

Experts' opinion on sustainable use of digital health tools for effective future pandemic preparedness and response: Questionnaire study

Kabelo Leonard Mauco, John H. Holmes, Anthony Luberti, Badisa Mosesane

Submitted to: JMIR Public Health and Surveillance
on: September 15, 2025

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on its website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressly prohibit redistribution of this draft paper other than for review purposes.

Table of Contents

Original Manuscript.....	5
---------------------------------	----------

Preprint
JMIR Publications

Experts' opinion on sustainable use of digital health tools for effective future pandemic preparedness and response: Questionnaire study

Kabelo Leonard Mauco¹ PhD; John H. Holmes² PhD; Anthony Luberti^{3, 4} MD; Badisa Mosesane⁵ BSc

¹Center for Global Health Perelman School of Medicine University of Pennsylvania Philadelphia US

²Department of Biostatistics, Epidemiology, and Informatics Perelman School of Medicine University of Pennsylvania Philadelphia US

³Department of Pediatrics Perelman School of Medicine University of Pennsylvania Philadelphia US

⁴Department of Biomedical and Health Informatics Children's Hospital of Philadelphia Philadelphia US

⁵Global Health Informatics Department of Biomedical and Health Informatics Children's Hospital of Philadelphia Philadelphia US

Corresponding Author:

Kabelo Leonard Mauco PhD
Center for Global Health
Perelman School of Medicine
University of Pennsylvania
240 John Morgan Building
3620 Hamilton Walk
Philadelphia
US

Abstract

Background: The COVID-19 pandemic demonstrated the potential role of digital health tools in enhancing pandemic preparedness and response. These tools became essential, supporting not only healthcare delivery but also decision-making, communication, case identification, contact tracing, surveillance, vaccination rollout, and intervention evaluation. The interest in applying digital health tools towards pandemic preparedness and response motivated conversations about digital epidemiology. A field of study that aims to provide insight into health and disease determinants by leveraging diverse digital data sources. In a globalized world, effective preparedness and response to pandemics require a coordinated global action.

Objective: This study investigates expert opinions on strategies for improving global health security through the effective use of digital epidemiology, considering the current landscape of digital determinants of health.

Methods: Epidemiologists, public health specialists, data scientists, and professionals with expertise in various components of digital health were recruited through convenience and snowball sampling methods. Expert opinions were elicited using an electronic questionnaire developed by the authors in REDCap. To ensure a global perspective, participants were recruited from Africa, North America, Oceania, and Europe. Thematic analysis and the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis framework were used to analyze participants' responses.

Results: Most participants were familiar with the concept of digital epidemiology and expressed positive sentiments about its potential in strengthening global health security. Privacy and security, along with ethical and legal considerations, were ranked by most experts as high priority areas that decision makers and implementers must consider ensuring sustainable integration of digital epidemiology tools in future pandemic preparedness and response. A SWOT analysis of participants' views on the promise of digital epidemiology, revealed fewer strengths and more weaknesses compared to other components of the analysis framework.

Conclusions: This study highlights the growing recognition of digital epidemiology as a critical tool for enhancing global health security, particularly using non-traditional data sources and emerging technologies including artificial intelligence. The study affirms the need for a globally coordinated approach to governance, regulation, and investment in digital health infrastructure to ensure the responsible and effective application of digital innovations in epidemiological practice.

(JMIR Preprints 15/09/2025:84164)

DOI: <https://doi.org/10.2196/preprints.84164>

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible to all users.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <http://www.jmir.org/>

No. Please do not make my accepted manuscript PDF available to anyone. I understand that if I later pay to participate in <https://www.jmir.org/>

Original Manuscript

Experts' opinion on sustainable use of digital health tools for effective future pandemic preparedness and response: Questionnaire study

Kabelo Leonard Mauco^{1*}, PhD; John H. Holmes², PhD; Anthony Luberti^{3,4}, MD and Badisa Mosesane⁵, BSc

¹Center for Global Health, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104-6055, USA. ²Department of Biostatistics, Epidemiology, and Informatics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104, USA. ³Department of Pediatrics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104, USA. ⁴Department of Biomedical and Health Informatics, Children's Hospital of Philadelphia, Philadelphia, PA 19104, USA. ⁵Department of Biomedical and Health Informatics, Global Health Informatics, Children's Hospital of Philadelphia, Philadelphia, PA 19104, USA.

Corresponding author:

Kabelo Leonard Mauco, PhD

kabeloleonard.mauco@fulbrightmail.org

Abstract

Background The COVID-19 pandemic demonstrated the potential role of digital health tools in enhancing pandemic preparedness and response. These tools became essential, supporting not only healthcare delivery but also decision-making, communication, case identification, contact tracing, surveillance, vaccination rollout, and intervention evaluation. The interest in applying digital health tools towards pandemic preparedness and response motivated conversations about digital epidemiology. A field of study that aims to provide insight into health and disease determinants by leveraging diverse digital data sources. In a globalized world, effective preparedness and response to pandemics require a coordinated global action. This study investigates expert opinions on strategies

for improving global health security through the effective use of digital epidemiology, considering the current landscape of digital determinants of health.

Methods Epidemiologists, public health specialists, data scientists, and professionals with expertise in various components of digital health were recruited through convenience and snowball sampling methods. Expert opinions were elicited using an electronic questionnaire developed by the authors in REDCap. To ensure a global perspective, participants were recruited from Africa, North America, Oceania, and Europe. Thematic analysis and the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis framework were used to analyze participants' responses.

Results Most participants were familiar with the concept of digital epidemiology and expressed positive sentiments about its potential in strengthening global health security. Privacy and security, along with ethical and legal considerations, were ranked by most experts as high priority areas that decision makers and implementers must consider ensuring sustainable integration of digital epidemiology tools in future pandemic preparedness and response. A SWOT analysis of participants' views on the promise of digital epidemiology, revealed fewer strengths and more weaknesses compared to other components of the analysis framework.

Conclusions This study highlights the growing recognition of digital epidemiology as a critical tool for enhancing global health security, particularly using non-traditional data sources and emerging technologies including artificial intelligence. The study affirms the need for a globally coordinated approach to governance, regulation, and investment in digital health infrastructure to ensure the responsible and effective application of digital innovations in epidemiological practice.

Keywords: digital health; eHealth; public health informatics; digital epidemiology; pandemic

preparedness; pandemic response; digital health readiness; global health; COVID-19

Introduction

The COVID-19 pandemic underscored the critical role of digital health tools in enhancing pandemic preparedness and response. It is estimated that the COVID 19 pandemic caused deaths to more than 2 million people worldwide [1]. A report of the independent panel for pandemic preparedness concluded that the alert system was too slow, the World Health Organization was under-resourced, and global political leadership was absent [2]. de Souza et al. (2022) identified five critical areas associated with the global failure in facing the pandemic: deficiency in the global alert system and the fragility of the international health regulations; problems of the international response to the pandemic related to global health governance; the dispersed global adoption of the elimination strategy (Zero Covid); fragile control of the disease with a narrow reading of the associated problems; and lastly, global setbacks in achieving the sustainable development goals [3]. The need for coordinated global efforts and effective early detection and timely surveillance for a robust pandemic and epidemic early warning and preparedness has been widely discussed amidst the Covid-19 pandemic [4].

Digital health tools became a necessity and their popularity increased during the pandemic. Not only for the provision of healthcare services but also to support decision making, communication and information, case identification, contact tracing, surveillance and monitoring, rolling out of vaccination programmes as well as evaluation of interventions [5-7]. Digital health technologies illustrated the potential to support diverse needs and approaches for early warning and forecasting of epidemics [8]. Albeit in their report, Al Knawy et al. (2022) acknowledges that COVID 19 highlighted widespread chronic underinvestment in digital health that hampered public health responses to the pandemic [9]. The often-*ad hoc* adoption and use of digital health during the

pandemic further illuminated its potential to transform future pandemic preparedness and response efforts [10].

The discussion on applying digital health tools towards future pandemic preparedness and response has motivated frequent conversations around digital epidemiology. *Digital epidemiology* has been defined as a field of study that aims to provide insight into health and disease determinants in human populations by building on diverse digital data sources [11]. Furthermore, Tarkoma et al. (2020) posits that digital epidemiology is envisaged as having the potential to contribute towards global health security through inputs such as syndromic surveillance, public health surveillance, and early pandemic detection [11].

In the era of globalization, efficient preparedness and response to future pandemics requires a united global action [12-13]. However, realizing the full potential of digital epidemiology as part of such global efforts becomes elusive due to persistent geopolitical tensions as well as the global digital divide and digital access gap [14]. This study aims to investigate experts' opinions on possible means of improving global health security through the effective use of digital epidemiology within the context of the current global landscape of digital determinants of health.

Methods

Sampling and recruitment of study participants

Epidemiologists, public health specialists, data scientists, and professionals with expertise in the various components of digital health were recruited using convenience sampling. To gather a global perspective, potential study participants were recruited from Africa, North America, Oceania, and Europe.

For recruitment of potential participants from Africa, an initial email was sent to the general membership of the pan-African health informatics association called Health Informatics in Africa (HELINA). For the United States, initial recruitment of study participants involved sending an email to members of the American Medical Informatics Association (AMIA). Snowball sampling method was also employed. This continued until no further referrals were made. The initial email to potential study participants, described the study objectives and the role of a potential study participant. Study data were collected and managed using the research electronic data capture (REDCap) tool hosted at the Children's Hospital of Philadelphia[15] . The email package also included a link to an electronic questionnaire developed using the REDCap platform. The electronic questionnaire included a consent form that a potential study participant had to agree to before proceeding to answer the questionnaire.

Recruitment of potential study participants was also done at the medical informatics Europe 2023 (MIE 2023) conference held in Göteborg, Sweden. Paper flyers about the study were placed at convenient places throughout the conference venue. In addition to containing details about the study objectives and participant's role, the paper flyers also included a QR code with a link to the electronic questionnaire developed using REDCap.

Since an electronic questionnaire was used for this study, the authors aimed to comply with the Checklist for Reporting Results of Internet E-surveys (CHERRIES) [16].

Study questionnaire design and development

The initial draft of the study questionnaire was designed based on a review of relevant literature.

Following an iterative process, the authors developed a study questionnaire aimed at capturing participants' opinion on effective approaches to improving global health security using digital epidemiology\ within the context of the current global landscape of digital determinants of health.

A panel consisting of five staff members from the Department of Biomedical and Health Informatics at the Children's Hospital of Philadelphia and the Perelman School of Medicine at the University of Pennsylvania, was consulted to ensure content validity of the study questionnaire. The panel received the initial draft questionnaire via email and could make suggestions for improvement where needed. Their suggestions were discussed and agreed upon among the authors and final updates made on the questionnaire. The structured questionnaire included both closed-ended (Likert-scale responses) and open-ended questions, allowing for quantitative analysis of trends as well as qualitative insights into experts' recommendations. This mixed-method approach facilitated a comprehensive evaluation of participants' responses.

Data analysis

Thematic analysis was employed to analyze the qualitative responses from the questionnaire, following an iterative process [17]. All textual data were imported into NVivo 12 software (QSR International) to facilitate systematic coding and theme identification. Initial codes were generated based on both predefined study objectives and emerging patterns from the data. Through repeated review and refinement, broader themes and subthemes were developed to capture key insights

For quantitative data, descriptive statistics (frequencies, percentages) were computed to summarize responses. The integration of qualitative and quantitative findings provided a robust assessment of the participants' responses. Participants' responses were analyzed using the Strengths, Weaknesses,

Opportunities, and Threats (SWOT) analysis framework [18] to identify key strengths, weaknesses, opportunities, and threats of the digital epidemiology approach.

Ethical Considerations

Ethical approval for the study and related documents was obtained from the Institutional Review Board (IRB)at the Children’s Hospital of Philadelphia. IRB protocol number: IRB 22-020667.

Results

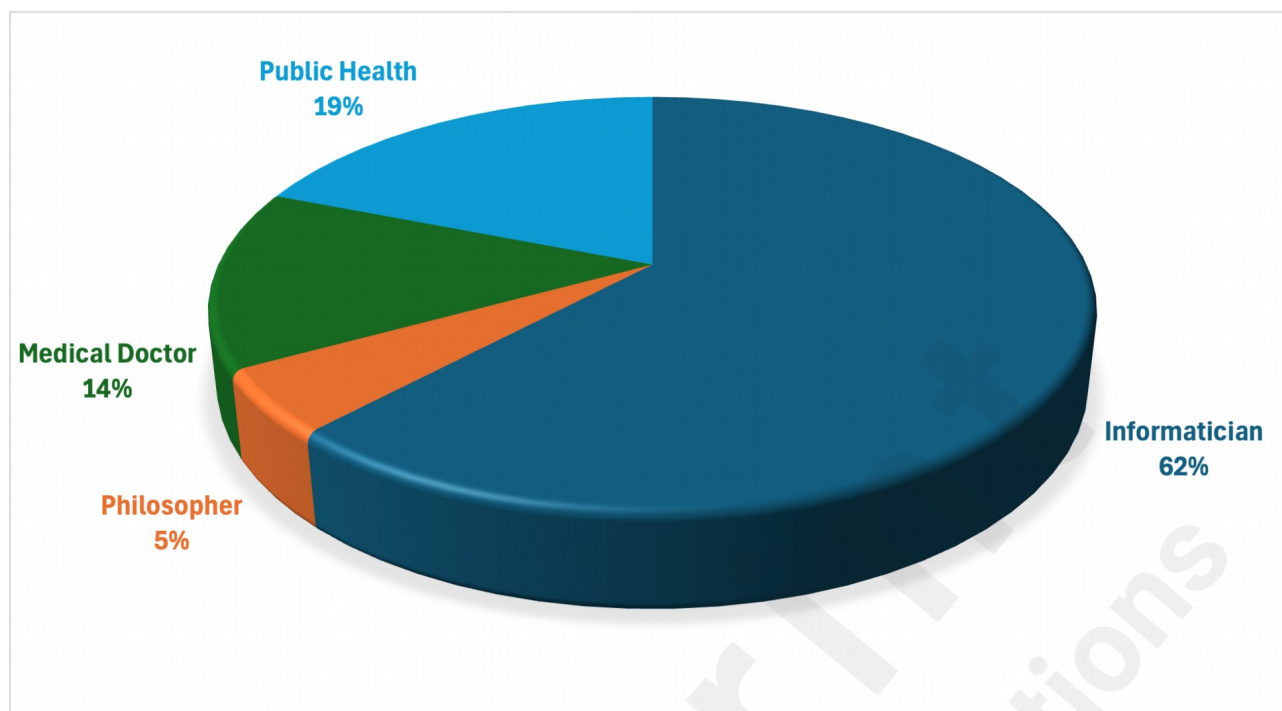
Following the data collection phase (February 2023-February 2024), a total of 22 fully completed questionnaires were retained for analysis, while incomplete responses were excluded. Questionnaires were deemed incomplete if participants failed to respond to any of the mandatory sections or to questions measuring key outcome variables. The study participants represented diverse geographical regions, including Africa (n=7, 31.8%), the Americas (n=7, 31.8%), Europe (n=6, 27.2%), and Oceania (n=2, 9.1%). A detailed breakdown of this distribution is presented in Table 1.

Table 1: Study participants and countries represented.

Region	Sub-Region	Country	No. Participant s	Total Per Region
Africa	Eastern Africa	Rwanda	1	
		Uganda	2	
		Malawi	1	
	Western Africa	Ghana	1	
	Middle Africa	Cameroo	1	

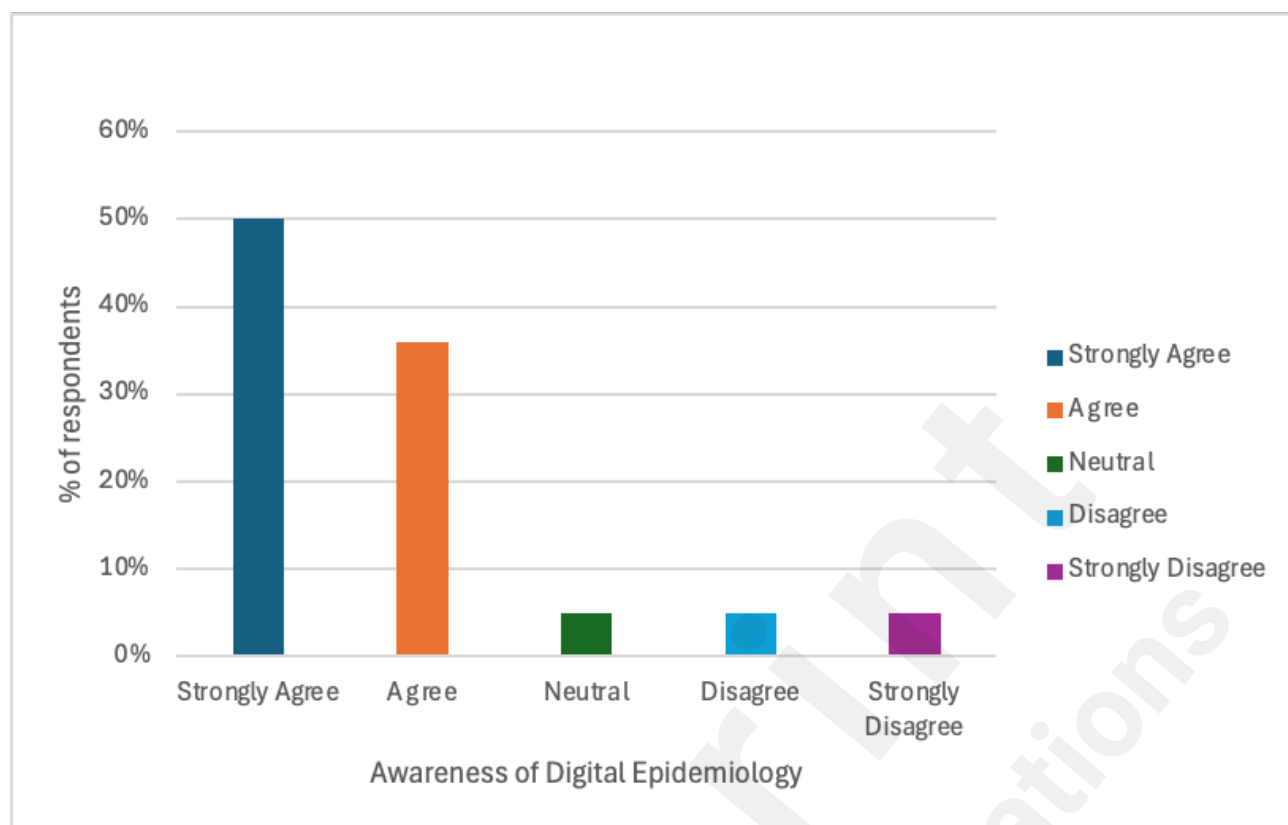
		n		
	Southern Africa	South Africa	1	7
America	Northern America	USA	6	7
		Canada	1	
Europe	Western Europe	Switzerland	3	6
		France	1	
		Netherlands	1	
		Greece	1	
Oceania	Australia and New Zealand	Australia	2	2
Total				22

The study participants represented diverse professional backgrounds, with 14 (62%) participants (62%) identifying as informaticians, 4 (19%) participants were public health specialists, 3 (14%) participants as medical doctors, and only 1 (5%) participant was a philosopher (Figure 1). Participants were required to identify with only one mutually exclusive professional category.

Figure 1: Study participants' occupation.

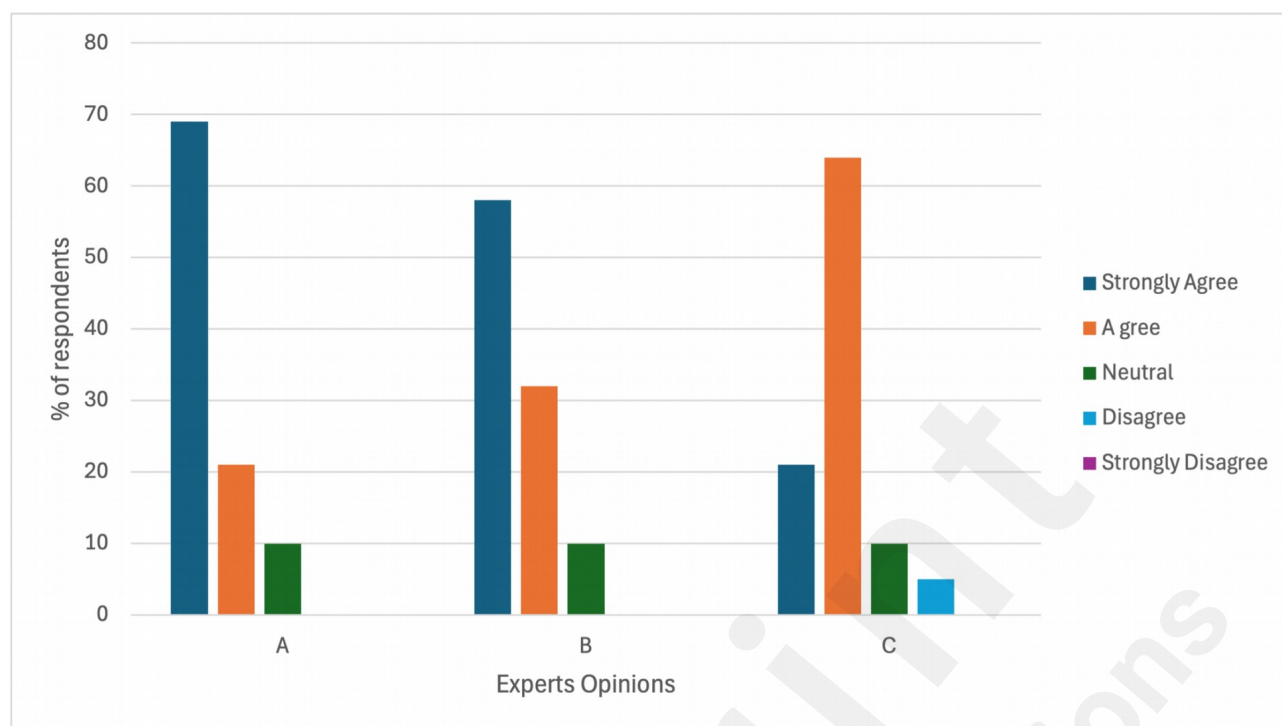
This study aimed to explore experts' opinions on what they would consider as optimal conditions necessary for the use of digital epidemiology to enhance future pandemic preparedness and response. Accordingly, it was essential to assess participants' awareness of the concept of digital epidemiology, as this could influence the study's findings and interpretations. As illustrated in Figure 2, the majority of study participants were aware of the concept of digital epidemiology, with more than half of the participants either strongly agreeing or agreeing that they were familiar with digital epidemiology.

Figure 2: Study participants' awareness of the concept of digital epidemiology



Participants who either strongly agreed or agreed that they were aware of the concept of digital epidemiology (Figure 2), generally expressed positive sentiments regarding its potential impact and effectiveness in improving global health security (Figure 3).

Figure 3: Study participants' sentiments regarding potential impact and effectiveness of digital epidemiology



Key

A = Digital Data can enhance Epidemiology Purposes

B = Digital Epidemiology can be effectively applied at a global level towards a coordinated global health surveillance

C = Digital epidemiology is reliable

Effective integration of digital epidemiology as part of a united global action toward future pandemic preparedness and response would require a certain level of readiness from the global community [7,18]. Key readiness indicators for decision-makers and implementers to consider are outlined in Figure 4. Study participants ranked these indicators based on their perceived importance and priority. In order of importance and priority, from highest to lowest, the indicators were ranked as follows: privacy and security; ethical and legal aspects; user acceptance and usability of the epidemiologic approach; governance; safety and reliability of the epidemiological approach; data sharing; workforce education and training; ICT infrastructure and infostructure; standards and interoperability; health information exchange; and costs and economic aspects (Figure 4). Participants also identified associated strengths, weaknesses, opportunities, and threats. It is noteworthy that fewer strengths and more weaknesses were identified relative to the other

components of the SWOT analysis (Table 2).

Figure 4: Study participants' priority ranking of key readiness indicators for effective integration of digital epidemiology in pandemic preparedness and response

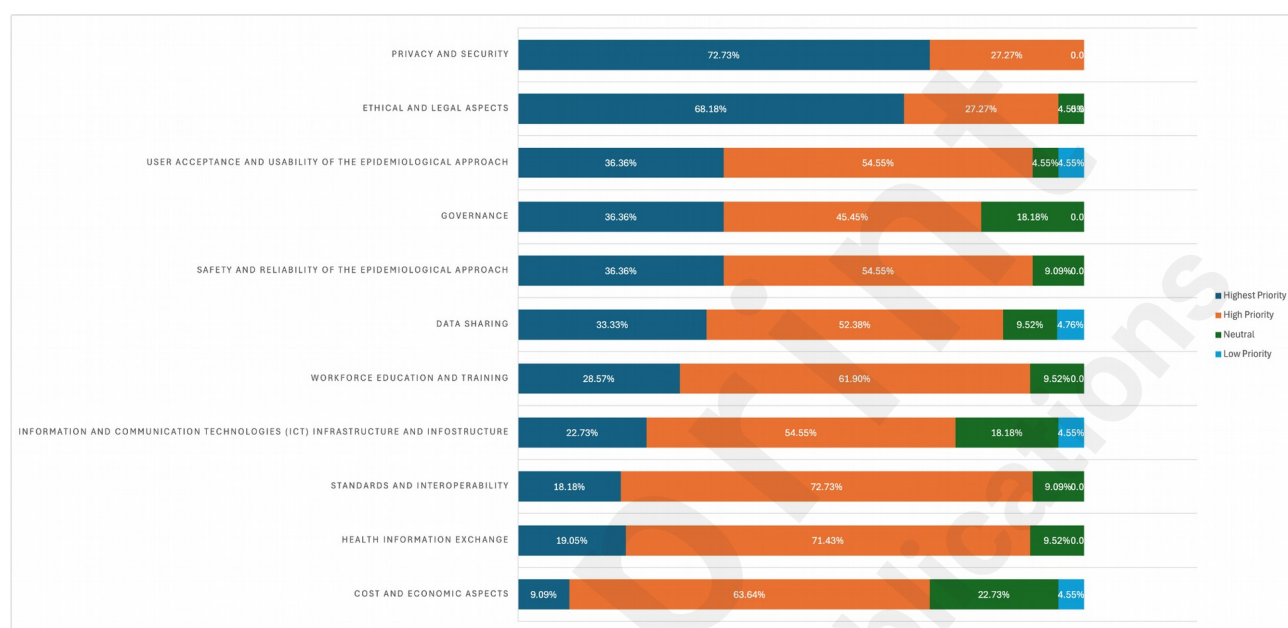


Table 2: Experts' opinions on strengths, weaknesses, opportunities, and threats for effective integration of digital epidemiology in pandemic preparedness and response

SWOT Analysis Categories	Themes Emerging from Participants Responses
Strengths	- Increasing investments in digital technologies by countries
Weaknesses	- Existence of digital health strategies by countries - Limited competent workforce - Weak digital health infrastructure - Digital divide - Poor data quality - Limited data sharing - Digital illiteracy - Limited use of AI/ML - Weak ethical and legal considerations - Disconnect between public health departments and hospitals
Opportunities	- Global open standards that promote data exchange - Global design - International coordination on ethical considerations - Inclusion of the non-health sector
Threats	- Data security - Global economic challenges - Patient acceptance - Ethics - Political interference - Political unawareness

Discussion

Digital epidemiology is a relatively new field that has grown rapidly in recent years, with its humble beginnings traced back to when researchers began mining the increasing amount of internet data for epidemiological purposes [19]. The growth of the field, and thus increased awareness, has been fueled by the growing utility of new data sources and artificial intelligence in epidemiology [20]. The *ad hoc* use of digital epidemiology methodologies and techniques during the COVID-19 pandemic likely contributed to the heightened awareness of the field [21]. This may explain why the majority of study participants, especially in light of their professional backgrounds, reported being aware of the concept of digital epidemiology (Figure 2). However, it is important to note that the attitude of

stakeholders, rather than their awareness, may play a more crucial role in driving sustainable use of digital epidemiology. The Technology Acceptance Model (TAM) features prominently among the methodologies used to measure attitudes toward technology adoption [22-23]. According to TAM, perceived usefulness (PU) is characterized by an individual's belief that using technology improves their job performance, while perceived ease of use (PEOU) refers to their belief that using technology requires minimal effort [22]. Both PU and PEOU are primary drivers that influence attitudes toward using technology [23]. The majority of study participants agreed that digital data can enhance epidemiological purposes (PU), that digital epidemiology can be effectively applied at a global level toward coordinated global health surveillance (PU), and that digital epidemiology is reliable (PU + PEOU). This is illustrated in Figure 3 and reflects participants' positive attitudes toward digital epidemiology, particularly regarding its potential impact and effectiveness in improving global health security.

The Riyadh declaration on digital health is a global call to action promoting the development of infrastructure and best practices necessary for sharing high-quality, real-time data both locally and globally in the fight against pandemics. Its goal is to enable health systems to access actionable information that can inform timely responses to public health threats [24]. Similarly, the U.S. Centers for Disease Control and Prevention (CDC) launched the Data Modernization Initiative (DMI) to enhance the quality, availability, and use of data related to pandemics and public health emergencies [25]. Together, these frameworks serve to guide the integration of digital innovations into national and global health systems as part of coordinated efforts to strengthen preparedness and response to future pandemics. A shared theme emphasized across these frameworks is that leveraging digital epidemiology to address global health threats requires a more robust and integrated global health architecture that is capable of better preparing local, national, regional, and global public health partners to predict, prevent, detect, assess, and respond effectively to emerging threats. This calls for intentional efforts by governments and public health authorities to mitigate digital exclusion at all

levels (global, regional, national, and local) and to address data governance and interoperability challenges inherent in using and sharing diverse data sources [26].

Privacy and security, along with ethical and legal considerations, were ranked by the majority of experts as high priority areas that must be considered by decision makers and implementers to ensure sustainable integration of digital epidemiology tools in preparedness and response to future pandemics (Figure 4). Digital epidemiology, as previously explained, makes effective use of data not originally intended for epidemiologic purposes. Examples of such data include internet searches, social media posts, webpage access logs, mobile phone network data, mobile health applications, wearable devices, sensor generated data, call center records, health and patient registries, and environmental monitoring data [19,21]. Since some of this data is generated outside traditional public health systems and those involved in generating such data may not have consented to or even be aware of its use for epidemiologic purposes, indeed this raises legitimate concerns related to potential data privacy breaches, security vulnerabilities, and ethico-legal issues. The pertinent literature suggests that data on one's health status has potential to be re-used by third parties to discriminate and restrict individual rights, and that institutional and government access to personal data (e.g., geospatial data) could inhibit the exercise of basic freedoms, if individuals feel watched as to what they do or with whom they spend time [27]. In the context of the existing global digital divide and digital access gap, reliance on digital epidemiology to drive pandemic preparedness and response strategies may inadvertently perpetuate existing health disparities. Benefiting overrepresented populations in the data, while not providing gains to, and even possibly harming populations whose data is underrepresented [28]. In light of the current fragmented regulatory landscape and in the absence of a common set of principles on data privacy, security and ethics, a global coordinated approach is required to establish frameworks that will ensure safe and responsible use of digital epidemiology as part of a unified global effort toward future pandemic preparedness and response [29]. Findings from a study based on the Unified Theory of Acceptance and Use of

Technology (UTAUT) framework indicated that cost did not moderate behavioral intention to adopt the technology [30]. This may help explain why, in the current study, experts ranked cost and economic aspects lower among the key readiness factors for the adoption of digital epidemiology (Figure 4).

The World Health Organization's (WHO) Global Strategy on Digital Health 2020–2025 provides a structured roadmap to guide member states in systematically integrating digital health technologies into their national health systems. According to WHO, the vision of the global strategy is to improve health for everyone, everywhere by accelerating the development and adoption of appropriate, accessible, affordable, scalable and sustainable person centric digital health solutions to prevent, detect and respond to epidemics and pandemics [31]. Existence of such a document is indeed a strength in creating an enabling environment for the use of digital epidemiology in future pandemic preparedness and response. Increasing investments in digital technologies by countries and existence of digital health strategies by countries (Table 2), are part of the strategic objectives advanced by the document. The four strategic objectives outlined in the Global Strategy on Digital Health are as follows; 1) promote global collaboration and advance the transfer of knowledge on digital health, 2) advance the implementation of national digital health strategies, 3) strengthen governance for digital health at global, regional and national levels and 4) advocate people-centred health systems that are enabled by digital health [30]. These strategic objectives align with concerns highlighted as weaknesses by experts in Table 2. In addition to data privacy, security, and ethics already discussed, experts identified socio-political challenges and economic constraints as potential threats to a global approach to digital epidemiology (Table 2). This aligns with Davis (2025), who discusses the political determinants of digital health, defining them as the intersecting areas of national and international law and policy, local and global governance, civic engagement, and the influence of transnational commercial interests. The author explains that these factors collectively shape access

to, uptake of, and the design of digital health systems [32]. As a case point, global geopolitical tensions and varying digital health maturity levels of nations can significantly impact data sharing in public health, resulting in lapses in global health security.

The full potential of digital epidemiology in achieving coordinated pandemic preparedness and response can indeed be leveraged through advancements in global design and international collaborations on digital health related issues (Table 2). Opportunities exist in open health data standards [33], which promote interoperability and enable effective data sharing across diverse settings. The World Health Organization's Global Digital Health Strategy Extension: 2025–2027 endeavors to provide critical guidance on artificial intelligence in health, including the ethics and governance of artificial intelligence for health, and aims to support member states through global workshops on ethical AI implementation [34] and the code of ethics for health information professionals of the International Medical Informatics Association (IMIA) [35], are but examples of opportunities that offer a pathway toward safe and responsible use of digital epidemiology as part of a unified global effort for future pandemic preparedness and response. As previously explained, digital epidemiology utilizes data sources beyond the traditional health sector to gain insight into disease patterns and trends. As such, a significant opportunity exists in the continued efforts by global health actors to engage representation from non-health sectors in plans for future pandemic preparedness and response (Table 2). These sentiments are emphasized in the WHO Pandemic Agreement which sets out principles, approaches and tools for better international coordination across a range of areas, in order to strengthen the global health architecture for pandemic prevention, preparedness and response [36]. The WHO Pandemic Agreement perhaps holds great promise towards significantly contributing to creation of an enabling environment for the effective role of digital epidemiology in future pandemic preparedness and response efforts.

Limitations

This study is subject to limitations inherent in its design. The use of convenience and purposive sampling methods limits the generalizability of the findings. The sample may have excluded critical perspectives from underrepresented geographic regions or professional backgrounds. For instance, within the North American region, participants from the United States were heavily overrepresented, with only one participant from Canada, thereby excluding perspectives from other countries in the region. The composition of professional backgrounds represented in the sample may have influenced participant responses, potentially skewing perceptions toward more favorable views of digital epidemiology. These notable imbalances may have constrained the diversity and balance of expert opinions captured.

Conclusions

This study explored experts' perspectives on the potential, readiness factors, and challenges associated with integrating digital epidemiology into global pandemic preparedness and response strategies. The findings underscore a growing recognition of digital epidemiology as a critical tool for enhancing global health security, particularly using non-traditional data sources and emerging technologies such as artificial intelligence. Participants demonstrated high awareness and positive attitudes toward the utility and applicability of digital epidemiology, especially in advancing coordinated global health surveillance. However, the study also identified key barriers that must be addressed to ensure sustainable integration of digital epidemiology into health systems. These barriers include concerns related to data privacy, security, ethics, socio-political influences, and digital inequities across and within countries. The study affirms the need for a globally coordinated approach to governance, regulation, and investment in digital health infrastructure. By highlighting

the complex interplay between technological, institutional, political, and social determinants of digital epidemiology, this research contributes important insights into how global health actors can leverage digital innovations responsibly and effectively for epidemiological purposes. Future research directions should focus on developing and validating context specific frameworks that offer clear guidance for the responsible and sustainable integration of digital epidemiology into existing health systems, to support preparedness for and response to future pandemics.

Acknowledgements

This research was supported by the US Fulbright Scholar Program and the Children's Hospital of Philadelphia, Global Health Informatics Program. We also acknowledge the valuable insights and support from faculty at the Perelman School of Medicine, University of Pennsylvania.

Author contributions

KLM contributed to the study concept and design, as well as data collection. KLM, JHH, AL, and BM contributed to data analysis and interpretation of the results. All authors participated in manuscript preparation, critically reviewed the article, and approved the final version of the manuscript.

Funding

This research was funded by the US Fulbright Scholar program and the Children's Hospital of Philadelphia global health informatics program.

Data availability

The data used and analyzed during the current study is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval for the study and related documents was obtained from the Institutional Review Board (IRB) at the Children's Hospital of Philadelphia (IRB protocol number: IRB 22-020667). Informed consent was obtained from all participants, ensuring their privacy and confidentiality throughout the study. Participants received the survey electronically using REDCap, and consent was obtained after they read the introduction and consent materials prior to starting the survey.

Consent for publication

Not applicable.

Conflicts of Interest

The authors declare no competing interests.

Author details

¹Center for Global Health, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104-6055, USA.²Department of Biostatistics, Epidemiology, and Informatics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104,USA.³ Department of Pediatrics, Perelman School of Medicine, University of Pennsylvania,Philadelphia, PA 19104,USA.⁴Department of Biomedical and Health Informatics,Children's Hospital of Philadelphia,Philadelphia,PA 19104,USA.⁵Department of Biomedical and Health Informatics, Global Health Informatics, Children's Hospital of Philadelphia,Philadelphia,PA 19104,USA.

References

1. International Monetary Fund. Global prospects and policies. In: World Economic Outlook: A Long and Difficult Ascent. 2020. Available from: <https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020>
2. Sirleaf EJ, Clark H. Report of the Independent Panel for Pandemic Preparedness and Response: making COVID-19 the last pandemic. *Lancet*. 2021 Jul 10;398(10295):101–3.
3. de Souza LEPP, Castro MC, Hage Carmo E, Polidoro M. The global failure of facing the pandemic. *Glob Health Action*. 2022 Dec 31;15(1):2124645. doi:10.1080/16549716.2022.2124645. PMID: 36285582; PMCID: PMC9621274.
4. Kamalrathne T, Amaratunga D, Haigh R, Kodituwakku L. Need for effective detection and early warnings for epidemic and pandemic preparedness planning in the context of multi-hazards: Lessons from the COVID-19 pandemic. *Int J Disaster Risk Reduct*. 2023 Jun 15;92:103724. doi:10.1016/j.ijdrr.2023.103724. PMID: 37197332; PMCID: PMC10148710.
5. Williams GA, Fahy N, Aissat D, Lenormand MC, Stüwe L, Zablitz-Schmidt I, et al. COVID-19 and the use of digital health tools: Opportunity amid crisis that could transform health care delivery. *Eurohealth*. 2022;28(1):29–34.
6. Budd J, Miller BS, Manning EM, et al. Digital technologies in the public-health response to COVID-19. *Nat Med*. 2020;26:1183–92. doi:10.1038/s41591-020-1011-4.
7. Ezenwaji CO, Alum EU, Ugwu OPC. The role of digital health in pandemic preparedness and response: securing global health? *Global Health Action*. 2024;17(1):2419694.
8. Asia-Pacific Economic Cooperation. Digital tools for addressing infectious diseases in the Asia-Pacific region: challenges and opportunities. 2021. Available from: https://www.apec.org/docs/default-source/publications/2021/12/digital-tools-for-addressing-infectious-diseases-in-the-asia-pacific-region-challenges-and-opportunities/221_hwg_digital-tools-for-addressing-infectious-diseases-in-the-asia-pacific-region.pdf

9. Al Knawy B, McKillop MM, Abduljawad J, et al. Successfully implementing digital health to ensure future global health security during pandemics: A consensus statement. *JAMA Netw Open*. 2022;5(2):e220214. doi:10.1001/jamanetworkopen.2022.0214.
10. Olusanya OA, White B, Melton CA, Shaban-Nejad A. Examining the implementation of digital health to strengthen the COVID-19 pandemic response and recovery and scale up equitable vaccine access in African countries. *JMIR Form Res*. 2022;6(5):e34363. doi:10.2196/34363.
11. Tarkoma S, Alghnam S, Howell MD. Fighting pandemics with digital epidemiology. *EClinicalMedicine*. 2020 Sep 1;26.
12. European Council. Pandemic treaty op-ed. 2021 Mar 30. Available from: <https://www.consilium.europa.eu/en/press/press-releases/2021/03/30/pandemic-treaty-op-ed/>
13. World Health Organization. WHO welcomes historic commitment by world leaders for greater collaboration, governance and investment to prevent, prepare for and respond to future pandemics. 2023 Sep 20. Available from: <https://www.who.int/news/item/20-09-2023-who-welcomes-historic-commitment-by-world-leaders-for-greater-collaboration--governance-and-investment-to-prevent--prepare-for-and-respond-to-future-pandemics>
14. United Nations. Pandemic discussion at General Assembly. 2023. Available from: <https://press.un.org/en/2023/gaef3587.doc.htm>
15. Harris, Paul A., et al. "Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support." *Journal of biomedical informatics* 42.2 (2009): 377-381.
16. Eysenbach G. Improving the quality of Web surveys: the Checklist for Reporting Results of Internet E-Surveys (CHERRIES). *J Med Internet Res*. 2004 Sep 29;6(3):e34. doi:10.2196/jmir.6.3.e34. PMID:15471760; PMCID:PMC1550605.
17. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol*. 2006;3(2):77–

101.

18. Van Wijngaarden JD, Scholten GR, van Wijk KP. Strategic analysis for health care organizations: the suitability of the SWOT-analysis. *Int J Health Plann Manage* 2012;27(1):34-49.
19. Salathé M. Digital epidemiology: what is it, and where is it going? *Life Sci Soc Policy*. 2018 Jan 4;14(1):1. doi:10.1186/s40504-017-0065-7. PMID:29302758; PMCID:PMC5754279.
20. Jiao Z, Ji H, Yan J, Qi X. Application of big data and artificial intelligence in epidemic surveillance and containment. *Intell Med*. 2023;3(1):36–43.
21. Fallatah DI, Adekola HA. Digital epidemiology: harnessing big data for early detection and monitoring of viral outbreaks. *Infect Prev Pract*. 2024 Jun 29;6(3):100382. doi:10.1016/j.infpip.2024.100382. PMID:39091623; PMCID:PMC11292357.
22. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q*. 1989 Sep;13(3):319. doi:10.2307/249008.
23. Rahimi B, Nadri H, Lotfnezhad Afshar H, Timpka T. A systematic review of the technology acceptance model in health informatics. *Appl Clin Inform*. 2018 Jul 15;9(3):604–34. doi:10.1055/s-0038-1668091. PMID:30112741.
24. Al Knawy B, et al. The Riyadh Declaration: the role of digital health in fighting pandemics. *Lancet*. 2020;396(10262):1537–9.
25. Centers for Disease Control and Prevention. CDC Global Digital Health Strategy: Appendices. Atlanta, GA: U.S. Department of Health and Human Services; 2022. Available from:
https://www.cdc.gov/global-health/media/pdfs/GDHS_Strategy2022_Appendices_REV_508.pdf
26. Li L, Back E, Lee S, Shipley R, Mapitse N, Elbe S, et al. Balancing risks and opportunities: data-empowered-health ecosystems. *J Med Internet Res*. 2025;27:e57237.

27. Ferretti A, Vayena E. In the shadow of privacy: overlooked ethical concerns in COVID-19 digital epidemiology. *Epidemics*. 2022;41:100652.
28. Howe EG III, Elenberg F. Ethical challenges posed by big data. *Innov Clin Neurosci*. 2020;17(10–12):24.
29. United Nations Development Group. Data privacy, ethics and protection: guidance note on big data for achievement of the 2030 Agenda. United Nations; 2017. Available from: https://unsdg.un.org/sites/default/files/UNDG_BigData_final_web.pdf
30. Ahmed ER, Zirari B, Tabet Derraz I. The moderating role of cost and convenience on the relationship in the UTAUT model to adopt e-payment services. *J Int Technol Inf Manag*. 2024;32(1):334–63.
31. World Health Organization. Global strategy on digital health 2020–2025. Geneva: World Health Organization; 2021. Available from: <https://www.who.int/publications/i/item/9789240020924>
32. Davis SL. Political determinants of digital health: beyond the rainbow. *Health Promot Int*. 2025;40(2):daaf014.
33. Kapitan D, Heddema F, Dekker A, Sieswerda M, Verhoeff BJ, Berg M. Data interoperability in context: the importance of open-source implementations when choosing open standards. *J Med Internet Res*. 2025;27:e66616.
34. World Health Organization. Seventy-eighth World Health Assembly – Daily update: 23 May 2025. 2025 May 23. Available from: <https://www.who.int/news/item/23-05-2025-seventy-eighth-world-health-assembly---daily-update--23-may-2025>
35. International Medical Informatics Association. IMIA Code of Ethics for Health Information Professionals. 2016. Available from: <https://imia-medinfo.org/wp/wp-content/uploads/2015/07/IMIA-Code-of-Ethics-2016.pdf>
36. World Health Organization. World Health Assembly adopts historic pandemic agreement to

make the world more equitable and safer from future pandemics. 2025 May 20. Available from: <https://www.who.int/news/item/20-05-2025-world-health-assembly-adopts-historic-pandemic-agreement-to-make-the-world-more-equitable-and-safer-from-future-pandemics>

