Schematic illustration of the iMAP pipeline for automated pathogens' genomics analysis.

Big data, AI powering antimicrobial resistance, zoonotic pathogen tracking

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ANTIMICROBIAL resistance (AMR) is a growing global health crisis characterized by the diminishing effectiveness of antibiotics and other antimicrobial agents. This resistance arises when pathogenic agents such as bacteria, viruses, fungi, and parasites evolve to withstand the drugs that previously killed them or inhibited their growth. AMR poses a severe threat to human and livestock health by leading to longer-lasting infections, higher treatment costs, and increased morbidity and mortality rates. Economically, the rise in AMR strains healthcare systems by extending hospital stays, necessitating more expensive medications, and increasing the burden of care on health services. Socially, it undermines progress in medicine and public health, making previously treatable infections potentially deadly.

Zoonotic pathogens are infectious agents that can be transmitted from animals to humans, often causing serious health issues. These pathogens include bacteria, viruses, fungi, and parasites that can cause diseases such as avian influenza, rabies, and Ebola. Zoonotic diseases are particularly concerning because they can lead to outbreaks that cross species barriers and result in significant public health emergencies. Many zoonotic pathogens are associated with AMR, as resistance mechanisms in animals can transfer to human pathogens through direct contact or environmental exposure. Understanding and managing these pathogens are crucial for preventing disease spread and mitigating the impact of emerging infectious diseases.

Integrated surveillance of AMR and zoonotic pathogens is vital for effectively preventing and controlling health crises. Monitoring both AMR and zoonotic pathogens (One-Health) provides a comprehensive view of health threats, allowing for early detection and timely response to potential outbreaks. Surveillance systems that combine data on AMR and zoonotic diseases can identify trends and correlations that might not be apparent when these areas are examined separately. This integrated approach enables better risk assessment and management, enhances preparedness for epidemics and pandemics, and supports the development of targeted interventions to reduce the spread of infectious diseases.

Big data plays a crucial role in the surveillance of AMR and zoonotic pathogens by aggregating information from various sources. Public health databases provide records of disease incidence and treatment outcomes, while laboratory results offer insights into pathogen resistance profiles and effectiveness of antimicrobial agents. Environmental monitoring contributes data on pathogen presence in soil, water, and other environmental samples, helping to identify potential sources of contamination. Additionally, veterinary, and agricultural data are essential for understanding pathogen prevalence and resistance patterns in animals and plants, which can influence human health outcomes. Combining these diverse data sources provides a more comprehensive understanding of health threats and supports effective surveillance.

The data collected for AMR and zoonotic pathogen surveillance includes genomic (human, animal, plants, environment) epidemiological, clinical, and environmental information. Genomic data involves sequencing the DNA of pathogens to identify resistance genes and understand their evolutionary patterns. Epidemiological data tracks disease incidence, spread, and demographic information to map disease outbreaks and identify trends. Clinical data from patient records provides details on symptoms, treatments, and outcomes, which can reveal patterns of resistance and treatment failures. Data from animal reservoirs, including livestock and wildlife, helps to trace the origin and transmission pathways of zoonotic diseases, contributing to a holistic understanding of health threats.

Integrating big data from various sources presents several challenges. Data heterogeneity arises from differences in data formats, standards, and sources, making it difficult to combine and analyse information effectively. The sheer volume of data collected can be overwhelming and requires robust systems for storage, processing, and analysis. Privacy concerns are paramount, as sensitive health information must be protected from unauthorised access and misuse. Additionally, achieving interoperability between human and animal health systems is crucial for a unified surveillance approach, but it often requires overcoming technical and organisational barriers.

Role of AI

Artificial intelligence (AI) offers powerful techniques for analysing large and complex datasets in AMR and zoonotic pathogen surveillance. Machine learning models can detect patterns and make predictions based on historical and real-time

Dashboard displaying integrated AMR and zoonotic pathogen data using simulated data from Kenya.

data, improving the ability to identify emerging threats and trends. Natural language processing (NLP) is used to extract valuable information from unstructured data sources, such as research papers and clinical notes, which can provide insights into disease dynamics and resistance patterns. These AI techniques enhance the accuracy and efficiency of data analysis, supporting better decision making and response strategies.

AI-driven predictive analytics play a critical role in assessing risks associated with AMR and zoonotic diseases. Predictive models use historical data to forecast potential outbreak hotspots and identify areas at high risk of disease spread. These models can help public health officials prioritise interventions and allocate resources more effectively. Risk assessment tools powered by AI evaluate the likelihood of resistance development and zoonotic disease transmission, providing actionable insights to prevent and manage health emergencies. By leveraging predictive analytics, stakeholders can proactively address potential threats before they escalate into major crises.

AI enables real-time monitoring of AMR and zoonotic pathogens by processing continuous data streams and providing timely alerts on emerging health threats. AI algorithms can analyse data from various sources, including surveillance systems, laboratory reports, and environmental sensors, to detect anomalies and identify potential outbreaks. Early warning systems powered by AI support rapid response efforts by alerting health authorities to emerging risks and enabling swift action to contain and mitigate threats. Real-time monitoring enhances situational awareness and improves the overall effectiveness of epidemic preparedness and response efforts.

AI has great potential in pathogens genomic and drug discovery research. It is a powerful tool for creating new hypotheses and helping with diagnosis and experimental drug testing. From databases on gene and disease models, it can help in the detection of gene-related disorders. AI and Machine Learning (ML) developments offer an excellent possibility for rational pathogenic disease treatment design and validation, eventually impacting livestock and human lives.

As many health and veterinary service providers are incorporating medical electronic records into their care operations, healthcare data become more accessible remotely, with some levels of regulations. Different acquisition methodologies are used in the field of AI genome sequencing to improve capabilities, increase accuracy, and expand the applications of genomic data analysis to support one health research and also have great potential impact in breeding and selection in livestock agriculture.

Connecting AMR and zoonotic pathogens through dashboards

The rising occurrence of AMR poses a threat to global health. It is projected that by 2030 AMR infections resulting in increased morbidity, disability, premature death and reduced effective labour will become a significant threat to the global economy. Africa is not equipped like other regions of the world to face that threat. Thus, it is critical to strengthen systems to detect and monitor the occurrence of AMR-related infections.

Dashboards that integrate AMR and zoonotic pathogen surveillance data provide a holistic view of health threats by linking information on resistance patterns with disease occurrences. Interactive maps enable users to visualise hotspots where AMR and zoonotic diseases overlap, highlighting areas of concern and guiding targeted interventions. Combining data from these two domains allows for a more comprehensive understanding of how antimicrobial resistance and zoonotic diseases interact, enhancing the effectiveness of surveillance and response efforts.

Advanced analytics tools within dashboards facilitate the exploration of correlations between AMR and zoonotic outbreaks. By analysing patterns and relationships between resistance and disease occurrences, users can identify potential causative factors and underlying mechanisms. AI-driven insights provide a deeper understanding of how resistance contributes to the spread of zoonotic diseases, informing strategies to address both issues simultaneously. This analysis supports evidence-based decision-making and enhances the overall effectiveness of epidemic preparedness and response.

Dashboards generate automated reports that provide actionable insights for policymakers, helping them make informed decisions based on real-time data. Scenario modeling and forecasting tools use combined AMR and zoonotic data to predict potential future outbreaks and assess the impact of different intervention strategies. By offering comprehensive and timely information, dashboards support effective decision making and enhance the capacity to respond to biological emergencies.

Africa should not be left out of the information revolution and system thinking approach, moving toward building database systems based on the One Health concept to prevent and manage outbreaks of catastrophic biological risks or zoonotic diseases. The existing surveillance system may appropriately concentrate on early outbreak detection, including restraint and response, but prediction would be key for prevetion and preparation for rapid response. This would rightly be supported by machine learning. While standards for interoperability should be adopted for clinical clinical, they should also be speaking from causal information and associated metadata surveillance for understanding the dynamics of the pathogen-host cycles between outbreaks in changing environment. Capacity development for such longitudinal surveillance will inevitably provides insight into disease burden and helps countries to detect possible predictable patterns in outbreaks at a much lower economic cost than responding after the pathogens emerge.