

One Health in a Digital World: Technology, Data, Information and Knowledge

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Summary

Objectives: To describe the origins and growth of the One Health concept and its recent application in One Digital Health.

Methods: Bibliometric review and critical discussion of emergent themes derived from co-occurrence of MeSH keywords.

Results: The fundamental interrelationship between human health, animal health and the wider environment has been recognized since ancient times. One Health as a distinct term originated in 2004 and has been a rapidly growing concept of interest in the biomedical literature since 2017. One Digital Health has quickly established itself as a unifying construct that highlights the critical role of technology, data, information and knowledge to facilitate the interdisciplinary collaboration that One Health requires. The principal application domains of One Digital Health to date are in FAIR data integration and analysis, disease surveillance, antimicrobial stewardship and environmental monitoring.

Conclusions: One Health and One Digital Health offer powerful lenses to examine and address crises in our living world. We propose thinking in terms of Learning One Health Systems that can dynamically capture, integrate, analyse and monitor application of data across the biosphere.

Keywords

One health; informatics; health policy; global health; learning health system

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1 Introduction

All living things on planet Earth co-exist in a shared biosphere. Our biological world is a complex web of dependencies, symbioses, food chains and habitats. This common living space is situated in our atmospheric, terrestrial and aquatic environments and includes the transmission of pathogens and parasites from one species to another. So when we consider “health”, we cannot consider the life of one species – *homo sapiens*, so called – in isolation. This is the essential insight of the One Health philosophy.

The fundamental truth that human and animal life share common principles in their physical anatomy, physiology, aetiology and pathology has long been recognised [1]. Aristotle (4th century BC) and Galen (2nd century AD) used animal dissection and experiment to infer knowledge, not always correctly, about human physiology. William Harvey (17th century) also used animal anatomy in his articulation of cardiopulmonary circulation theory. Vivisection became frequent in human medical research. The veterinary schools, started in the 18th century, often also involved physicians and surgeons. More recently, the medically historic figures Rudolf Virchow and William Osler, respectively, are credited with coining the terms ‘zoonosis’ (the origin of human diseases from animal populations) and ‘one medicine’ in the 19th century [2, 3], the latter term being brought to the fore again in the late 20th century through the work of Calvin Schwabe. Whereas ‘one medicine’, as the term implies, was limited to an integrative approach to human and veterinary medicine, the One Health concept also takes into account the broader ecosystem and physical environment.

Modern usage of the term One Health is usually dated to 29 September 2004, when the symposium “One World, One Health: Building Interdisciplinary Bridges to Health in a Globalized World” was held in New York City. Its aim was to declare priorities for “*an international, interdisciplinary approach for combating threats to the health of life on Earth*” [4]. These priorities were articulated in the twelve Manhattan Principles, updated in 2019 to the ten Berlin principles, the first of which calls on the global community to: “*Recognize and take action to retain the essential health links between humans, wildlife, domesticated animals and plants, and all nature; and ensure the conservation and protection of biodiversity which, interwoven with intact and functional ecosystems, provides the critical foundational infrastructure of life, health, and well-being on our planet*” [5].

While there is yet no one universally accepted definition of One Health, the core concept is inter-disciplinary collaboration for the well-being of humans, animals and the surrounding environment. Some sources extend the construct to include related topics such as land use, urbanization, social issues, food security, clean water supply and promoting biodiversity [6, 7]. The succinct definition given for the Medical Subject Headings (MeSH) term One Health is “*An integrative effort of multiple disciplines working collaboratively and locally, nationally, and globally in all aspects of health care for humans, animals, and the environment*” [8].

The scale and complexity of the issues involved in One Health can seem overwhelming. It has been estimated that 60% of existing human infectious diseases and

75% of emerging human infectious diseases originated in animal populations and that global production of animals for human food is reduced by 20% by disease [9]. The global environmental challenges facing humanity, and the multi-national political reluctance to urgently and seriously address climate change as an artefact of human activities, offer a disappointing context in which to promote positive change. The tragic realities of the COVID-19 pandemic came despite the fine words about One Health in various international policy statements about zoonotic diseases in the late 2000s [10]. Clearly, actions to date have been insufficient to realise the policy intent.

The contemporary relevance of One Health for biomedical informatics is evident in the selection of “One World, One Health: Global partnership for digital innovation” as the theme for the virtual MedInfo 2021 conference [11], which was particularly timely given the likely zoonotic origins of the COVID-19 pandemic. The digital responses to the pandemic have highlighted rapid progress in some fields, yet many significant challenges remain

to be resolved, for example in service delivery, data sharing and application of artificial intelligence [12].

The aim of this article is to demonstrate the growth and importance of the One Health field and to emphasize the significant contribution that biomedical and health informatics (BMHI) can make. We first offer a bibliometric review of the increasing attention given to One Health in the biomedical literature, with an analysis of the main topic clusters. We then consider the specific applicability of One Health in the digital world and signpost recent work on “One Digital Health” (ODH) [13].

2 One Health Trends and Topics in the Biomedical Literature

We performed a bibliometric analysis using PubMed, given the biomedical focus. The objective is to provide an overview, not a systematic review. In total, there are more

than 8,000 articles that mention “One Health” between 2012-2022. The search terms are shown in the appendix. Our filtered search on One Health and ODH found 805 relevant full text papers, with the earliest published article from 2015 and more than 66.8% of the studies published between 2020 and 2022. We imported the results into Tableau version 2021.04 [14] for visualisation and VOSviewer [15] and PubReminder [16] to analyse authors, publication types, MeSH, journals and countries. Figure 1 illustrates the increase in published articles on the topic since 2015 (linear trend: $p < 0.001$, $R^2 = 0.93$).

Table 1 shows the rank ordered count of the top ten national affiliations of the (co-) authors, to provide a sense of geographical contribution to One Health and ODH. In total, authors from 100 different countries contributed to this literature. There are 193 member states of the United Nations [17] and two recognised observer states, so this means that just over half of the countries in the world (100/195, 51.3%) have contributed to some publication in this field. Perhaps unsurprisingly, the top ten includes six of the

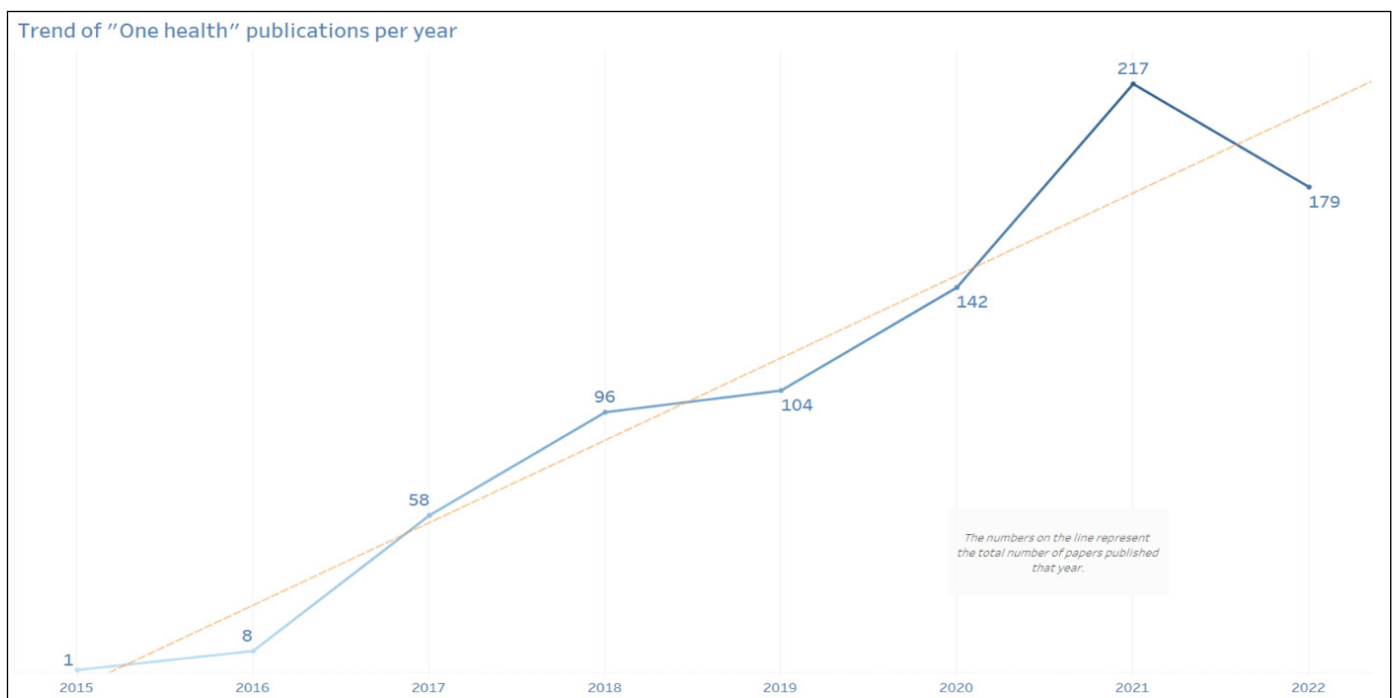


Fig. 1 Number of One Health and ODH related publications per year from 2015 to 2022.

G7 countries (all except Japan) and 8/10 are high income countries by World Bank ratings. These are typically the nations that have the resources and policy interests to fund academic research and publication, and perhaps, at least among their scholarly communities, a recognition of their historical culpability for much of the harm done to the biosphere.

Table 1 Top ten national affiliations of (co-)authors of One Health and ODH related publications.

Country	Number of papers
United States	195
United Kingdom	166
India	69
Australia	66
France	56
Switzerland	56
Italy	55
Germany	54
China	48
Canada	37

We analysed the co-occurrence of the MeSH keywords, to identify the key related topics for One Health and ODH. A keyword co-occurrence graph was created in VOSviewer, with a minimum of 20 occurrences of a MeSH keyword to analysis among all 1,354 keywords, and 45 MeSH keywords met the threshold. The created network of topics and their relationships is shown in Figure 2, with the associated keywords listed in Table 2. The node size illustrates the number of times the MeSH keyword appears, with the distance and thickness of the line connecting the nodes determining the strength of co-occurrence between pairs of MeSH keywords. The colours represent the five MeSH keyword clusters.

Cluster 1 is the largest identified cluster in terms of MeSH keyword inclusion and we can observe that it is largely focused on the human element of One Health. Cluster 2 focusses on two out of three main elements of One Health, namely human and veterinary health. These two elements were the initial elements of One

Table 2 MeSH keyword clusters related to One Health and ODH.

Cluster	Colour	Keywords
1	Red	animals; anti-bacterial agents; anti-infective agents; bacteria; drug resistance bacteria; drug resistance microbial; Escherichia coli; global health; health policy; humans; One Health; public health; United States; veterinary medicine; World Health Organization.
2	Green	adult; cattle; child; female; livestock; male; middle aged; swine.
3	Blue	Africa; coronavirus infections; COVID-19; pandemics; phylogeny; pneumonia, viral; SARS-COV-2.
4	Yellow	India; communicable diseases; disease outbreaks; ecosystem; population surveillance; zoonoses.
5	Purple	animals, wild; communicable disease control; dog diseases; dogs and rabies.

Health, with ecosystem being the third [7,13] before the inclusion of plants in 2022 [18,19]. Cluster 3 contains two other popular themes of One Health since 2020, the COVID-19 pandemic and the inclusion of plants in 2022. One Health rose in coverage after the COVID-19 pandemic initiation, in part due to the theory that the virus jumped from bats to humans [20]. Cluster 4 focusses on animals with elements of epidemiology, and with an interest in prevention via surveillance of either humans or animals. The link between the “zoonoses” term and the red cluster is clear due to their proximity in the diagram. Cluster 5 indicates the relation between the example of rabies as a zoonosis controlling the transmission to humans.

We also used VOSviewer to group the included publications into further clusters, based on co-occurring words in titles and abstracts. With a minimum of 30 occurrences of a term to analyse among all 16,269 keywords, 118 terms met the threshold. After analysis of the relevant score, only the 40 more relevant keywords were selected (for clarity) to create the three clusters and the visualisation of their density as shown in Figure 3. This density is measured in terms of cluster density and the strength of the colour and the approximation of the items per cluster indicate the number of the items in the neighbourhood of a point and the weight of these.

Cluster 1, like cluster 4 in Figure 2, has a substantial focus on epidemiology of zoonoses. Cluster 2 covers ways to resolve the transmission of diseases and potential obstacles in line with the One

Health perspective. Cluster 3, like cluster 1 of Figure 2, highlights the specific applicability of the principles of One Health to antimicrobial stewardship, defined as “a coherent set of actions which promote using antimicrobials responsibly” for both animals and humans [21].

All the clusters from the MeSH keyword clustering (Figure 2) and abstract and title clustering (Figure 3) are very similar and, as expected, discuss the same topics. From a direct, high-level comparison, we can infer that the most prevalent themes to date for One Health and ODH are: communicable disease management (SARS COV/COVID-19 especially), antimicrobial stewardship, veterinary medicine, zoonosis, public health, health policy, ecosystem and multi-stakeholder collaboration.

3 One Digital Health

The COVID-19 pandemic dramatically manifested the need for data, information and knowledge sharing across governments, health systems, clinicians, citizens and other stakeholders. The ODH framework, published in 2021, highlights the digital interconnections between human health, animal health, plant health and the environment. The body of literature on One Health is growing rapidly, as evidenced in the bibliometric analysis above, and several papers have already been published on ODH.

The ODH framework involves using digital capabilities in collecting, processing, and sharing data, information, and

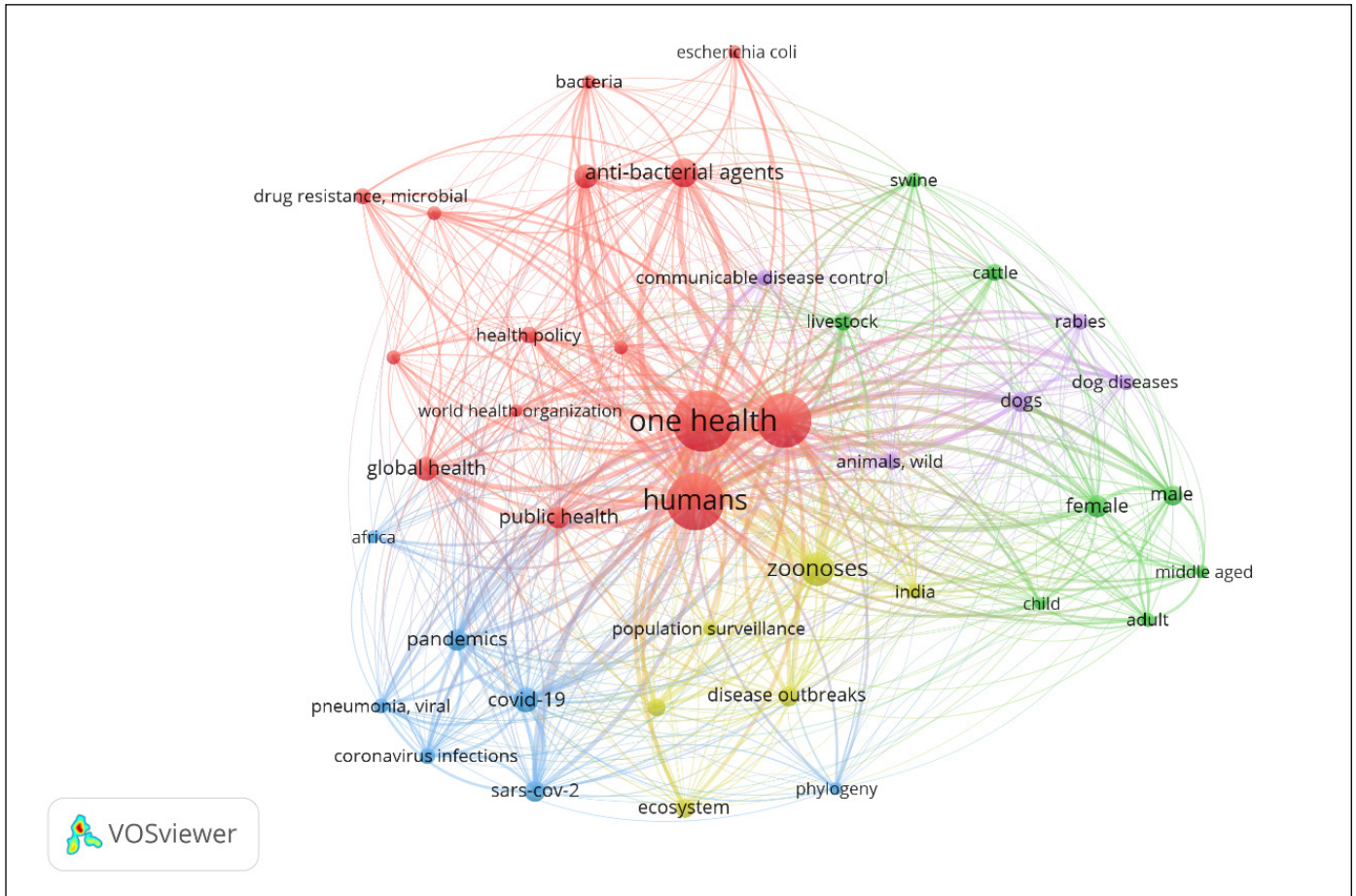


Fig. 2 MeSH keyword clustering of One Health and ODH related publications.

Table 3 Article title and abstract word clusters of One Health and ODH related publications.

Cluster	Colour	Keywords
1	Red	case, covid, dog, epidemiology, exposure, infection, livestock, majority, pandemic, pathogen, patient, prevalence, sample, SARS-COV, source, species, transmission, virus, wildlife.
2	Green	action, capacity, climate change, collaboration, communication, concept, discipline, field, framework, implementation, opportunity, participant, rabies, resource, sector, stakeholder, support.
3	Blue	antibiotic, antimicrobial resistance (AMR), and resistance.

knowledge across multisectoral domains in the One Health space. It relies on collaborative efforts from diverse stakeholders locally, nationally, regionally, and globally. For example, surveillance of human and animal pathogens [22] and genomes [23] by public health professionals, healthcare

practitioners, veterinarians and citizen scientists will inform an ecosystem approach to disease management, prevention and future planning.

The ODH framework is defined by the diagram shown in Figure 4, reproduced with the authors’ permission from [13].

The core of the model is the linkage of One Health with Digital Health, the latter term encompassing everything previously subsumed under the rubrics of eHealth and BMHI. This core has five “dimensions” and three distinct perspectives (individual, population and ecosystem) as scale factors of the model. We illustrate each perspective in the discussion below.

It may not always be obvious which elements of ODH fit into which ‘perspective’ and there is some inevitable overlap. Although the ODH authors describe it somewhat differently, for this discussion we have taken the view that the ecosystem perspective is about ‘universal’ principles or mechanisms and that the population and individual perspectives cover specific applications at those respective levels.

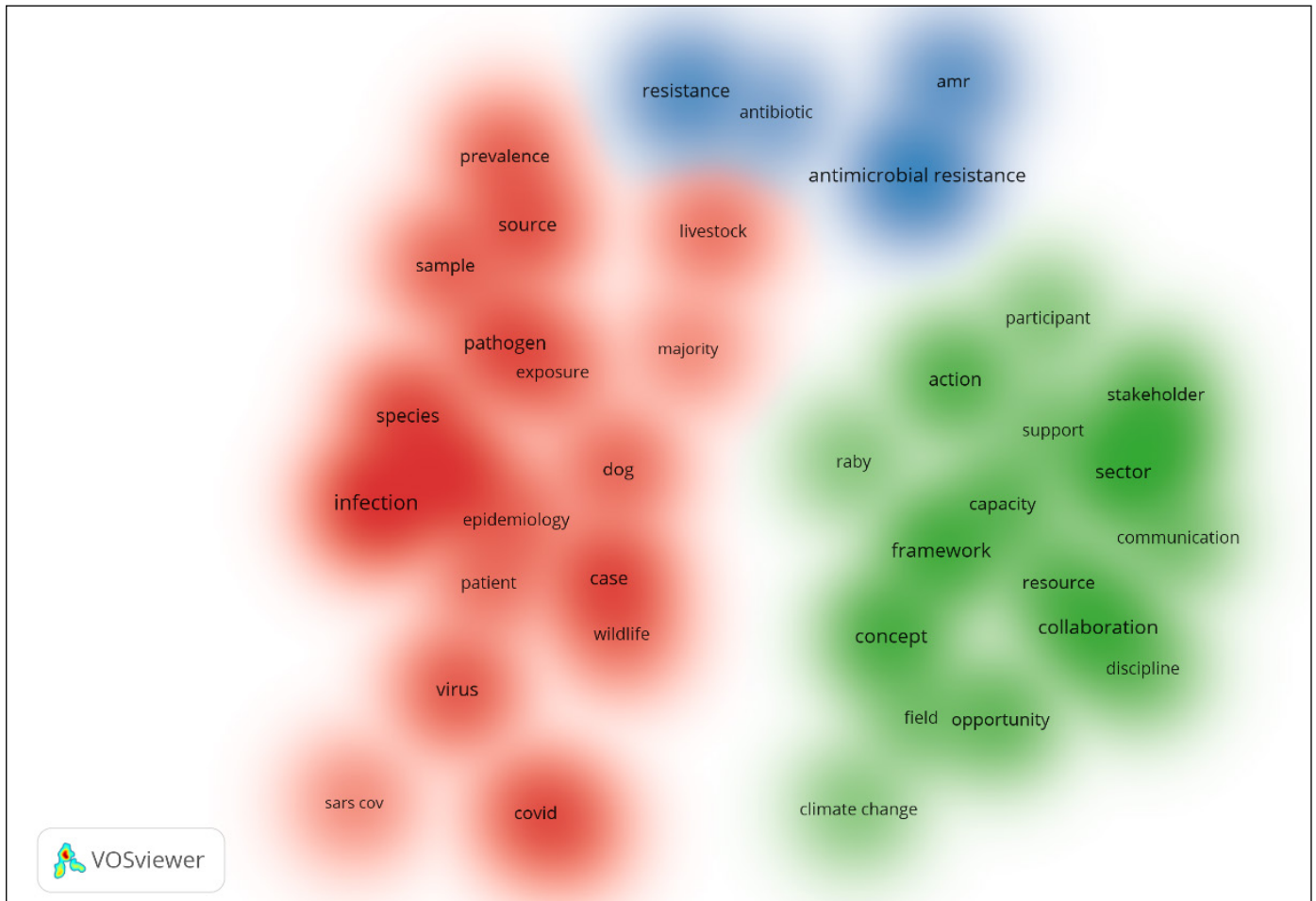


Fig. 3 Abstract and title clustering of One Health and ODH related publications.

4 Ecosystem: One Health Data, FAIR Data

The basic ‘currency’ of ODH is data, but data alone does nothing. The complexity of the One Health domains suggests the diversity of stakeholders and the types of data to be generated and the sources and locations of such One Health data. For example, pathogens, genomes, and signals can be derived from humans, animals and plants located in the healthcare provider environment, wildlife, wastewater, and hospital sewage [23,24]. The key challenge for ODH is how to collect, store, manage and analyse the real-time data generated from multiple organisations and linked

systems. This poses questions of infrastructure (physical, policy and legal) and interoperability standards (interchange, APIs, terminologies, data structures) and efforts must be made to ensure that the data is findable, accessible, interoperable, reusable (FAIR), ethical, and revisable [25]. The FAIR principles should also apply to how information and knowledge derived from raw data are shared across the One Health domains.

Artificial intelligence (AI) techniques have been applied to human health in fields such as precision medicine, drug discovery and vaccine development. However, less attention has been paid to the use of AI for zoonotic diseases [26]. With the intersecting domains of One Health, there is po-

tential to generate large datasets which the AI techniques could exploit/explore [27]. However, simply because data is available and machine learning is relatively straightforward does not mean it necessarily adds value. The proliferation of machine learning models during the COVID-19 pandemic led to very few that were actually useful or reliable: a systematic review found that “*Most published prediction model studies were poorly reported and at high risk of bias*” [28]. Research waste is important to avoid, as research itself comes at a human and environmental cost [29].

WHO proposed the Global Tricycle Surveillance, an integrated multisectoral surveillance system using the One Health approach with a focus on antimicrobial re-

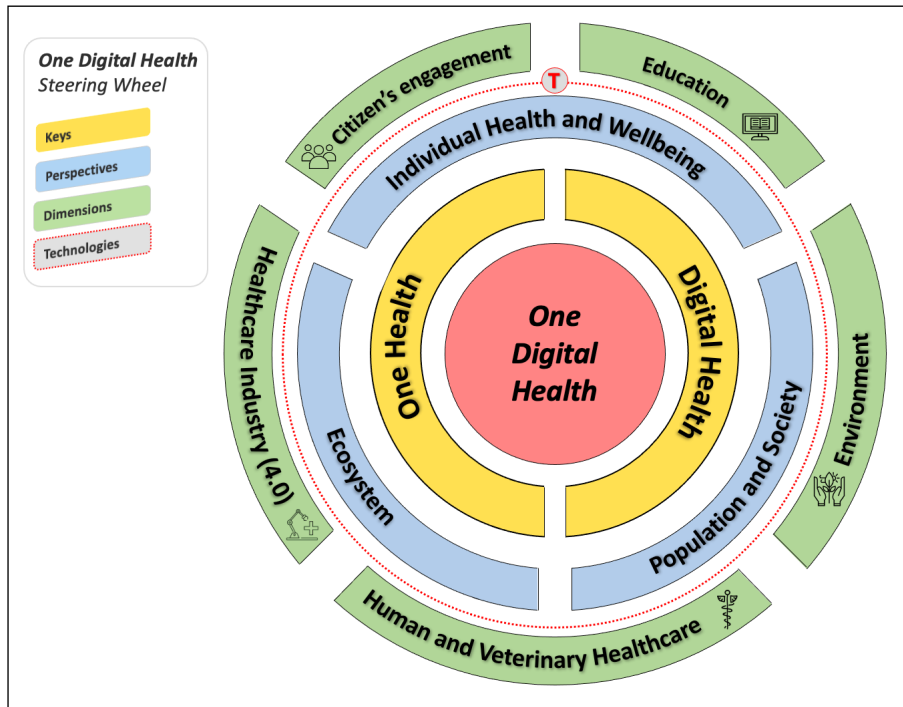


Fig. 4 One Digital Health [13].

sistance (AMR). Although this surveillance system is not digitised, it suggests that data should be processed digitally in healthcare providers and laboratory settings. The system uses the WHONET software [30] to collect aggregate data from humans, the animal food chain and the environment [31].

A landscape analysis identified 60 single-sector and multisector participatory surveillance systems across the One Health domains and geographical regions, which used some form of digital technology [32]. From the analysis, the prominent digital technologies used individually or together were email communication or websites ($n=40$, 67%) and smartphones ($n=29$, 48%). The COVID-19 pandemic also demonstrated the utility of contact tracing, especially when integrated with device geolocation tracking, laboratory results and recorded diagnoses [33]. Citizen toleration of this level of monitoring seems to vary by national culture and individual political disposition, but arguably much more public education (from school age onwards) is needed to make the case for appropriate levels of

surveillance in ‘normal’ times, subject to proper limits and controls, so that there is societal preparedness for necessary tracing in future pandemics.

5 Populations: Antimicrobial Stewardship and Food Chain

One Health helps to clarify the relationship between people, antimicrobial stewardship (AMS), food safety, and ecosystems. For example, when food-producing animals are treated with antibiotics, this can favour the survival and multiplication of resistant bacteria [34]. Resistant bacteria can then enter the food chain via animals, water or soil and so contaminate food which is produced from these animals such as meat, milk or eggs. Furthermore, resistant bacteria can spread to crops which are irrigated with contaminated water or fertilised with animal manure [35]. This is where data sharing can play a signifi-

cant part in reducing the use of antimicrobials in animals which can help in reducing the overall risk of AMR to humans [36].

Due to the practical challenges of implementing the One Health approach, the OH-SMART toolkit was developed. The toolkit uses six steps in addressing One Health challenges: identify network, interview stakeholders, map system, analyse system, identify opportunities, and develop plan. It has been deployed in 17 countries as a prototyping process to practically address AMR issues, detect zoonotic disease outbreaks, and respond to emergencies. The OH-SMART toolkit has been claimed to be user-friendly, robust and have the capabilities of solving complex One Health problems [37].

At the population level, clinical decision support (for human patients) has been shown to support AMS [38, 39]. An ODH viewpoint would suggest that there also seems to be an opportunity for decision support to be implemented for veterinary antibiotic prescribing [40].

AMS (both human and animal) is also supported by standardised reporting of medication usage levels and resistance statistics at local and regional levels [41, 42]. There is potential for such data sets to be standardised, or at least normalised for aggregation, thereby enabling cross-analysis of human and animal infections, antimicrobial usage and resistance trends.

6 Individuals: Exposome and Long-term Conditions

The ‘exposome’ is defined as “*the measure of all the exposures of an individual in a lifetime and how those exposures relate to health*” [43]. This includes environmental and lifestyle factors and accounts for a substantial proportion of the global burden of disease [44]. The exposome comprises the general external environment, a specific external environment of an individual at a point in time and space, and the internal biological environment of an individual body, including factors such as metabolism, microbiome and inflammation [45]. The exposome concept clearly has very broad informatics implications and obvious relevance for One Health [46, 47].

Numerous data sources exist for individual exposome factors, with varying coverage and level of available detail, covering aspects such as air pollution levels [48] and water quality [49]. Increasing use of environmental sensors, whether personal or community devices, offers opportunities for the individual exposome to be enriched, integrated and understood more deeply both for humans and animals.

Long-term conditions such as diabetes and chronic obstructive pulmonary disease are among the major causes of mortality and reduced quality of life. For many conditions, there are mobile apps or personal health records (PHRs) that can help people to manage their health, with support such as mood tracking, blood pressure recording, blood sugar trends and prescription reminders [50]. Apps can also promote healthy living through self-monitoring and behaviour change prompts, although the evidence of app quality and effectiveness remains limited [51]. As average human lifespans have increased, multi-morbidity, i.e. the co-occurrence of two or more long-term conditions, has become a growing issue [52] and this is another important area where ODH can contribute [53].

7 Discussion

One Health is a unifying model that overlaps significantly with other synthesising frameworks. There is a clear connection between the One Health vision and the United Nations Sustainable Development Goals (SDGs) [54]. Like the SDGs, One Health involves ‘wicked problems’ which take time to progress despite their urgency.

One Health thinking also has much in common with the Gaia concept [55], that “*life (the biota), atmosphere, hydrosphere (ocean, ice, freshwater), dead organic matter, soils, sediments and that part of the lithosphere (crust) that interacts with surface processes*” are vitally interconnected. Gaia theory makes the (still controversial) proposition that life evolves self-regulatory cybernetic systems (organic, chemical, geophysical) that account for the remarkable stability of the planetary biosphere over geologic time, whereas One Health puts the

onus on human actors to collaborate and initiate positive change.

Another relevant system theory is the notion of Learning Health Systems [56], based on continuous cycles of deriving knowledge from operational health data, implementing the knowledge and monitoring the results. We suggest that ODH considers adopting a visionary framework of what we might call “Learning One Health Systems” that dynamically integrate across the wealth of data, information and knowledge from humans, animals and the environment that we have briefly signposted in this article.

The One Health bibliometric clusters suggests that authors are focused predominantly on human health, zoonoses and AMS. One Health also includes wildlife, plant and nature and ODH includes the capabilities of the digital world too. The digitalisation of data, information and knowledge is currently under-represented as a One Health theme, core to ODH. This is clearly an opportunity for increased collaboration between the health informatics and broader One Health communities. Another potential gap in current ODH work is adequate attention to environmental issues and climate change. Increasing use of technology comes at a price, given the nature of the whole technology lifecycle [57]. The mining and processing of raw materials often has devastating consequences for biodiversity. Product marketing strategies usually have planned obsolescence and hence repeated waste cycles. The imaginary ‘cloud’ is actually vast data centres consuming massive amounts of energy. Big technology companies use accounting tricks like “carbon offsetting” to mask this, but in reality the damage is still done [58]. How can ODH help to address this?

8 Conclusion

One Health highlights important principles and ways of working for the continued viability of life on this planet. What is the implication for the digital world? The emerging body of work on ODH has shown the vital role of technology, data, information and knowledge. We call on the global informatics community to embrace and advance the One Health concept as a professional and ethical responsibility.

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Appendix: Search terms

((("one health"[MeSH Terms]) OR ("one digital health")) AND (((("2012/01/01"[Date - Publication] : "2022/12/31"[Date - Publication]))) AND ((English[Language]))) AND ((human OR mortal OR person OR citizen OR resident OR inhabitant OR dweller OR civilian)))AND ((animal OR creature OR beast OR veterinary OR pet)) AND ((environment OR ecosystem OR ecological)) AND (plant OR vegetable OR tree OR plantation OR forest OR jungle OR seed))