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Developing a one health approach by using a multi-dimensional matrix

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ABSTRACT

The One Health concept that human, animal, plant, environmental, and ecosystem health are linked provides a framework for examining and addressing complex health challenges. This framework can be represented as a multi-dimensional matrix that can be used as a tool to identify upstream drivers of disease potential in a concise, systematic, and comprehensive way. The matrix can involve up to four dimensions depending on users' needs. This paper describes and illustrates how the matrix tool might be used to facilitate systems thinking, enabling the development of effective and equitable public policies. The multidimensional One Health matrix tool will be used to examine, as an example, global human and animal fecal wastes. The fecal wastes are analyzed at the microbial and population levels over a timeframe of years. Political, social, and economic factors are part of the matrix and will be examined as well. The One Health matrix tool illustrates how foodborne illnesses, food insecurity, antimicrobial resistance, and climate change are inter-related. Understanding these inter-relationships is essential to develop the public policies needed to achieve many of the United Nations' Sustainable Development Goals.

One Health is the concept that human, animal, plant, environmental and ecosystem health are linked [1]. It has been recognized as an important strategy for examining and addressing complex global health issues [2]. Zoonotic diseases, antimicrobial resistance, foodborne illnesses, food insecurity, and climate change are generally treated as separate problems. But from a One Health perspective, they are interrelated. Identifying and understanding these inter-relationships are essential for achieving many of the United Nation's Sustainable Development Goals [3].

The importance of a One Health approach has been recognized. For example, the US Agency for International Development (USAID) employs a One Health approach integrating health, agriculture, environment, trade, and finance to advance global health security. USAID identified five dimensions that are essential to establish on-the-ground multisectoral coordination needed to implement One Health policies. The most important dimension is political commitment. One Health champions are critical to convince policymakers to support the implementation of One Health policies. The four other dimensions are management and coordination capacities, joint planning and implementation, technical and financial resources, and adequate institutional structures [4].

This paper develops a framework that can be used to develop One Health policies by facilitating systems perspectives rather than limited linear thinking. Developing effective, strategic public policies that mitigate, or ideally, prevent health threats requires using data based on sound science to identify upstream drivers of disease potential [5]. The One Health framework can be represented as a multi-dimensional matrix which provides users with a tool to research, analyze, and address complex health threats in a concise, systematic, and comprehensive way. The matrix can involve up to four dimensions depending on the users' needs and will be briefly described below before illustrating how it might be used.

1. First dimension

The first dimension represents the essential One Health factors: humans, animals, plants, environments, and ecosystems. Humans can be stratified by age, gender, or other relevant characteristics such as health or disease status. Animals and plants can be either wild, domestic, or both. Environments cover the abiotic (e.g. soil, water, air, chemicals) aspects of defined geographic areas. Ecosystems involve the biotic (e.g. microbial, flora, fauna) interactions within defined geographic areas. Environments and ecosystems can be indoors, inside buildings and structures, or outdoors in urban, suburban, rural, or undeveloped, natural settings.

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2. Second dimension

The second dimensions' factors are divided into different levels of complexity: microbial, individual, and population [6]. The second dimension's levels of complexity should intersect with the first dimension's One Health factors creating a two-dimensional matrix. (Please see Fig. 1) For example, humans, animals, plants, environments, and ecosystems could be studied at any or all microbial, individual, and/or population levels. Microbial levels could include normal microbial flora, invading pathogens, or both. At the individual level, a single human, animal, plant, environment and/or ecosystem could be examined regarding specific questions relevant for an individual's health. Population levels of humans and animals could be examined using standard epidemiologic methodologies; while population levels of domestic and wild plants and trees could be studied as agricultural fields, urban and suburban parks, wild grasslands, savannas, marshes, forests, and other flora groupings. Environments and ecosystems at population levels could examine abiotic contaminants and biotic interactions, respectively, in defined geographic areas.

3. Third dimension

The third dimension involves political, social, and economic factors which could be examined within political boundaries: local/regional, national, and international/global levels. Political factors could include government infrastructures, laws and regulations, relevant public policies and funding. Social factors could include cultural, religious, and educational factors. Negative social factors could include corruption, prejudice, bigotry, racism, anti-Semitism, misogyny, xenophobia and other factors adversely affecting diversity, equity, inclusion, justice, and health. Economic factors could include corporate interests and income, employment rates, poverty rates, health care access and availability rates.

The third dimension intersects with the first two dimensions forming a three-dimensional matrix, or a cube. (Please see Fig. 2) Specifically, the five One Health factors intersect with the Complexity factors. Both of these dimensions intersect with the Political, Social, and Economic (PSE) factors within the specified political boundaries.

4. Fourth dimension

The fourth dimension involves time such as days, months, years, decades, or centuries. In most cases, time would involve months or years. For long-term analyses, five-year or ten-year periods might be preferable. Time periods involving climate change might include decades, centuries or even eras, such as the Holocene or Anthropocene eras, if using geologic timeframes. Visualizing all four dimensions is possible, involving changing the three- dimensional cube over time, but will not be done in this paper.

5. Using the one health matrix

Ideally, developing One Health policies involves collaborating individuals, contributing their areas of expertise when using the multidimensional matrix. In this paper, for brevity, the five One Health factors will intersect with the microbial and population Complexity factors at the international/global level of political boundaries. The timeframe will be in years.

In essence, this One Health matrix analysis will be a satellite perspective of the global human and domesticated terrestrial food animal populations microbial impacts on the planet's plants, environments and ecosystems. Political, social, and economic factors will be briefly reviewed focusing on global animal protein demand and livestock production. The global impacts on agriculture, food safety and security, antimicrobial resistance, and climate change will be discussed.

One Health & Complexity Factors	Microbial	Individual	Population
Humans			
Animals			
Plants			
Environments			
Ecosystems			

Fig. 1. Two-Dimensional One Health Matrix.

6. Humans and domesticated food animals/populations and microbes

According to the U.S. Census Bureau, as of 2021, the world's population has grown to over 7.7 billion people [7]. As the global human population approaches 8 billion, domesticated livestock have surpassed 30 billion animals. The UN Food and Agriculture Organization's FAOSTAT database shows that in 2019 the global domesticated animal population was approximately 33.3 billion animals, excluding companion animals such as dogs and cats [8]. Ruminants (i.e. buffaloes, cattle, goats, and sheep), chickens, and pigs make up approximately 93% of the livestock. Demand for animal proteins is increasing, particularly in developing countries, with a projected doubling of livestock production by 2050 [9]. Currently, humans and their domesticated mammalian livestock constitute approximately 96 to 98% of the total global terrestrial mammalian biomass [10].

Collectively, humans and their domesticated animals impact the planet in many ways. This paper will focus on the global impact of human and animal fecal wastes. Berendes et al. (2018) conducted a global-scale accounting of human and livestock fecal matter and estimated that in 2014, the total global fecal mass produced was almost 4 trillion kilograms. Livestock contributed 80% of it. To visualize this, 4 trillion kilograms of fecal matter would cover the entire surface areas of Los Angeles, California and New York City, New York combined under 6 ft (1.83 m) of feces [11]. As human and animal populations grow, fecal waste production will increase by approximately 52 million kilograms each year [12].

Fecal matter has long been recognized as a source of disease. Pathogens in human feces include *Campylobacter* and *Salmonella*, *Norovirus* and *Rotavirus*, helminths, and protozoa such as *Cryptosporidium* and *Giardia* [13]. Animal fecal matter contains many pathogenic bacteria, helminths, protozoa, viruses, and microsporidia. Specific organisms include *Campylobacter*, *E. coli*, *Klebsiella*, *Salmonella*, *Shigella*, *Vibrio*, *Cryptosporidia*, *Giardia*, *Toxoplasma*, *Rotavirus*, *Adenovirus*, and others [14].

Fecal contamination contributes to foodborne and waterborne illnesses causing diarrheal diseases and is particularly problematic for young children. In 2015, almost half a million children younger than five years of age died from diarrheal diseases; they represented 8.6% of the total 1.3 million deaths from diarrheal diseases. The top pathogens causing all diarrheal disease deaths were *Rotavirus*, *Shigella*, and *Salmonella*. In children, the top diarrheal pathogens were *Rotavirus*, *Cryptosporidium*, *Shigella*, and *Adenovirus* [15]. Some of these pathogens are present in both human and animal feces, others such as *Shigella* are present primarily in animal feces. *Shigella* has been recognized as a major contributor of global diarrheal diseases, contributing around 160,000 deaths annually, a third of which are associated with young children [16]. Whole genome sequencing surveillance of microbes such as *Shigella* provides important information regarding the epidemiology of foodborne illnesses as well as the acquisition of antimicrobial resistance [17]. This technology would assist in identifying the human, animal, and environmental sources of these pathogens which would facilitate improved prevention strategies.

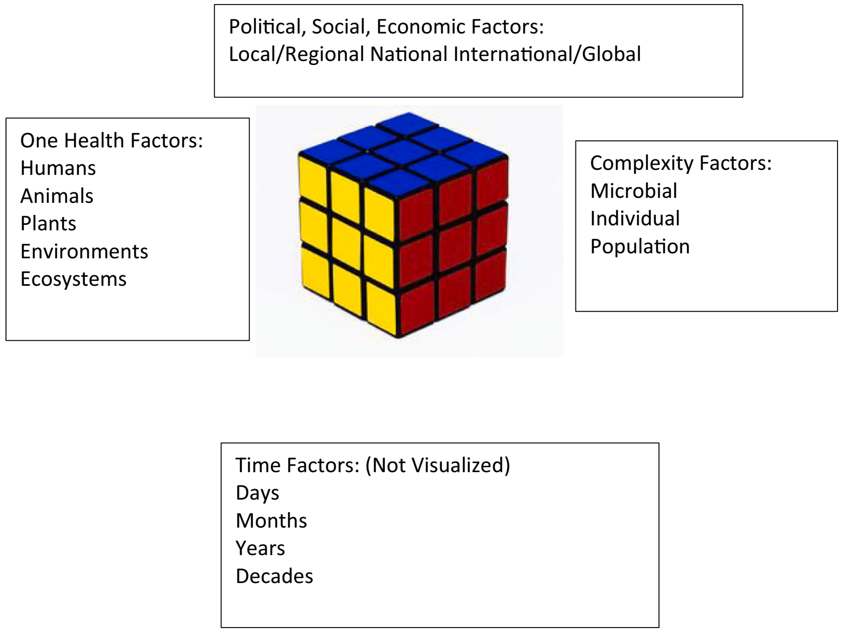

Fig. 2. One Health Multidimensional Matrix Tool.

According to WHO, in 2017, about 2 billion people lack toilets, latrines, and other basic sanitation systems. Over 670 million practice open defecation. The rest of the world's population has access to sanitation services including sewers and wastewater treatment facilities [18]. But sanitation services primarily process human not animal fecal matter [19].

Animal fecal matter, called 'manure,' can serve as fertilizer for crops if properly processed to eliminate harmful pathogens beforehand. Proper manure management generally includes the collection, treatment, storage, and application of livestock urine and fecal waste. In 2014, a global assessment of manure management in developing countries in Central and South America, South and East Asia, and Sub-Saharan Africa found a wide variation in policies, practices, and farmer knowledge about the subject. In contrast to traditional small-scale farmers who raise a few livestock alongside their crops, rapidly growing industrial livestock operations around major urban centers in developing countries produce far more manure than can be used as fertilizer. In general, the report found that manure is poorly stored and handled and often discharged into surrounding lands [20].

The challenges of manure management is not limited to developing countries. In developed countries, Concentrated Animal Feeding Operations (CAFOs) which are defined as agricultural enterprises in which more than 1000 animal units are raised in confined situations, produce millions of tons of manure each year [21]. These wastes may be used as fertilizer on adjacent cropland, or if too much is produced, may contaminate nearby waters and soils and release toxic emissions into the atmosphere. Although environmental regulations such as 'The Clean Water Act' are meant to reduce environmental contamination, the assumption that government agencies collect reliable manure contamination data on CAFOs should not be made [22].

7. Domesticated plants (Crops)/populations

Of the approximately 50,000 edible plants in the world, three provide 60% of the world's food energy intake: rice, maize, and wheat [23]. The 'Green Revolution' in the 1960s focused on boosting production of these three crops which are fundamental to global food security. The development of high-yielding, semi-dwarf wheat and rice along with the application of synthetic fertilizers dramatically increased global annual production and yields [24]. From 1961 to 2019, global production and yields increased over 80% for maize and increased over 70% for both rice and wheat [25]. For developing countries the gains were dramatic: 208% increase for wheat, 157% for maize, and 109% for rice [26]. The Green Revolution reduced poverty and averted hunger for millions of people in developing countries, but it came with costs including a reliance on pesticides and synthetic fertilizers [27].

Crops need three primary nutrients (i.e. nitrogen, phosphorus, and potassium) as well as secondary and micronutrients to grow and thrive. Primary nutrients are typically provided by the use of organic (i.e. manure, sewage sludge) or inorganic (synthetic) fertilizers [28]. In 1961, more than 1.5 times animal manure was applied to agricultural fields globally than synthetic fertilizer. In 2018, the rates were reversed: almost 2 times more synthetic fertilizers were applied to the world's agricultural fields than animal manure [29]. Long-term use of manure appears to improve soil quality better than inorganic fertilizer [30].

8. Environments and ecosystems/populations and microbes

While manure is important for crop and soil health, too much of it contaminates environments. Manure deposited on pastures, used as fertilizer on agricultural soils, and management practices are major sources of global nitrous oxide. According to the Intergovernmental Panel on Climate Change (IPCC), agriculture contributes almost a quarter of total global anthropogenic greenhouse gas emissions and over 50% of methane and nitrous oxide emissions [31]. Methane and nitrous oxide are far more potent than carbon dioxide at trapping heat; their greenhouse gas potentials (GWP) are estimated to be between 28 and 36 and 265–298 over 100-year timeframes each, respectively. By comparison, carbon dioxide has a GWP of 1 but lasts in the atmosphere for thousands of years [32]. Besides manure, microbes in the rumens of ruminants also contribute potent greenhouse gasses. Livestock production, particularly enteric fermentation in ruminants, is the largest global source of anthropogenic methane [33].

Manure microbes can disrupt ecosystems. Improperly processed manure can contaminate food, water, and spread antimicrobial resistant genes to soil microbes. Animal manure has been found to be a potential hot spot, a perfect breeding ground, for antimicrobial resistance gene dissemination via horizontal gene transfer mechanisms [34]. Manure microbes mix with soil microbes, altering microbial biomes, and potentially changing the 'Global Resistome,' the total amount of resistance genes in the world's microbial ecosystems [35]. Antimicrobial resistance is ancient, naturally occurring, ubiquitous, and predates the selective pressures of modern antibiotic use [36]. Antimicrobial resistance is unlikely to be controlled as long as trillions of kilograms of manure laden with antibiotic resistant microbes continues to mix with the world's soil microbes.

9. Political, social, and economic factors

Food security is so important that the United Nations listed 'zero hunger' as its second out of seventeen sustainable development goals. Animal proteins contain important micronutrients such as iron and vitamin B12 and serve as essential components of many people's diets. Eating meat is an integral part of many cultural traditions and religions, and raising livestock is a vital source of livelihood and food for millions of people, especially in low- and middle-income countries.

In 2016, almost 130 billion pounds of beef were consumed globally with affluent countries consuming far more beef per capita than low- or middle-income countries [37]. Reducing animal protein consumption on a societal level, particularly in high-meat consuming countries, to benefit public and planetary health would not be simple or straightforward. Even India, which has the largest percentage of vegetarians in the world, is experiencing an increased demand for animal proteins [38,39].

But animals did not evolve to live by the hundreds, thousands, or tens of thousands in packed facilities that produce massive amounts of wastes, particularly manure. Some manure is being used as fertilizer and as a source of renewable energy [40]. Currently, there is no global surveillance system of manure for disease prevention and environmental protection purposes.

10. Discussion

The One Health matrix revealed the interconnected environmental and ecosystem impacts of human and animal fecal wastes and the political, social, and economic challenges of lowering global demand for animal proteins to reduce the negative externalities associated with intensive animal agriculture. For about 2 billion people, basic sanitation systems such as toilets and latrines are lacking around the world. For animal manure management, the situation is worse.

However, there are efforts to improve animal manure management and to convert manure into useful products such as fertilizer through composting which kills pathogens and provide plants with important nutrients such as potassium and phosphorus [41]. Biogas production uses bacteria to break down animal manure and wastewater biosolids through anaerobic digestion in a sealed container called a reactor; the resultant methane, carbon dioxide, and other gases can be used as a natural fuel for electricity, heat, and other uses [42]. Other innovative technologies are being developed to use manure for algae production, mushroom cultivation, building materials, among other things [43].

In September 2016, the United Nations General Assembly agreed that antimicrobial resistance threatened global health and recognized that a One Health approach was essential [44]. The World Health Organization's global antimicrobial resistance framework's third objective to reduce the incidence of infection through effective sanitation, hygiene, and infection control measures makes no mention of the need to address manure's role in disease spread and antimicrobial resistance [45].

In December 2015, almost 200 nations adopted the Paris Agreement to limit global greenhouse gas emissions. But the Paris Agreement makes no mention of agriculture's role in methane and nitrous oxide emissions and does not provide stimulus or guidance to address them. No country has developed policies to reduce them. In the US, California has passed policies, specifically to reduce methane emissions from dairy farms [46].

As Earth's resources diminish and as human and livestock numbers continue to grow, One Health policies will become increasingly important to achieve the United Nation's Sustainable Development goals. This paper demonstrates the use of a multi-dimensional One Health matrix tool in uncovering linkages between foodborne illnesses, antimicrobial resistance, and climate change at the global level. Multi-dimensional One Health matrices help to examine complex health challenges, facilitating the development of effective and equitable public policies.

Author statement

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Declaration of Competing Interest

I have no conflict of interest to declare.

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[11] For volume, assume that fecal matter has the density of water: 3.9 X 1012 kg = 3.9 X 109 meters3. The combined surface areas of NYC + LA = 303 + 503 miles2 = 806 miles2 = 2087 kilometers2 = 2 X 109 meters2. Height = Volume ÷ Surface Area. Therefore, height = 3.9 X 109 meters3 ÷ 2 X 109 meters2 = 1.95 meters = 6 feet. Therefore, fecal matter would cover NYC + LA to the height of 1.95 meters or 6 feet. For NYC alone, height would equal around 16 feet of fecal matter, 2021.

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