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Editorial

Synergistic integration of climate change and zoonotic diseases by artificial intelligence: a holistic approach for sustainable solutions

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ABSTRACT

Artificial intelligence (AI) is a rapidly evolving field that can impel research in communicable diseases with respect to climate projections, ecological indicators and environmental impact, at the same time revealing new, previously overlooked events. A number of zoonotic and vector-borne diseases already show signs of expanding their northern geographical ranges and appropriate risk assessment and decision support are urgently needed. The deployment of AI-enabled monitoring systems tracking animal populations and environmental changes is of immense potential in the study of transmission under different climate scenarios. In addition, AI's capability to identify new treatments should not only accelerate drug and vaccine discovery but also help predicting their effectiveness, while its contribution to genetic pathogen speciation would assist the evaluation of spillover risks with regard to viral infections from animals to human. Close collaboration between AI experts, epidemiologists and other stakeholders is not only crucial for responding to challenges interconnected with a variety of variables effectively, but also necessary to warrant responsible AI use. Despite its wider successful implementation in many fields, AI should be seen as a complement to, rather than a replacement of, traditional public health measures.

1. Introduction

In the general field of medicine, artificial intelligence (AI) is still in search for applications. However, in pathology, it has found a tentative use for image studies of organs [1] and Agrebi and Larbi [2] list potential applications in the field of infectious diseases. The purpose of this editorial is trying to illustrate the potential use of AI in the field of communicable diseases, and trigger more researchers to implement AI as a tool to improve the public health outcomes.

There has been a wide use of AI in the field of communicable diseases, where a number of zoonotic and vector-borne diseases, including dengue fever [3], malaria [4], schistosomiasis [5], borreliosis (Lyme disease) [6] as well as the Zika [7] and West Nile [8] virus infections, have presented signs of expanding their northern geographical ranges. The connection with the recent increase of Earth's average temperature that has become critical after the millennium shift is evidenced at the website (https://www.ipcc.ch/) of the Intergovernmental Panel on Climate Change (IPCC). Strong reasons support the idea that the 150-year old industrial revolution releases more carbon dioxide into the atmosphere than natural processes can remove and that this leads to global warming. While effective strategies to decelerate climatic change (CC) are urgently needed, the altered conditions for the transmission of zoonotic and other vector-borne diseases demand parallel attention.

The end of the latest Ice Age, followed by a rapid global temperature rise around 11,700 years ago, marks the beginning of Holecene [9], a geological epoch characterized by stable temperatures with only minor cold-spells (Fig. 1). However, even if this average temperature change can be limited to somewhere between 1.5 and 2.5 °C, its impact on vector-borne diseases will overwhelm any current restrictive factors requiring innovative ideas and extensive collaborative research. It is also very probable that zoonotic infections would escalate since many reservoir hosts can traverse large distances, something particularly true for migratory birds. While CC is associated with the geographic disease panorama, it is not the sole factor contributing to the changes envisaged. Environmental, socio-economic and health-related variables also play significant roles. Overall, however, there is no doubt that large-scale, complex interventions will be crucial for dealing with the changing patterns of communicable diseases that seem to be in store.

1.1. Challenges and opportunities

Due to their dependence on the sensitivity to temperature and precipitation, vector-borne infections are bellwether indicators. The presumed expanding endemic ranges will require strengthened public health systems in endemic as well as non-endemic areas. Epidemiologists and managers of endemic disease programmes need to focus on control and response with emphasis on pathogen identification, transmission modelling, vector analysis and outbreak prediction. The interconnections between human, animal and environmental health, in line with the principle of One Health, demand collaboration and data-sharing at the local, national and global levels and across a variety of disciplines, e.g., virology, parasitology, ecology, geography, environmental sciences and socio-economy as well as policy and governance.

The high cost-effectiveness of the One Health approach, due to transdiscipline cooperation with complex problems, is a great advantage but the increased data flow emanating from the impact of CC on vector-borne

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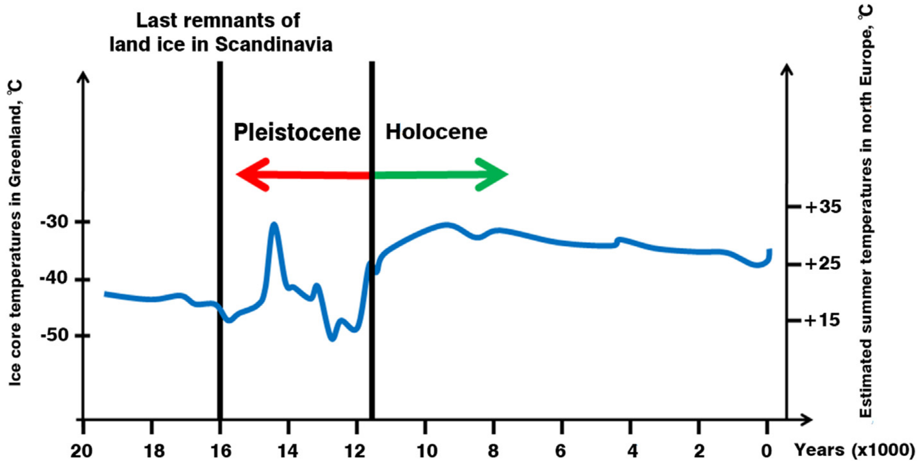

Fig. 1. Temperature variations during the last 20,000 years.

and zoonotic diseases can no longer be handled conveniently without technical support. To gain deeper insights into the complex interactions between climate, ecosystems and diseases with intricate life cycles, AI technologies can assist with respect to preparedness and follow-up mitigation. They are capable of handling big data and even 'thought processes' arriving at suggestions for responses based on obscure variations and interactions of environmental, climate and biological variables. Based on the One Health approach, AI optimizes energy consumption and improves resource management by combining and coordinating expertise from different domains. In addition, AI-driven communication platforms facilitate real-time information exchange between stakeholders, which includes not only scientists and healthcare professionals, but also the targeted local communities and the individuals who live there. Leveraged strategies for prevention, mitigation and adaptation of the CC impact on vector-borne and zoonotic diseases can thus be developed with focus on:

- prevalence information based on One Health data, both recorded and remotely sensed including satellite-generated imagery;
- field data as well as behavioural and socio-economic information;
- disease transmission including early detection and surveillance as well as predictive modelling; and
- resource management, e.g., allocation of healthcare infrastructures, treatment distribution (drugs and/or vaccines), availability of control programmes, vector control, health education, etc.

1.2. Areas where AI can be of decisive importance

When the World Health Organization (WHO) embarked on their plan for the control and elimination of the neglected tropical diseases (NTDs) [10], a group of 21 predominantly endemic diseases in tropical and subtropical regions, it became clear that a wide range of tasks must be addressed simultaneously. Although One Health interventions offer a way forward assuring connection between all components [11], the high complexity requires advanced computer systems to keep track of the interplay between human, animal and environment perpetuating NTD transmission [12].

Firstly, AI can optimize operations and maximize returns of interventions. In particular, the monitoring of transmission pathways of zoonotic diseases requires support from particular surveillance systems facilitated with AI due to the various animals involved. Real-time data streams need to be analyzed by integrating climate data, ecological indicators, historic and current health surveillance data with reference to identifying anomalies or irregular patterns that may indicate disease outbreaks.

Secondly, AI can develop predictive models to identify regions with a high risk of zoonotic transmission. Spillover of viruses from adapted animals to humans is a hazard creating new emerging diseases due to human behaviour changes. Examples from the last century cover a spectrum of such pathogens ranging from influenza virus [13] to the human immunodeficiency virus (HIV) [14] and the three coronaviruses, which caused the severe acute respiratory syndrome (SARS) [15], the Middle East respiratory syndrome (MERS) [16] and the coronavirus disease 2019 (COVID-19) pandemic [17]. Anticipation and response to emerging zoonotic diseases demand proactive research, rapid diagnostics and effective public health interventions. Necessary activities also comprise construction of early warning systems (EWS) with emphasis on surveillance, response and prevention by developing predictive models identifying regions with a high risk of zoonotic transmission.

Thirdly, AI can integrate diverse datasets for creation of comprehensive databases enabling AI-driven holistic analysis. Monitoring biodiversity and potential interactions between species would illuminate the impact of CC and human activities in relation to various ecosystems as well as assessing the impact of environmental changes on wildlife habitats. For this to occur, large volumes of data on climate, ecology and health, including satellite imagery, terrestrial sensor networks and public health records, must be collected, processed and applied to modelling.

Fourthly, AI can disseminate research results. In order to efficiently engage the general public by researchers, information based on social media, news articles and medical records can enhance EWS, while platforms for communication of CC and zoonotic disease research findings would raise awareness and promote behaviour change. Importantly, AI-powered chatbots could disseminate accurate information, answer questions and provide guidance to the public, hereby contributing to awareness and education.

Finally, AI can ensure that research is conducted with ethical considerations properly. Responsible actions applied in public health must always consider ethical concerns, such as privacy, bias, transparency and accountability, which are highly complex. One of AI systems' major advantage is that it can be designed with ethical principles in mind, such as transparency, accountability, and fairness, to ensure that research is conducted ethically. This includes identifying and addressing ethical concerns that may arise during the course of the continuing surveillance operations with respect to informed consent and connected issues.

2. Websites offering AI public health assistance

Several large-scale AI-assisted research projects already exist. For example, **PREDICT** examines zoonotic viruses with pandemic potential, **ClimateAi** tackles climate-related challenges, **Climate TRACE** keeps track of real-time global greenhouse gas emissions, **EcoHealth Alliance** considers relationships between human health, wildlife health and environmental changes, **Microsoft AI for Earth** focuses on environmental challenges, and IBM's **watsonx** initiative leverages AI to analyze environmental data with respect to climate-related issues. Additionally, **BlueDot** is an AI-driven platform that uses natural language processing and machine-learning to analyze global news reports in order to identify and predict disease outbreaks, **HealthMap** is a real-time disease surveillance system that employs AI algorithms to monitor and analyze online sources, such as social media, news reports and government websites, to detect and track disease outbreaks, **Climate Informatics** combines AI and climate science to develop models predicting CC impacts, **Conservation Metrics** deals with computer vision and machine-learning to monitor wildlife populations and detect changes in behaviour or habitat that may indicate disease transmission. Lastly, **AlphaFold** is specifically involved in prediction of protein folding and structures with remarkable accuracy, with potential to accelerate vaccine and drug discovery. Annex 1 describes these approaches in more detail.

3. Conclusion

Case studies have demonstrated the advantage of diverse AI-powered applications for addressing inexorable emerging infectious threats of high risk, such as pandemics, zoonotic and vector-borne diseases and their association with CC. AI-driven pathogen speciation studies at the molecular level would lead to analysis of large numbers of genetic data and patterns to support risk evaluations of spillover of viral diseases from animals to humans. In addition, genetic pathogen data can be tracked to provide information on how microorganisms might spread, while simulations can assist modelling and optimizing vaccine distribution strategies as well as assessing their effectiveness in different population groups. By analyzing vast datasets in this way, it might be possible to identify new, potential drug/vaccine candidates and predict their effectiveness. AI can thus accelerate the discovery process of effective drugs and vaccines.

It is recommended that close collaboration between AI experts, epidemiologists and other stakeholders is not only crucial for responding to challenges interconnected with a variety of variables effectively, but also necessary to warrant responsible AI use and its successful implementation. Importantly, malicious applications must be prevented and AI should be seen as a complement to, not replacement of, traditional public health measures and expertise, while AI applications have significantly influenced public health outcomes.

The developments in this rapidly evolving field can impel research on zoonotic and vector-borne diseases with respect to climate projections, ecological indicators and environmental impact as well as spearheading new previously overlooked events. It can also provide evidence-based recommendations for policymakers, healthcare professionals and public health agencies to implement appropriate interventions for risk assessment and decision support, with the deployment of AI-enabled monitoring systems tracking animal populations and environmental changes leading to expanded areas of transmission.

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Declaration of competing interest

Xiao-Nong Zhou is the Editor-in-Chief of *Science in One Health*. Robert Bergquist is the editorial board member of this journal. They were not involved in the peer-review or handling of the manuscript. The authors have no other competing interests to disclose.

Submission declaration and verification

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Authors' contributions

Data analysis and result visualization: Robert Bergquist, Jin-Xin Zhen, Xiao-Nong Zhou; Writing (original draft preparation, review, and editing): Robert Bergquist, Xiao-Nong Zhou; Resource: Robert Bergquist, Jin-Xin Zhen; Funding acquisition: Xiao-Nong Zhou.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.soh.2024.100070.

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