One Health data resource.

We discuss an upcoming pilot program as a use case focusing on antimicrobial resistance (AMR) surveillance to illustrate the application of this framework. Our ambition is to leverage technology to create data as a shared resource using DOH not only to overcome current structural barriers but also to address prevailing ethical and legal concerns. By doing so, we can enhance the efficiency and effectiveness of decision-making processes in the One Health community of practice, at a national, regional, and international level.

Background

One Health in a global health security context

A holistic One Health (OH) approach is central to the world's ability to detect and respond to health challenges caused by emerging pathogens and antimicrobial resistance (AMR) [1]. Indeed, 60.3% of emerging infectious diseases are zoonotic, and most (54%) are caused by bacteria, including drug resistant strains [2]. While OH seeks to optimise the health of humans, other animals, and their shared ecosystems [3], its current implementation focuses on how people collaborate, not how the data streams integrate. Understandably, such data has ethical, legal, political, and social constraints, particularly regarding the balance between individual privacy and collective benefits of data sharing. Differing standards for data collection, reporting, and sharing result in challenges for harmonization, sharing and interpretation and create boundaries between data collected in different settings across the OH sphere. The social and legal thresholds for data sharing are highest in human health and lowest in the environmental sector respectively and have not been updated in line with evolving global circumstances such as the use of big data to address rapidly evolving global health threats. Here, we challenge stakeholders to look beyond current data boundaries and identify shareable variables needed for initiatives such as the WHO-hub's International Pathogen Surveillance Network (IPSN) and the federated genomic pathogen surveillance [4,5].

Why is OH data integration important?

COVID-19 has highlighted the importance of early data sharing for virus strain tracking. For example, platforms such as the Global Initiative on Sharing All Influenza Data (GISAID) have ensured sequence data integration and analysis to inform response strategies. Now more than ever, decentralized infrastructure of this kind is needed at National Institutes of Public Health

(NPHIs) to allow national outbreak monitoring and preparedness strategies and anchor global health preparedness. However, the assessment tools for preparedness, such as Joint External Evaluation (JEE), need to reflect the OH paradigm in alignment with current global health strategies. Therefore, the challenge to the OH community of practice is how to enrich the JEE with quantitative data covering veterinary and environmental health indicators to create a One Health Joint External Evaluation (OH-JEE) [6]. We argue that this must be informed by a unified view of the risk using a shared OH data resource.

Reasons to look beyond human health

Even with OH research, an anthropocentric paradigm prevails; for example, AMR research frequently treats animals as merely a source or reservoir of resistance. The focus is instead on human clinical outcomes, discounting the intrinsic value of animal health [7]. Adequately funded veterinary infrastructure and surveillance are key to addressing this and providing vital data [7]. Meanwhile, environmental health is often neglected in OH research [8], hence the advocacy of the quadripartite 2022-2026 One Health Joint Plan of Action (One Health JPA) for the integration of environment parameters in OH surveillance [3]. The WHO’s Global Antimicrobial Resistance and Use Surveillance System (GLASS) project incorporates a “Tricycle” approach with built-in harmonization, monitoring AMR in clinical, veterinary, and environmental isolates, although implementation is in its early stages. These “cross-sectoral asymmetries”, with animals and the environment underserved regarding budget and implementation, have been attributed to anthropocentric framings of AMR in policy documents and research [7]. DOH can help redress this balance, facilitating a more profound understanding of the interrelationships between aspects of the more-than-human world – both in a scientific context and at a broader cultural level [9].

What are the current efforts towards OH integration and data sharing?

Current efforts to share data use FAIR (Findability, Accessibility, Interoperability, and Reuse of digital assets) [10] as the overarching principle for data management. For example, the global think-tank System for Enteric Disease Response, Investigation, and Coordination (SEDRIC) focuses on effective AMR surveillance through data sharing with health workers [11], while the Public Health Alliance for Genomic Epidemiology (PHA4GE) works to establish consensus standards in Public Health Bioinformatics to enable reproducibility [12].

WHONET is an established microbiology software package for international monitoring of priority pathogens principally in human health. It is supported by the WHO Collaborating Centre for Surveillance of Antimicrobial Resistance and is used alongside the GLASS information technology platform for data integration [13]. WHONET comes with modules for harmonising and standardising data [14], including "BacLink" to facilitate automatic, scheduled updating of data from the local computer. This tool was primarily designed for human health priority pathogens and its extensions to animal and environmental microbiology are not widely utilized [15]. The scarcity of tangible efforts for OH data integration suggests that harmonization at this scale is the Achilles heel of cross-sectoral data sharing. The One Health Data Alliance for Africa (OHDAA) is one of the few initiatives focusing on OH data [16]. However, its primary focus on policy development and capacity building leaves much room for improving data integration, as recommended by the One Health JPA to improve global preparedness [3].

In Europe, the COHESIVE Common Information System (COHESIVE CIS), developed under the One Health European Joint Program (OH EJP), represents an example of an integrated system for genomic surveillance and epidemiology of foodborne infections from human and veterinary sector across EU member states [1]. The system harmonizes data collected in a range of languages but uses secondary rather than primary data from member states [17]. Similarly, the ORION initiative [18] and BeOne [19] support the harmonisation and integration of surveillance data across sectors within Europe by providing infrastructure and software [20]. These projects represent important efforts towards data integration in HICs with robust surveillance systems; even so, full integration is still hampered by legal issues regarding data sharing [21].

Crucially, none of these efforts has managed to tackle data integration in the broader OH context. It is here that the comparative advantage of DOH becomes evident, as it explicitly addresses ethical and legal controls within its framework, recognising the unique difficulties of integrating data with such disparate ethical and legal boundaries. Additionally, in modernizing multi-sectoral data collection and processing, rather than integrating secondary data into inventories, DOH harmonizes data at point of capture, automating the process with consideration to applications in low resource settings and across the human, animal, and environmental sectors.

What are the bottlenecks for OH data integration?

Foci of risk

Medical, veterinary, and environmental practitioners have different perspectives on risk and its prioritization, influenced by their training and experiences. Clinicians, for instance, tend to concentrate on the risk to the individual patient under their care, prioritizing diagnosis and treatment [22]. In contrast, farm veterinarians, as well as public and environmental health practitioners, often handle risk assessment at the herd and population levels. This difference in frame of reference inevitably impacts the actors' respective priorities, perceived roles, trust, and ultimately, the ability to share data within the OH framework [23].

Data ethics and governance

There are marked differences in the stringency of ethical and legal constraints on data access across the OH spectrum, with human and environmental health subject to the tightest and loosest restrictions, respectively. Appropriate data integration requires significant shifts towards a commonality between these two extremes. In some cases, the ethical threshold is set deliberately high by institutions that fear losing data rights and the competitive advantages of monopolising pathogen-specific data [24]. However, we argue that preventing data access should be considered unethical where a clear public health benefit is articulated.

Lack of evidence of direct utility

The sustainability of data integration is highly dependent on the reasons for, and benefits of, data sharing, which must therefore be made clear to stakeholders. While reasons for sharing can easily be extrapolated from current OH and global health security frameworks, evidence of direct utility for contributors is still lacking. For example, clinicians might be motivated to share microbiological data from their cases if they knew this would provide them with access to clinically relevant population-wide information in the form of well-trained AI models drawing on a wealth of OH data to support differential diagnosis [25].

Lack of digital integration platforms for OH data

Despite the recommendations of the One Health JPA [3], there is as yet no functional platform that effectively integrates and processes OH data. Consequently, data pertaining to zoonotic diseases and antibiotic resistance within specific niches tends to be fragmented across various systems. This fragmentation limits the comprehensive understanding of the interconnections and potential risks involved.

Digital One Health as a solution for integration

We propose DOH as a framework for leveraging technology to create a shared data resource for OH decision-making. It centres on five pillars informed by the FAIR principles of data sharing (**Figure 1B**). It emphasizes sustainability, quality and efficiency, interoperability and, importantly, data governance structures to safeguard the use of shared data resources. Performance can be evaluated using key performance indicators (KPIs), which inherently enforce data protection standards. DOH embodies solutions to identified gaps and bottlenecks for current OH data integration efforts (**Figure 1B**), using software tools with inbuilt ethical, legal, and social thresholds as "digital filters" that triage metadata variables to create a shared resource (**Figure 1A**).

Pillar 1: Harmonization, standardization, as trust building activities

Harmonization relies on the consistency and compatibility of systems, arguably the foundation of data integration. This encourages the OH community of practice to agree on standards, variables to record, and minimum required sample processing and interpretation. We will refer to these simply as "standards", and these must be developed in collaboration with statisticians and data scientists to ensure that the agreed-upon standards yield a useful data product that facilitates varied downstream statistical analyses. We believe negotiating common ground to arrive at such standards represents the foundation for trust building between stakeholders. Trust-building activities are embedded within stakeholder meetings/workshops, training, and conferences to nurture co-design and shared ownership of the data integration (**Figure 1A**).

Pillar 2: Automating standardization processes to ensure quality and efficiency

Standards are coded into intelligent "digital filters", which drive the automation of data triaging using a traffic light system. Stakeholders agree on "green channel" variables, which can be shared without violating ethical and legal boundaries, such as pathogen characteristics or patient gender. “Orange channel” are variables that may be shared with privacy-preserving modifications, such as locations recorded as a partial address or jittered GPS, ages transformed into categories, and socioeconomic variables compounded into an index. “Red channel” are variables that cannot be shared, including names, contact and financial details **(Figure 1A**).

Pillar 3: Data integration at the point of capture to limit bureaucracy

As applied to infectious disease, DOH aims to combine specific data variables (metadata) and AMR or zoonotic disease ecology data generated from human, animal, and environmental sectors to form a unified understanding of the problem. The challenges of AMR and zoonoses are characterized by complex and inextricable links across and between these sectors; they cannot be adequately addressed by viewing data from one of these in isolation. The integration tools must intelligently capture, transform where necessary, and triage data streams to create a shared resource for joint analyses and interpretation (**Figure 1B)**. The DOH framework is novel in that it will integrate data at capture to limit institutional bureaucracy while providing the offline support necessary for adoption in low- and middle-income countries (LMICs) (**Figure 1C**). This includes digital applications for data capture without internet and secure transmission to Laboratory Information Systems (LIMs) and World Health Organisation's microbiology database software (WHONET) when internet access is available.

Pillar 4: Integrated data processing with onboard analytics and visualization to articulate the value of data

Stakeholders are motivated to share data when the value and benefit are well articulated. Therefore, embedding analytics and interpretation of output improves data utility and its immediate value, so the shared metadata resource is directly used to develop insights from OH data. Guided by PH4GE pipeline and visualization protocols, the fourth pillar aims to optimize the portability of analytical and computational pipelines to ensure their utility on regular computers. This can be achieved by assigning heavy computation to cluster computing at hubs such as NPHIs, and national veterinary or environmental institutes while the spokes (local surveillance sites) implement basic analysis that summarizes trends.

Pillar 5: Sharing and archiving data

The fifth pillar of DOH focuses on ensuring that the OH data gathered is accessible to all stakeholders, from a local to global scale (**Figure 1C**), within legal and ethical frameworks. This pillar incorporates both governance and more practical concerns. In order to facilitate future re-use of the harmonized data, the expertise of library scientists is needed to develop suitable archiving methods. The availability of the data to those making clinical, public health, veterinary and environmental health decisions is a vital outcome of DOH. Historically, data have been concentrated in the global North; we consider it crucial for data to be accessible equitably.

Integrated OH data as a shared resource for decision-making

Our proposed guidelines represent an operational management and governance structure for how this shared resource could be utilized to achieve the following:

Encourage structured decision-making for OH

A shared data resource represents unified evidence about the dynamics underpinning global health challenges, inherently laying the foundation for structured decision-making [26]. The pillars of DOH become incentives for structuring evidence for decision-making a) by clearly defining objectives for integration, b) with motivations informed by a unified view of evidence, and c) data sources structured to encourage us to reflect on the uncertainty, d) producing an output that allows for transparent communication of risk to societies.

Support capacity building, ethics, and data governance

A shared data resource can also be mined for novel hypotheses to drive capacity building and innovation for OH. Capacity building is critical to the sustainability of OH activities, not only to improve awareness but as a key element for trust building. Tailored capacity building also ensures that supervision structures of the workforce maintain the critical control points for data integration such as ethical, legal and data governance. This also opens opportunities for public-private collaborations to maximise use and reuse of data, however, this must be done with ethical considerations in mind.

Nurture shared decision-making for OH

Shared decision-making is a well-established practice in healthcare [27], with utility in healthcare professionals working with patients to arrive at a decision based on available clinical and epidemiological evidence. Here, OH professionals should use the shared data resource as a catalyst to arrive at shared decisions using the available unified evidence. This is crucial in empowering stakeholders, defining roles, and building and maintaining trust.

An example of a DOH framework for AMR surveillance

In an upcoming pilot we aim to test the DOH framework in a platform that integrates metadata and sample collection, analysis, and output visualization. This will be done with AMR surveillance laboratories as the OH community of practice in Uganda, with the following specific objectives: a) Organise data harmonization workshops for OH microbiologists as our selected community of practice, b) Test the utility of a mobile phone application to automate the triage and integration of metadata linked to AMR samples, c) Pilot the use of sequencing on routinely cultured pathogens, d) Develop a portable and integrated data workflow to feed into our prototype data sharing and analysis web portal and finally, e) Support local capacity building through training seminars on long-read sequencing and data analysis (**Figure S1**). It aims to streamline local data streams (**Figure 1C**) to feed initiatives such as WHO IPSN [4,28].

Conclusions

A unified view of emerging zoonotic and AMR risks is vital for effective preparedness. This requires bringing together epidemiological data as they are collected and rapidly making insights available, so that surveillance and research outputs generate tangible benefits rather than languishing in a fragmented data landscape. In LMICs, this is particularly crucial: with limited resources available for data collection and analysis, it is vital to make the most of the collected data and ensure equitable access to outputs. The DOH framework is structured to improve OH outcomes globally, streamlining processes and explicitly accounting for unequal distribution of resources such as computing power and internet access. The global health risk landscape requires coordinated rapid responses, therefore DOH is designed to anchor and guide activities that leverage technology to create OH shared data resources that supports decision-making while addressing ethical and legal complexities.

Author contributions

CRW: original draft; writing, review & editing

KL: writing – original draft; writing – review & editing

AM: conceptualised the idea and framed the question and structure of perspective, participated in the writing on the original draft and its review

VQ: section writing, review & editing

TNL: section writing, review and editing

BW: section writing, review and editing

GM: section writing, review and editing and context

Declaration of interests

The authors declare no conflicts of interest

Role of the funding source

AM & BW are funded by the BBSRC at Roslin institute (BB/T00875X/1) and AM as Chancellor's fellow at University of Edinburgh, the Digital One Health pilot is funded by the Royal Society (RGS\R1\231137), CRW acknowledges support for a PhD studentship from the UKRI Biotechnology and Biological Sciences Research Council (BBSRC) and Zoetis (BB/T00875X/1). TNL & VQ are funded by a Wellcome One Health Model PhD studentship and KL is jointly funded in a One Health PhD by the University of Edinburgh and the University of Glasgow Jointly Funded PhD studentships. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript

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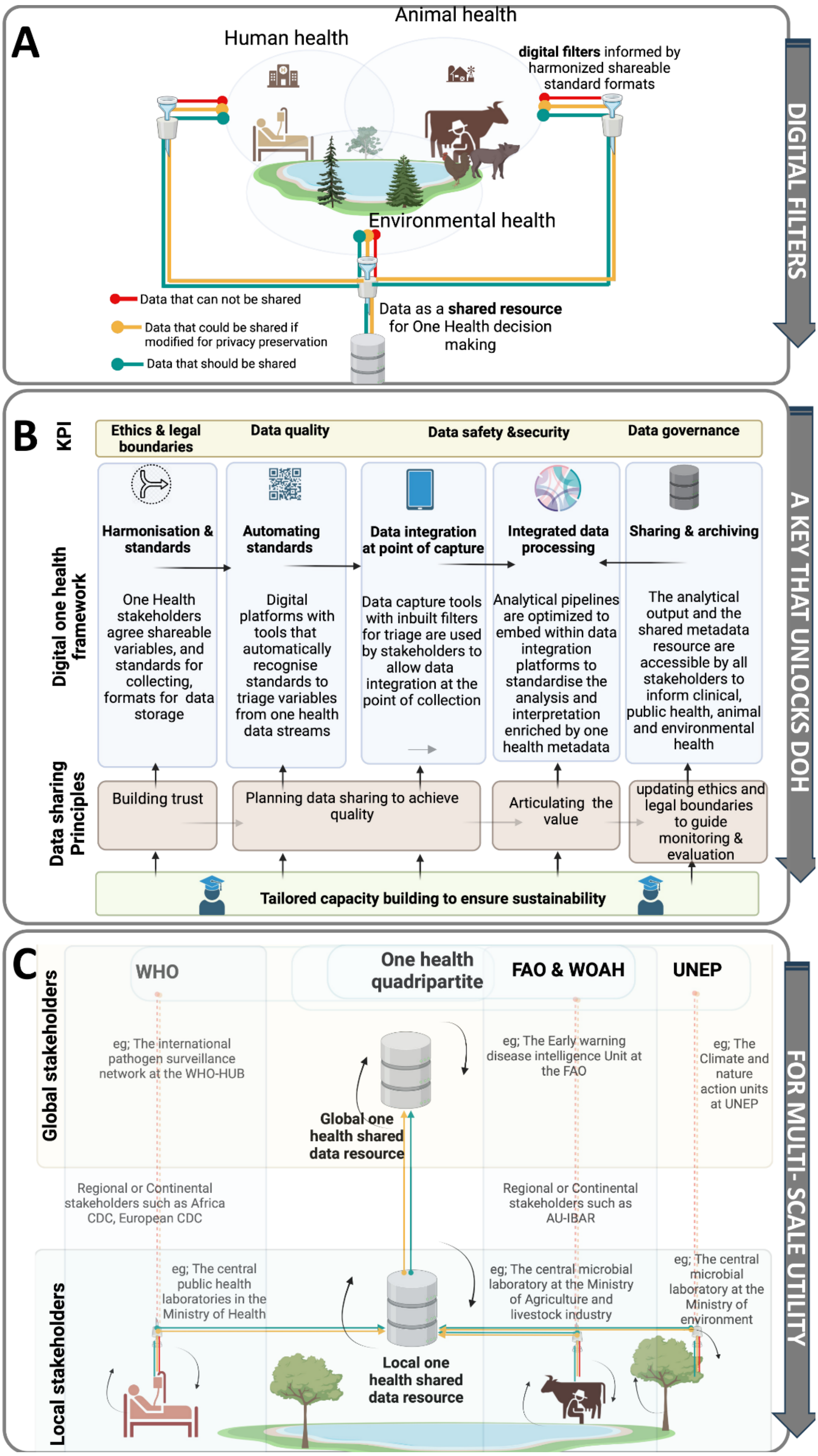
A
Human health
Animal health
digital filters informed by harmonized shareable standard formats
Environmental health
Data that can not be shared
Data that could be shared if modified for privacy preservation
Data that should be shared
Data as a shared resource for One Health decision making
DIGITAL FILTERS
B
KPI
Ethics & legal boundaries
Data quality
Data safety &security
Data governance
Digital one health framework
Harmonisation & standards
One Health stakeholders agree shareable variables, and standards for collecting, formats for data storage
Automating standards
Digital platforms with tools that automatically recognise standards to triage variables from one health data streams
Data integration at point of capture
Data capture tools with inbuilt filters for triage are used by stakeholders to allow data integration at the point of collection
Integrated data processing
Analytical pipelines are optimized to embed within data integration platforms to standardise the analysis and interpretation enriched by one health metadata
Sharing & archiving
The analytical output and the shared metadata resource are accessible by all stakeholders to inform clinical, public health, animal and environmental health
Data sharing Principles
Building trust
Planning data sharing to achieve quality
Articulating the value
updating ethics and legal boundaries to guide monitoring & evaluation
Tailored capacity building to ensure sustainability
A KEY THAT UNLOCKS DOH
C
Global stakeholders
WHO
One health quadripartite
FAO & WOAH
UNEP
eg; The international pathogen surveillance network at the WHO-HUB
eg; The Early warning disease intelligence Unit at the FAO
eg; The Climate and nature action units at UNEP
Global one health shared data resource
Regional or Continental stakeholders such as Africa CDC, European CDC
Regional or Continental stakeholders such as AU-IBAR
Local stakeholders
eg; The central public health laboratories in the Ministry of Health
eg; The central microbial laboratory at the Ministry of Agriculture and livestock industry
eg; The central microbial laboratory at the Ministry of environment
Local one health shared data resource
FOR MULTI- SCALE UTILITY

Figure 1

Figure Legend

Figure 1A is the DOH (Digital One Health) framework for creating data as shared resources for decision-making. Key performance indicators (KPIs)are based on the principles of data sharing. The component of capacity-building is central to the sustainability of the framework. **Figure 1B** is the key to operationalizing DOH as it shows how digital filters for triaging data can be developed. **Figure 1C illustrates** how DOH feeds into the global data-sharing strategies. The cyclic arrows indicate that the data are collected/collated, triaged, analysed, and used on-site; dotted lines represent data flows within sectors. Abbreviations: AU-IBAR = African Union Interafrican Bureau for Animal Resources, CDC = Center for Disease Control, FAO = Food and Agriculture Organization, UNEP = United Nations Environment Programme, WHO-HUB = World Health Organization Pandemic Hub. The figures are generated using https://www.biorender.com.

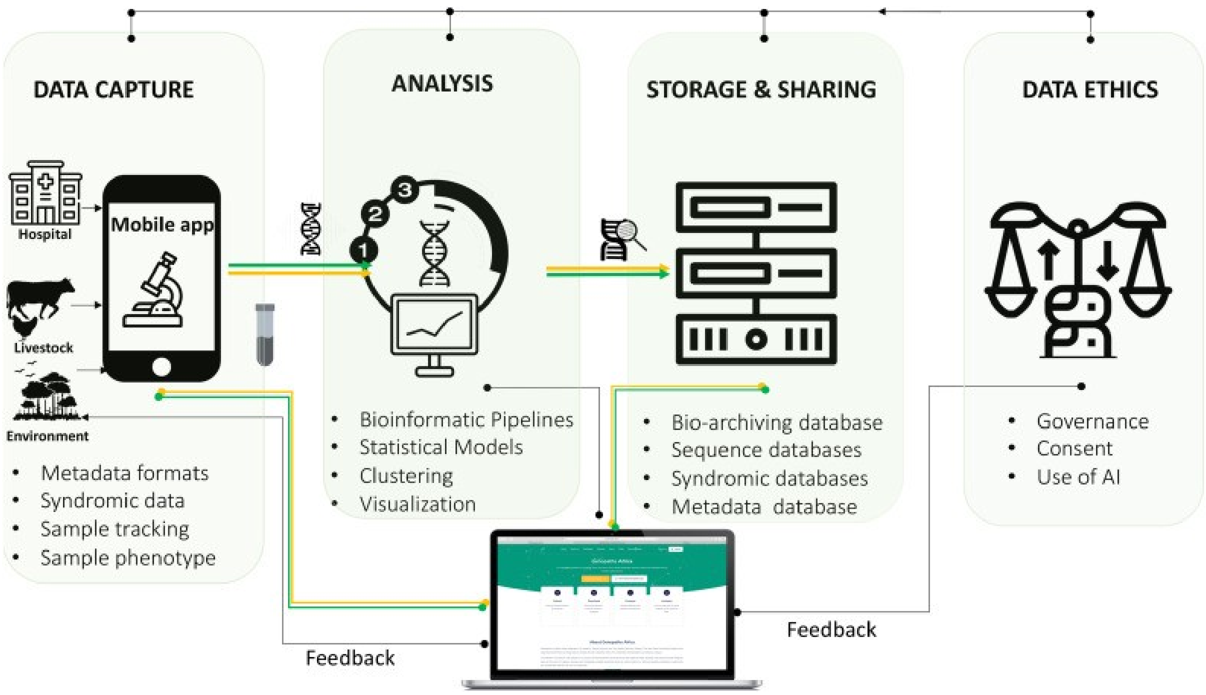

Figure S1 An example of how an integrated Digital One Health (DOH) framework for antimicrobial resistance (AMR) surveillance can be designed and implemented. Notably, the

Digital One Health Laboratory at the Roslin Institute has now received funding from The Royal Society to pilot this framework in Uganda. This framework is a detailed representation of the "Local stakeholders" compartment in Figure 1C.