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SYNERGIZING HUMAN, ANIMAL, AND ENVIRONMENTAL HEALTH: A COMPREHENSIVE ONE HEALTH REVIEW

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ABSTRACT

One Health is a multi-sectorial collaborative approach to combat the ongoing pandemic of multi drug resistance and diseases of human, animal, and the environment. This also focuses on next pandemic preparedness. Urbanization causing more interactions with the wild animals and harming the environment resulting in zoonoses. The multidrug resistance organisms and the antibiotic resistance genes are spreading because of non-therapeutic antibiotics usage in livestock. The multidrug resistant genes are found in the environment such as river, soil and drainage. Loss of multi billion dollar in health care settings and economic are encountered globally. To mitigate the burden a holistic approach 'One Health' is in top priority.

KEYWORDS: One Health, AMR, MDROs, Environmental Health.

INTRODUCTION

One Health is a scientifically established and proven notion of great societal value derived from a thorough examination of zoonotic diseases (Couto et al., 2020).

One Health is a collaborative, cross-sector, and multidisciplinary strategy that functions at the local, regional, national, and global levels. Its goal is to obtain the best health results by recognizing the interconnectedness of humans, animals, plants, and their shared environment (Centers for Disease Control and Prevention., 2022). This strategy brings together many sectors, disciplines, and communities at different social levels to promote well-being and address challenges to health and ecosystems. It emphasizes the shared need for clean water, electricity, and air, as well as safe and healthy food, while also taking action to combat climate change and promote sustainable development (World Health Organization., 2023).

The growth of novel infectious illnesses, the rise of antibiotic resistance, and the persistent challenges of environmental degradation underline the critical need for coordinated, multidisciplinary approaches. Urbanization, climate change, and growing human-animal interactions have resulted in a landscape in which health challenges are no longer limited to one species or habitat. Instead, they are woven into a larger, more complex web of cause and effect (Magnano et al., 2023).

This detailed review will go deeply into the One Health concept, exploring its origins, present uses, and future possibilities. We can create more effective solutions for disease prevention and control, food safety and security, and sustainable ecosystems by collaborating across the human, animal, and environmental health sectors. This article will look at the fundamental components of One Health, underlining its relevance in modern healthcare and public health programs, and provide potential solutions for implementing it to solve some of today's most important health concerns.

History of One Health: Although the term "One Health" is relatively new, the notion has long been acknowledged both nationally and internationally. Scientists have seen similarities in illness processes between animals and people since the 1800s, but human and animal medicines were treated independently until the 20th century.

Rudolf Virchow, MD, a renowned physician from the 19th century, was a pioneering German pathologist who investigated the links between human and veterinary medicine. His attention was piqued by his research on Trichinella spiralis, a roundworm prevalent in pigs. Dr. Virchow used the word "zoonosis" to characterize infectious illnesses that spread between humans and animals. He aggressively campaigned for the merger of animal and human medicine, claiming that there should be no distinction between the two. He thought that, while the aims may change, the information obtained serves as the foundation for all medical practice.

Year	History
1821-1902	• Virchow Recognizes the Link Between Human and Animal Health
1849-1919	• William Osler, Father of Veterinary Pathology • One of his first publications was titled, "The Relation of Animals to Man."
1947	• The Veterinary Public Health Division is Established at CDC
1927-2006	• Calvin Schwabe coined the term "One Medicine" and calls for a unified approach to zoonotic diseases that uses both human and veterinary medicine.
2004	• The Wildlife Conservation Society Publishes the 12 Manhattan Principles
2007	• The One Health Approach is recommended for pandemic preparation. • The American Medical Association passes the One Health Resolution, which promotes the partnership between human and veterinary medicine.
2008	• One Health Becomes a Recommended Approach and a Political Reality • FAO, WOAH, and WHO. Work with UNICEF, UNSIC, and the World Bank to create a Joint Strategic Framework in Response to the Changing Risk of Emerging and Re-emerging Infectious Diseases.
2009	• Key Recommendations for One World, One Health™ are Developed • USAID Establishes the Emerging Pandemic Threats Program
2010	• The European Union Reaffirms its Commitment to Operate Under a One Health Umbrella • The United Nations and the World Bank Recommend Adoption of One Health Approaches

	• Experts Identify Clear and Concrete Actions to Move the Concept of One Health from Vision to Implementation • The Tripartite Concept Note is Published • The Hanoi Declaration, Which Recommends Broad Implementation of One Health, is Adopted Unanimously
2011	• The High Level Technical Meeting to Address Health Risks at the Human-Animal-Ecosystem Interface Builds Political Will for The One Health Movement • The First International One Health Congress is Held in Melbourne, Australia
2012	• The Global Risk Forum sponsors the first One Health Summit
2013	• The Second International One Health Congress is held in conjunction with the Prince Mahidol Award Conference
2014	• **Global Health Security Agenda (GHSA):** Launching of GHSA included One Health as a key component to address global health security threats, particularly zoonotic diseases. • **Emerging Infectious Diseases:** The approach was increasingly applied to study and combat emerging infectious diseases such as Ebola, highlighting the need for a coordinated response across sectors.
2015	• **Sustainable Development Goals (SDGs):** The United Nations' SDGs acknowledged the importance of One Health in achieving goals related to health, food security, and environmental sustainability. • **National One Health Platforms:** Several countries began establishing national One Health platforms to facilitate cross-sectoral collaboration.
2016	• **Research and Publications:** The body of research and publications on One Health grew, with numerous articles and studies demonstrating the benefits of integrated health approaches. • **AMR and One Health:** Antimicrobial resistance (AMR) was recognized as a significant One Health issue, leading to the development of multi-sectoral AMR action plans.
2017	• **WHO-OIE-FAO Collaboration:** These organizations formalized their collaboration through the Tripartite Agreement, focusing on One Health approaches to tackle zoonotic diseases, AMR, and food safety. • **Educational Initiatives:** More universities worldwide incorporated One Health into their curricula, fostering the next generation of interdisciplinary health professionals.
2018	• **Funding and Support:** Increased funding from governments and international agencies supported One Health initiatives, including research, capacity building, and infrastructure development. • **Public Awareness:** Public awareness campaigns highlighted the importance of One Health in preventing and managing health threats.
2019	• **Policy Development:** Many countries developed and implemented national One Health policies, integrating them into public health, veterinary, and environmental sectors. • **Pandemic Preparedness:** The One Health approach was increasingly recognized as crucial for pandemic preparedness and response.
2020	• **COVID-19 Pandemic:** The COVID-19 pandemic underscored the interconnectedness of human, animal, and environmental health, leading to a surge in support for One Health approaches globally. • **Global Conferences:** Virtual global conferences and webinars on One Health proliferated, sharing knowledge and best practices during the pandemic.
2021	• **Strengthening Systems:** Efforts to strengthen health systems through One Health approaches were accelerated, focusing on surveillance, diagnostics, and response mechanisms. • **International Collaborations:** International collaborations and partnerships expanded, promoting global health security.
2022	• **WHO One Health Global Leaders Group on AMR:** Established to advocate for urgent action to address AMR using a One Health approach. • **Climate Change and One Health:** The impact of climate change on health was increasingly integrated into One Health discussions, emphasizing the need for comprehensive strategies.
2023	• **Global Framework:** The development of a global framework for One Health, incorporating lessons learned from the COVID-19 pandemic and other health crises, aimed at standardizing and guiding One Health practices worldwide. • **Future Directions:** Ongoing efforts focused on enhancing interdisciplinary research, policy-making, and community engagement to address emerging health threats and ensure sustainable health outcomes for humans, animals, and the environment.

Over the past decade, the One Health approach has evolved from a concept to a critical component of global health strategies, driven by the recognition that the health of people, animals, and the environment are inextricably linked.

Urbanization: Emerging Causes for Epidemics

(1) Increased Human-Animal Interactions

- **Encroachment on Wildlife Habitats**: As cities expand, they often encroach on natural habitats, bringing humans into closer contact with wildlife. This increased interaction can facilitate the spill over of pathogens from animals to humans. For example, urbanization in West Africa has been linked to the Ebola virus, which is transmitted from fruit bats to humans. The bats, which are natural reservoirs of the virus, are forced into closer proximity to human populations due to habitat loss, increasing the likelihood of disease transmission (Smith et al., 2018; Jones et al., 2013).
- **Urban Livestock Farming**: In many developing countries, urban areas include livestock farming, where animals are kept within city limits. This practice can facilitate the transmission of zoonotic diseases such as brucellosis and leptospirosis. In India, for instance, urban dairy farming has been associated with the spread of brucellosis, a bacterial infection that can be transmitted from cattle to humans through direct contact or consumption of contaminated dairy products (Sharma et al., 2014; Kumar et al., 2017).
- **Pet Ownership**: The rise in pet ownership in urban areas also contributes to increased human-animal interactions. Pets can serve as vectors for diseases such as rabies, toxoplasmosis, and various parasitic infections. The close contact between pets and humans in urban settings increases the risk of these zoonotic diseases spreading (Davis et al., 2012; Lewis et al., 2014).
- **Wildlife Trade and Markets**: Urban centres often have markets where wildlife is sold and traded. These markets can be breeding grounds for zoonotic diseases due to the high density of various species and the poor sanitary conditions. The COVID-19 pandemic highlighted the risks associated with wildlife markets, as the virus is believed to have originated in a market in Wuhan, China, where live wild animals were sold (Wu et al., 2020; Holmes et al., 2021).
- **Urban Wildlife**: Some wildlife species, such as raccoons, pigeons, and bats, thrive in urban environments. These animals can carry and transmit diseases to humans. For example, urban raccoons can carry rabies, while pigeons can transmit histoplasmosis, a fungal infection that affects the lungs (Childs et al., 2007; Haider et al., 2020).

(2) Vector-Borne Diseases

- **Ideal Breeding Conditions**: Urban areas often provide optimal breeding grounds for vectors like mosquitoes due to poor drainage systems, stagnant water, and inadequate waste management. These conditions are prevalent in many cities, especially in rapidly urbanizing regions. For example, the proliferation of the Aedes aegypti mosquito in urban areas has been linked to the spread of diseases such as dengue fever, chikungunya, and Zika virus. The 2015-2016 Zika outbreak in Brazil was exacerbated by urban conditions that supported mosquito breeding (Hotez, 2016; Dick et al., 2016).
- **Population Density and Exposure**: High population densities in urban areas increase human exposure to vector-borne diseases. Urban slums, characterized by crowded living conditions and inadequate infrastructure, are particularly vulnerable. The combination of dense populations and poor living conditions facilitates the spread of diseases such as malaria and dengue. During outbreaks, the close proximity of individuals allows for rapid disease transmission (Eisen & Moore, 2013; Weaver & Reisen, 2010).

- **Climate Change and Urban Heat Islands**: Urbanization contributes to climate change and the creation of urban heat islands, which can alter the behaviour and distribution of vectors. Warmer temperatures in cities can extend the breeding season of mosquitoes and increase the efficiency of disease transmission. This has been observed with diseases like West Nile virus, where urban heat islands have been linked to higher mosquito activity and increased transmission rates (Kilpatrick et al., 2008; Paz, 2015).
- **Water Storage Practices**: In many urban areas, especially those with intermittent water supply, residents store water in containers, which can serve as breeding sites for mosquitoes. This practice has been linked to outbreaks of diseases such as dengue and chikungunya. Effective water management and the elimination of standing water are crucial in reducing the risk of vector-borne diseases in urban settings (Nathan & Knudsen, 1991; Heukelbach et al., 2001).
- **Migration and Mobility**: The high mobility of urban populations, including daily commutes and migration from rural to urban areas, can facilitate the spread of vector-borne diseases. People moving from areas with high disease prevalence to areas with lower prevalence can introduce new infections, complicating control efforts. This was evident in the spread of chikungunya and Zika viruses in the Americas, where human movement played a significant role in the dissemination of the viruses (Morrison, 2014; Musso & Gubler, 2016).
- **Inadequate Public Health Infrastructure**: Rapid urbanization can outpace the development of public health infrastructure, making it challenging to implement effective vector control measures. Inadequate health services, limited access to medical care, and poor disease surveillance systems contribute to the persistence and spread of vector-borne diseases in urban areas. Strengthening public health infrastructure and implementing integrated vector management strategies are essential for controlling these diseases (Gubler, 2011; Bhatt et al., 2013).

(3) High Population Density

High population density in urban areas is a significant factor contributing to the emergence and spread of epidemics, particularly in the context of the One Health framework, which considers the interconnected health of humans, animals, and the environment. Urban areas with high population densities face several challenges that exacerbate the transmission of infectious diseases.

- **Increased Transmission Rates**: High population density facilitates the rapid spread of infectious diseases due to the close proximity of individuals. This proximity allows for easier transmission of pathogens through direct contact, respiratory droplets, and other means. Diseases such as tuberculosis, influenza, and COVID-19 have shown higher transmission rates in densely populated urban areas compared to rural areas (Vlahov et al., 2007; Riley et al., 2020).
- **Overburdened Healthcare Systems**: Urban areas with high population densities often have overburdened healthcare systems, making it challenging to provide timely and adequate medical care during outbreaks. The increased demand for healthcare services during epidemics can overwhelm hospitals and clinics, leading to inadequate treatment and higher mortality rates. This was evident during the COVID-19 pandemic, where cities like New York and Mumbai experienced significant strain on their healthcare infrastructure (Verma et al., 2020; Ranganathan & Swamy, 2021).
- **Poor Living Conditions**: High population density is often associated with poor living conditions, particularly in urban slums and informal settlements. These areas typically lack adequate sanitation, clean water, and waste

management, creating environments conducive to the spread of infectious diseases. For example, cholera outbreaks are more common in densely populated areas with poor sanitation (Ali et al., 2017; Mengel et al., 2014).

- **Social and Economic Disparities**: High population density in urban areas can exacerbate social and economic disparities, which can influence the spread and impact of infectious diseases. Lower-income populations may have limited access to healthcare, nutrition, and sanitation, making them more vulnerable to diseases. This disparity was highlighted during the COVID-19 pandemic, where marginalized communities experienced higher infection and mortality rates (Patel et al., 2020; Millett et al., 2020).
- **Transportation Networks**: Urban areas with high population densities often have extensive transportation networks, including public transit systems, which can facilitate the spread of infectious diseases. The high volume of daily commuters and the close quarters of public transportation increase the risk of disease transmission. For instance, the rapid spread of COVID-19 in major cities was partly attributed to the use of public transportation (Chen et al., 2020; Goscé & Johansson, 2018).
- **Environmental Degradation**: High population density contributes to environmental degradation, including air and water pollution, which can impact human health. Poor air quality, for instance, has been linked to increased susceptibility to respiratory infections. In densely populated cities, the combined effects of pollution and high population density can exacerbate the spread and severity of infectious diseases (Bernstein & Rice, 2013; Huang et al., 2015).

(4) Inadequate Health Infrastructure

Inadequate health infrastructure is a significant factor that exacerbates the impact of epidemics in urban areas, particularly within the framework of One Health, which recognizes the interconnected health of humans, animals, and the environment. Several aspects of inadequate health infrastructure contribute to the vulnerability of urban populations to infectious diseases.

- **Limited Healthcare Facilities**: Rapid urbanization often outpaces the development of healthcare facilities, resulting in insufficient hospitals, clinics, and healthcare centers to meet the needs of growing urban populations. This limitation becomes particularly problematic during epidemics, when the demand for medical services surges. For instance, during the COVID-19 pandemic, many cities worldwide faced critical shortages of hospital beds, ventilators, and intensive care units, which hampered the ability to provide adequate care to patients (Ranney et al., 2020; Emanuel et al., 2020).
- **Insufficient Healthcare Workforce**: Urban areas, especially in low- and middle-income countries, frequently suffer from a shortage of healthcare professionals, including doctors, nurses, and public health workers. This shortage can lead to inadequate disease surveillance, delayed diagnosis, and suboptimal patient care. For example, the Ebola outbreak in West Africa highlighted the severe consequences of an overwhelmed and understaffed healthcare system, which struggled to contain the virus and treat infected individuals (Kilmarx et al., 2014; Evans et al., 2015).
- **Lack of Essential Medical Supplies and Equipment**: Inadequate health infrastructure often includes a lack of essential medical supplies and equipment, such as diagnostic tools, medications, and personal protective equipment (PPE). During epidemics, the scarcity of these supplies can significantly hinder disease control and treatment efforts. For instance, the scarcity of PPE and testing kits during the early stages of the COVID-19 pandemic

impeded efforts to curb the spread of the virus and protect healthcare workers (Lai et al., 2020; Cohen & Rodgers, 2020).

- **Poor Disease Surveillance Systems**: Effective disease surveillance is crucial for early detection and response to infectious disease outbreaks. Inadequate health infrastructure often includes poorly developed or non-existent disease surveillance systems, leading to delayed recognition of outbreaks and slower public health responses. This delay can allow diseases to spread more widely before interventions are implemented. The Zika virus outbreak in Brazil, for example, was exacerbated by delayed detection and reporting, which hampered timely public health measures (Heukelbach et al., 2016; Bogoch et al., 2016).
- **Inequitable Access to Healthcare**: In many urban areas, access to healthcare is inequitable, with marginalized communities often facing significant barriers to medical services. These barriers can include financial constraints, lack of transportation, and discrimination within the healthcare system. Inequitable access to healthcare exacerbates the impact of epidemics on vulnerable populations, who may be less able to seek timely and adequate care. The disproportionate impact of COVID-19 on racial and ethnic minorities in the United States highlights the consequences of inequitable healthcare access (Adhikari et al., 2020; Chowkwanyun & Reed, 2020).
- **Fragmented Health Systems**: Inadequate health infrastructure often results in fragmented health systems, where different components of the healthcare system do not effectively coordinate with one another. This fragmentation can lead to gaps in service delivery, inefficient use of resources, and suboptimal patient outcomes. During the H1N1 influenza pandemic, for example, the lack of coordination between public health and healthcare providers in some countries led to challenges in vaccine distribution and delivery (Balicer et al., 2010; Fowlkes et al., 2011).

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(6) Socioeconomic Inequalities

Socioeconomic inequalities are a critical factor that exacerbates the spread and impact of epidemics in urban areas, particularly within the One Health framework. These inequalities manifest in various ways, affecting access to resources, healthcare, and overall health outcomes.

- **Limited Access to Healthcare**: Individuals in lower socioeconomic strata often have limited access to healthcare services due to financial constraints, lack of insurance, and geographical barriers. This limited access means that diseases may go undiagnosed and untreated, leading to higher transmission rates and worse health outcomes. For instance, during the COVID-19 pandemic, people with lower incomes were less likely to access testing and treatment services promptly, contributing to higher morbidity and mortality rates in these populations (Patel et al., 2020).
- **Substandard Living Conditions**: Socioeconomic inequalities often force individuals to live in overcrowded and substandard housing conditions, which can facilitate the rapid spread of infectious diseases. Overcrowded living spaces make social distancing difficult, if not impossible and poor ventilation and sanitation can contribute to the transmission of airborne and waterborne diseases. Studies have shown that tuberculosis, for example, is more prevalent in densely populated urban slums where living conditions are poor (Lönnroth et al., 2009).
- **Food Insecurity and Malnutrition**: Socioeconomic disparities often lead to food insecurity and malnutrition, weakening individuals' immune systems and making them more susceptible to infections. Malnourished individuals are less able to mount an effective immune response to pathogens, increasing their risk of severe illness

and death. The association between malnutrition and increased susceptibility to infectious diseases like measles and diarrheal diseases is well-documented (Pelletier et al., 1995).

- **Employment in High-Risk Occupations**: People from lower socioeconomic backgrounds are more likely to work in high-risk occupations that expose them to infectious agents. Jobs in healthcare, sanitation, and public transport, for example, involve close contact with potentially infected individuals. During the COVID-19 pandemic, essential workers, many of whom are from lower socioeconomic groups, faced higher risks of contracting the virus due to their inability to work from home and their increased exposure to the public (Chen et al., 2020).
- **Barriers to Health Education and Information**: Socioeconomic inequalities can limit access to health education and information, resulting in lower health literacy among disadvantaged populations. This lack of health literacy can hinder individuals' understanding of disease prevention and management strategies, reducing the effectiveness of public health interventions. During the H1N1 influenza pandemic, lower health literacy was associated with reduced uptake of vaccination and other preventive measures (Bish et al., 2011).
- **Psychosocial Stress and Mental Health**: Chronic stress associated with socioeconomic deprivation can negatively impact mental health, leading to conditions such as anxiety and depression. These mental health conditions can weaken the immune system and reduce individuals' ability to engage in health-promoting behaviours. The link between socioeconomic stress and adverse health outcomes has been observed in various infectious disease contexts, including HIV/AIDS and COVID-19 (Cohen et al., 2007; Holmes et al., 2020).

AMR the Silent Pandemic

Antimicrobial agents such as antibiotics are used to treat some human and animal infectious diseases and also used in plant production. Anti-microbial resistance occurs when the microorganism changes and thus the antimicrobial agents no longer respond to the infection that was used to do. Various types of antimicrobials are available to treat various type of infections such as antibiotics are used against bacterial infections, antivirals are used against viral infection and so the antifungals. The AMR accelerates due to improper use of the antimicrobial agents such as use of antibiotic to treat viral fever, flu, or as a growth promoter in the livestock sector.

As the resistance is growing rapidly the world is running out of antimicrobials to treat the infectious diseases. Unless there is a proper judicial use of antimicrobials in various field of One Health approach. The One Health approach is essential in combating antimicrobial resistance (AMR): as resistant organisms can swiftly circulate across healthcare systems, animals, food sources, and environmental elements like soil and water. This widespread transmission makes treating certain infections in humans and animals more difficult and heightens the risk of disease spread, severe health complications, and mortality. The One Health approach is vital for addressing AMR, as it brings together diverse sectors, disciplines, and communities across different levels of society to collaboratively pursue a shared objective. (World Health Organization Regional Office for Europe, 2024).

The increased usage of antimicrobials in livestock farming enabled the global meat protein availability. But this costs AMR and produces the multi drug resistant organisms (MDROs) which affects the human as well as animal health and environmental ecosystems. Globally, antimicrobial usage was estimated at 99,502 tons (95% CI 68,535-198,052) in 2020 and is projected, based on current trends, to increase by 8.0% to 107,472 tons (95% CI: 75,927-202,661) by 2030. (Mulchandani, Wang, Gilbert, & Van Boeckel, 2023).

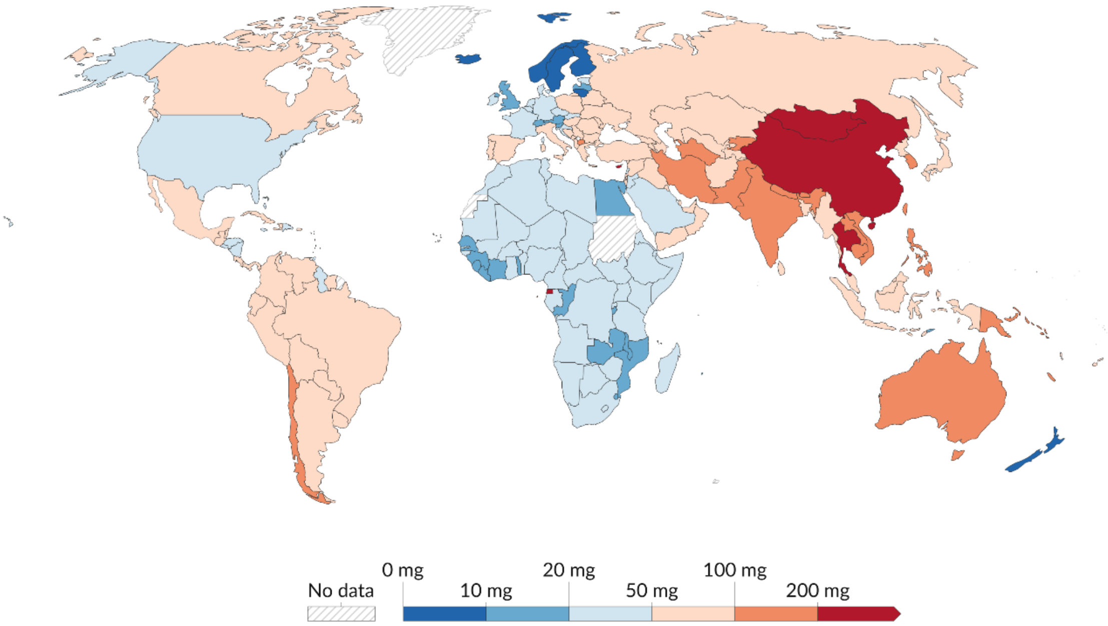

Fig: Antibiotic usage in livestock per kilogram of meat, 2020 [Mulchandani et al. (2023)].

The antimicrobials used in the livestock can be classified into the following reasons:

1. Therapeutic reasons: to treat the infections of animals.
2. Prophylactic reasons: to prevent any infection to come or treatment of at-risk population.
3. Metaphylactic reasons: when one animal is infected to certain infection, mass treatment is provided to whole group at high risk of infection.
4. Non therapeutic reasons: usage of antimicrobial agents other than treating infections, i.e. to enhance increased food intake and as growth promoter solely for economic reasons. (McEwen & Collignon, 2018).

World Health Organization (WHO) and world Organization for Animal Health (OIE) Classification of Important Antimicrobial Classes for Human and Animal Health.

1. Critically Important

Human Health (WHO): Aminoglycosides, Ansamycins, Carbapenems, 3rd/4th Gen Cephalosporins, Phosphonic acid derivatives, Glycopeptides, Glycylcyclines, Lipopeptides, Macrolides and Ketolides, Monobactams, Oxazolidinones, Penicillins, Polymyxins, Quinolones, Anti-tuberculosis drugs.

Animal Health (OIE): Aminoglycosides, Amphenicols, 3rd/4th Gen Cephalosporins, Macrolides, Penicillins (various types): Fluoroquinolones, Sulfonamides, Diaminopyrimidines, Tetracyclines.

2. Highly Important

Human Health (WHO): Amidinopenicillins, Amphenicols, 1st/2nd Gen Cephalosporins and Cephamycins, Lincosamides, Anti-staph Penicillins, Pleuromutilins, Pseudomonic acids, Riminofenazines, Steroid antibacterials, Streptogramins, Sulfonamides, Tetracyclines.

Animal Health (OIE): Rifamycins, 1st/2nd Gen Cephalosporins, Ionophores, Lincosamides, Phosphonic acid, Pleuromutilins, Polymyxins, 1st Gen Quinolones.

3. Important

Human Health (WHO): Aminocyclitols, Cyclic polypeptides, Nitrofurantoin, Nitroimidazoles.

Animal Health (OIE): Aminocoumarin, Arsenical, Bicyclomycin, Fusidic acid, Orthosomycins, Quinoxalines, Streptogramins, Thiostrepton. (World Health Organization Advisory Group on Integrated Surveillance of Antimicrobial Resistance, 2016 and World Organization for Animal Health, 2015).

Mechanism of drug resistance

Around the world, several kinds of antibiotic resistance genes (ARGs) are commonly found in livestock manure due to the extensive use of antibiotics in animal husbandry. Since ARGs are not entirely eliminated by traditional methods of treating cattle feces, they are released into soil and aquatic ecosystems. The increase in resistant clinical infections that are become harder to treat with antibiotics may be caused by a variety of exposure pathways for these ARGs to humans, such as ingestion and inhalation of antibiotic-resistant bacteria (ARB) that contain them. (He et al., 2020) ARGs can confer resistance to nine major classes of antibiotics, including tetracyclines (tet): sulfonamides (sul): β-lactams (bla): macrolide-lincosamid-streptogramin B (MLSB) (erm): aminoglycosides (aac): FCA (fluoroquinolone, quinolone, florfenicol, chloramphenicol, and amphenicol) (fca): colistin (mcr): vancomycin (van): and multidrug (mdr) through three fundamental resistance mechanisms (antibiotic deactivation, extrusion through efflux pumps and protection of targets—such as ribosomes—by specific proteins). The ARBs transfer the resistant genes by plasmid through conjugation and other methods of horizontal gene transfer. *Tet, sul, erm, fca, and bla* are the ARG classes that are most commonly found in cattle manure. (Huang et al., 2019, Qian et al., 2018).

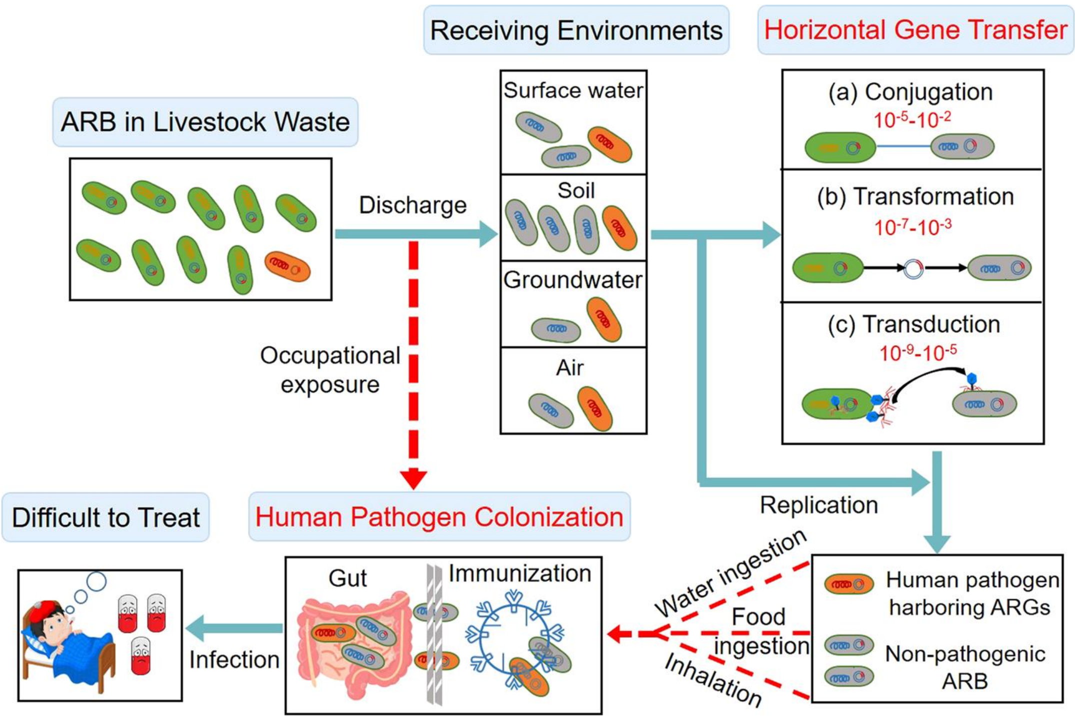

Fig: Various routes by which ARGs spread from animal manure to human infections.

Livestock farms release bacteria that contain ARGs into a variety of receiving environments through drainage, treated wastewater, and solid waste. According to the literature, there are three primary ways that Horizontal Gene Transfer (HGT) can happen between native bacteria and antibiotic-resistant bacteria (ARB): conjugation, transformation, and transduction. It is possible for certain opportunistic viruses that include ARGs to be released straight into habitats that receive them. (He et al., 2020)

Islam et al. (2019) found a high prevalence of the colistin-resistance gene mcr-1, especially in poultry-chicken isolates compared to native chickens. The author raises public health concerns as colistin is often a last-resort antibiotic. Ghafur et al. (2019) investigated colistin resistance in *Escherichia coli* and *Klebsiella pneumoniae* from Indian food samples. Out of 100 samples, 51 tested positive for colistin-resistant Gram-negative bacteria. The study identified chromosomal mutations, particularly in mgrB genes, contributing to colistin resistance, emphasizing the role of food in antimicrobial resistance transmission. Sobur et al. (2019) reported the presence of colistin-resistant *Escherichia coli* in poultry, house flies, and pond water in Mymensingh, Bangladesh. The authors highlighted the potential environmental spread of colistin resistance, with implications for both animal and human health.

The fresh vegetables often thought to be good for health, surprisingly Kläui et al. (2024) demonstrated 95% of the fresh produce associated with ARGs serving as the reservoir of MDROs and ARGs. The authors found *sul1* and *intl1* genes which indicates the presence of AMR in fresh produce. The resistance confers is due to the presence of plasmidome of the fresh produce.

Food Safety and Security

Food safety and security are fundamental components of public health and socio-economic stability. Food safety ensures that the food we consume is free from contaminants and safe for consumption, while food security guarantees that all people have access to sufficient, safe, and nutritious food to maintain a healthy life. These two concepts are interconnected and critical in addressing global health challenges (García-Díez J et al., 2021).

Food Safety: Ensuring Safe Consumption

Food safety refers to the handling, preparation, and storage of food in ways that prevent foodborne illnesses. This includes practices that avoid contamination by harmful bacteria, viruses, parasites, or chemical substances (Kamboj et al., 2020). Key components of food safety include:

(1) Hazard Analysis and Critical Control Points (HACCP): HACCP is a systematic preventive approach to food safety that identifies potential hazards and implements controls at critical points in the production process. It focuses on preventing hazards rather than detecting them after they occur (U.S. Food and Drug Administration., 2022).

(2) Foodborne Illnesses: Foodborne illnesses are a significant public health concern. Common pathogens such as Salmonella, E. coli, and Listeria can cause severe illness and even death. Effective food safety measures are essential to prevent outbreaks and protect public health (Bintsis T. et al., 2017).

(3) Regulations and Standards: Governments and international organizations have established food safety regulations and standards to protect consumers. The Food and Drug Administration (FDA): European Food Safety Authority (EFSA): and World Health Organization (WHO) play key roles in setting and enforcing these standards.

Food Security: Ensuring Adequate Access

Food security encompasses the availability, access, utilization, and stability of food supplies. It ensures that individuals have physical and economic access to sufficient, safe, and nutritious food (Peng et al., 2018). The four pillars of food security are:

(1) **Availability:** Availability refers to the presence of adequate food supplies through production, distribution, and exchange. It involves sustainable agricultural practices, effective supply chains, and resilient food systems (Bowdren et al., 2019).

(2) **Access:** Access to food involves economic and physical access to food supplies. It is influenced by factors such as income, food prices, and infrastructure. Social protection programs and policies can enhance access for vulnerable populations.

(3) **Utilization:** Utilization refers to the proper biological use of food, ensuring that individuals have the necessary knowledge and resources for a nutritious diet. It includes food safety, dietary diversity, and access to clean water and sanitation.

(4) **Stability:** Stability involves the consistency of food availability, access, and utilization over time. It addresses the impact of economic, environmental, and social shocks on food security, emphasizing the need for resilient food systems (Food and Agriculture Organization of the United Nations., 2006).

Challenges to Food Safety and Security

Despite advancements, several challenges threaten global food safety and security:

(1) **Climate Change:** Climate change impacts food production and distribution, leading to reduced crop yields, altered food quality, and increased vulnerability to foodborne illnesses. Sustainable agricultural practices and climate-resilient crops are essential to mitigate these effects (Tuomisto HL., 2017).

(2) **Population Growth:** The global population is expected to reach 9.7 billion by 2050, increasing the demand for food. Ensuring food security for a growing population requires innovative approaches in food production, distribution, and consumption (Food and Agriculture Organization of the United Nations., 2009).

(3) **Urbanization:** Urbanization affects food systems by increasing the distance between food production and consumption areas. It requires efficient supply chains and infrastructure to ensure that urban populations have access to safe and nutritious food (Bricas & Nicolas., 2019).

(4) **Antimicrobial Resistance (AMR):** The use of antibiotics in agriculture contributes to antimicrobial resistance, posing a significant threat to food safety. Reducing the use of antibiotics and implementing alternative practices are crucial in combating AMR (Manyi-Loh C et al., 2018).

Bad Environment Leads to Infectious Diseases

The relationship between environmental quality and the prevalence of infectious diseases is increasingly recognized as a critical public health issue. The degradation of environmental conditions, including air pollution, chemical contamination, and the presence of hazardous substances, has been linked to a rise in infectious diseases (Siddiqua A et al., 2022). This article reviews the impact of environmental factors on infectious disease prevalence, with a focus on recent epidemiological evidence and studies.

Environmental Chemicals and Risk of Infectious Disease in Children: Children and fetuses are particularly vulnerable to environmental pollutants, which contribute significantly to mortality and disease burden. Exposure to chemicals like persistent organic pollutants, heavy metals, and pesticides has been shown to impair immune function and increase susceptibility to infections. This concept of total exposure, or "exposome," includes all environmental and lifestyle factors influencing health outcomes (Mastorci F et al., 2021; UNICEF).

For example, per- and polyfluoroalkyl substances (PFAS) are widely found in the environment and linked to adverse health effects such as altered immune function and increased infection rates. Studies show that PFAS exposure can lead to febrile infections, respiratory tract infections, and impaired vaccine responsiveness in children (Fenton SE et al., 2021).

Air Pollution and COVID-19: Air pollution has been strongly associated with the severity and mortality of COVID-19. Long-term exposure to pollutants like particulate matter (PM10, PM2.5) and nitrogen dioxide (NO_2) is linked to increased COVID-19 cases and deaths. Studies suggest that chronic exposure to poor air quality exacerbates the impact of the virus, possibly through mechanisms involving oxidative stress and inflammation (Semczuk-Kaczmarek K et al., 2022).

For instance, a study in Italy showed a correlation between high levels of particulate matter and increased COVID-19 mortality rates (Dettori M et al., 2021). Similarly, in the UK, higher NO_2 levels were associated with a significant rise in COVID-19 cases and deaths (Travaglio M et al., 2021). These findings highlight the urgent need to address air pollution to mitigate the health impacts of pandemics.

Oxidative Stress and Respiratory Disease: Oxidative stress plays a crucial role in mediating the harmful effects of air pollution on respiratory health. Pollutants induce oxidative damage in the lungs, leading to increased susceptibility to respiratory infections and chronic diseases (Sierra-Vargas MP et al., 2023). Children exposed to high levels of traffic-related air pollution exhibit biomarkers of oxidative damage, which are linked to respiratory issues and reduced lung function growth (Zhang AL et al., 2022).

The Lancet Commission report on Pollution and Health emphasizes that pollution contributes to significant global mortality and morbidity. Long-term exposure to air pollutants is associated with higher risks of diseases like tuberculosis, potentially due to local lung damage that facilitates infection.

Strategies For One Health Implementation

Management of Risks: Effective risk management in the One Health framework necessitates a holistic, multi-disciplinary approach that encompasses human, animal, and environmental health. By identifying, evaluating, and mitigating risks, One Health seeks to tackle complex health challenges at their core.

(1) Comprehensive Risk Assessment

A fundamental aspect of risk management in One Health is conducting thorough risk assessments to identify potential threats across human, animal, and environmental health domains. This process involves gathering comprehensive data through epidemiological surveys, environmental monitoring, and socio-economic studies. Risks are evaluated based on their probability, impact, and potential for spread. Utilizing tools such as quantitative risk assessment models and scenario analysis helps predict outcomes and plan for various risk scenarios, enhancing preparedness and response strategies (Jones et al., 2008).

(2) Strengthening Public Health Infrastructure

Investing in public health infrastructure, including laboratories, diagnostic facilities, and healthcare personnel, is necessary to support effective risk management. Training healthcare workers in One Health principles and practices ensures they are equipped to handle complex health challenges. Adequate resource allocation for rapid outbreak response, including emergency funding, supplies, and personnel, is also critical. Establishing stockpiles of essential medicines, vaccines, and protective equipment ensures preparedness for health emergencies (Lee & Brumme, 2013).

(3) Integrated Surveillance Systems

Developing integrated surveillance systems that monitor disease trends in humans, animals, and the environment is crucial for early detection and effective response. Advanced technologies such as GIS mapping, remote sensing, and big data analytics enhance detection capabilities and response times. Intersectoral collaboration is essential to ensure timely data sharing and coordinated responses. Establishing standardized protocols for data collection and reporting facilitates integration and comparability of data across disciplines (Gebreyes et al., 2014).

(4) Effective Risk Communication

Clear and transparent communication of risks to all stakeholders, including the public, policymakers, and health professionals, is vital. Utilizing multiple communication channels, such as media, public announcements, and community meetings, ensures widespread dissemination of critical information. Building trust involves involving communities in the communication process and addressing their concerns openly and promptly. Providing regular updates and accurate information prevents misinformation and panic, fostering a collaborative environment for risk management (Covello & Sandman, 2001).

(5) Proactive Risk Mitigation

Implementing preventive measures such as vaccination programs, biosecurity protocols, and environmental management practices is essential to reduce risks. Promoting behaviours that minimize risk, including hand hygiene, safe animal handling practices, and responsible use of antibiotics, further mitigates potential threats. Continuous evaluation and adaptation of risk mitigation strategies based on new data and changing conditions ensure a resilient and responsive risk management system. Developing flexible plans that can be adjusted quickly in response to emerging threats is also crucial (Cleaveland et al., 2017).

(6) Fostering Community Engagement

Engaging communities in risk management processes by involving them in decision-making and intervention implementation is essential. Educating communities about the importance of One Health and their role in risk prevention fosters a sense of ownership and responsibility. Empowering communities to take proactive measures to safeguard their health and environment supports the effectiveness of risk management strategies. Community-based monitoring programs and local health initiatives ensure that communities are active participants in managing risks (Rabinowitz et al., 2013).

(7) Policy and Legislative Support

Developing and enforcing policies that promote One Health frameworks and ensure cross-sectoral coordination is vital for effective risk management. Advocating for international collaboration and policy alignment enhances global health security and addresses transboundary health threats. Establishing legal frameworks that support One Health initiatives and provide clear guidelines for risk management activities is also necessary. Ensuring policies are flexible and can be updated in response to new scientific evidence and emerging threats maintains the relevance and effectiveness of risk management strategies (Mackenzie et al., 2013).

Strategies for Enhancing Food Safety and Security: Addressing food safety and security challenges requires a multifaceted approach involving various stakeholders. Key strategies include:

(1) Policy and Governance: Governments must establish and enforce robust food safety regulations and food security policies. International cooperation and alignment of standards are crucial for effective governance.

(2) Technology and Innovation: Advancements in technology, such as precision agriculture, biotechnology, and digital platforms, can enhance food production, safety, and distribution. Innovations in food processing and packaging also play a vital role in extending shelf life and reducing waste.

(3) Education and Awareness: Raising awareness about food safety practices and nutrition is essential for consumers and producers. Education programs can empower individuals to make informed decisions and adopt safe food handling practices.

(4) Sustainable Practices: Promoting sustainable agricultural practices, such as crop rotation, organic farming, and agroforestry, can improve food security and reduce environmental impact. Sustainable fisheries and aquaculture are also critical for maintaining fish stocks and marine ecosystems.

Water Sanitation and Hand Hygiene: Water, sanitation, and hygiene (WASH) are critical components in preventing the spread of infectious diseases and ensuring overall public health. Key strategies include:

(1) Access to Clean Water:

(a) Ensuring that all communities have access to safe and clean drinking water.

(b) Investing in infrastructure to improve water supply systems.

(2) Sanitation Facilities:

(a) Building and maintaining proper sanitation facilities, especially in underserved areas.

(b) Promoting the use of toilets and other sanitation measures to reduce open defecation.

(3) Hand Hygiene:

(a) Encouraging regular handwashing with soap and clean water.

(b) Installing handwashing stations in public places, schools, and healthcare facilities.

(4) Public Education:

(a) Educating the public on the importance of hygiene practices.

(b) Conducting campaigns to promote regular handwashing and proper sanitation habits.

(5) Monitoring and Evaluation:

(a) Regularly monitoring water quality and sanitation facilities.

(b) Evaluating the effectiveness of WASH interventions to ensure they meet public health goals.

Implementing these strategies can significantly reduce the burden of diseases and promote healthier communities within the One Health framework.

CONCLUSION

The "One Health" approach recognizes the intrinsic interconnectedness of human, animal, and environmental health, advocating for a collaborative, cross-sector strategy to achieve optimal health outcomes. By addressing essential needs such as clean water, air, electricity, and safe food, while also combating climate change and promoting sustainable development, One Health presents a holistic framework for tackling contemporary health challenges. The concept's evolution can be traced back to the 19th century when Rudolf Virchow first identified the link between human and animal health. Today, the term "One Health" has gained international recognition, with numerous organizations and countries adopting this approach to mitigate zoonotic diseases, antimicrobial resistance, and enhance global health security.

Urbanization is identified as a significant contributor to the emergence of epidemics. Factors such as increased human-animal interactions, encroachment on wildlife habitats, urban livestock farming, and pet ownership facilitate the spill over of pathogens. Urban areas also pose challenges related to vector-borne diseases, with conditions favouring the proliferation of vectors like mosquitoes and high population densities accelerating disease spread. Additionally, high population density exacerbates the transmission of infectious diseases and overburdens healthcare systems. Inadequate health infrastructure, characterized by limited healthcare facilities, insufficient workforce, and a lack of essential medical supplies, further impedes effective epidemic response.

Socioeconomic inequalities compound these issues, disproportionately affecting marginalized communities with limited access to healthcare, substandard living conditions, food insecurity, and high-risk occupations. The non-therapeutic use of antibiotics in agriculture emerges as a major contributor to antimicrobial resistance, posing a critical global health threat.

Food safety and security are underscored as pivotal for public health and socio-economic stability. Ensuring food safety involves implementing Hazard Analysis and Critical Control Points (HACCP) systems and preventing foodborne illnesses. Food security encompasses the availability, access, utilization, and stability of food supplies. However, global challenges such as climate change, population growth, urbanization, and antimicrobial resistance threaten these objectives.

Environmental degradation is linked to the prevalence of infectious diseases, with air pollution and exposure to environmental chemicals notably impacting children's health. Implementing the One Health approach necessitates strategies focused on policy and governance, technology and innovation, education and awareness, and sustainable practices. Enhancing food safety and security, improving water sanitation and hand hygiene, and conducting public education campaigns are essential for fostering healthier communities within the One Health framework.

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