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Strengthening disease surveillance capacity at national level across five countries: a qualitative study

A. Meierkord [a, b, *], L. Körner-Nahodilová [a], C.I. Gotsche [a, c], J. Baruch [a], V. Briesemeister [a], C.L. Correa-Martinez [a], J. Hanefeld [a, c]

[a] Robert Koch Institute, Centre for International Health Protection, Nordufer 20, 13353 Berlin, Germany
[b] Charité-Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin and Humboldt-Universität zu Berlin, Charité Center for Global Health, Institute of International Health, 13353 Berlin, Germany
[c] London School of Hygiene and Tropical Medicine, Faculty of Public Health and Policy, 15-17 Tavistock Place, London, WC1H 9SH, United Kingdom

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ABSTRACT

Objectives: Disease surveillance is an essential component of public health and a core function of National Public Health Institutes (NPHIs), including to better prepare and respond to infectious diseases outbreaks. Strengthening NPHIs in their efforts to establish and maintain efficient surveillance systems is an opportunity to ensure future outbreak preparedness and response; yet, guidance on how to increase and prioritise capacity building efforts is limited. This study sought to investigate approaches to capacity building and training for disease surveillance at national level and understand the potential role of NPHIs.

Study design: Qualitative study.

Methods: This is a qualitative study, based on a literature review and interviews undertaken between June and November 2022. Fifty seven in-depth interviews were conducted in five countries: Côte d'Ivoire, Ecuador, Madagascar, Namibia, and the Kingdom of Saudi Arabia. Participants included a range of professionals from government, NPHIs, academic institutions and the private sector. Interviews were thematically analysed.

Results: Selected countries varied in terms of their disease surveillance capacities, as well as in the structure of their surveillance systems and decision-making. Research identified shared priority areas for action at national level, identifying common challenges and opportunities: 1) capacity building, here specifically the need for a training agenda at national level to ensure sustainability and guide donor funded training offers; 2) data tools and technology-to help decision-makers select the best software tool to address countries' identified need; 3) data sharing-the need for clear data sharing standards and norms for national to international data sharing; and 4) genomic sequencing-the need for national genomic surveillance strategies and reporting guidelines.

Conclusion: Addressing challenges and using opportunities to strengthen disease surveillance at national level is an important step to build capacity in this area and to help prevent future epidemic and pandemics globally. The findings of this study help decision-makers to identify priority areas for capacity building and understand the potential role and significance of NPHIs.

Introduction

Disease surveillance is an 'early warning system for impending outbreaks that could become public health emergencies'[1] and therefore key to protect the health of populations globally. Public health surveillance is defined as 'the ongoing, systematic collection, analysis and interpretation of health-related data with the a priori purpose of preventing or controlling disease or injury and identifying unusual events of public health importance, followed by the dissemination and use of such information for public health action'.[2] The World Health Organization (WHO) detects over 7000 public health threat signals every month of which 0.5% result in a field investigation and risk assessment.[3] Public health events of

* Corresponding author. Nordufer 20, 13353 Berlin, Germany.
E-mail address: MeierkordA@rki.de (A. Meierkord).

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international concern that occurred in recent years, such as the Ebola epidemic in West Africa 2014–2016, the COVID-19 pandemic or the recent spread of Mpox have emphasized the importance for countries to collaborate at global level for early detection of emerging infectious diseases and strengthen their national disease surveillance capacities to respond adequately.[4–6] To achieve this, the International Health Regulations (IHR) framework (2005) 'obligates State Parties to develop national capacity for the detection, investigation and reporting through WHO of potential public health emergencies of international concern'.[7] National Public Health Institutes (NPHIs) defined as "government agency, or closely networked group of agencies, that provides science-based leadership, expertise, and coordination for a country's public health activities"[8] are an important part of countries' public health systems' and commonly a countries' disease surveillance activities fall within their mandate.[9] Strengthening NPHIs in their efforts to establish and maintain efficient surveillance systems is an opportunity to ensure future outbreak preparedness and response.[10] Globally, a variety of different disease surveillance systems exist and challenges and opportunities of their effective operationalisation are context specific. The Integrated Disease Surveillance and Response approach is one of the strategies promoted to African countries by the World Health Organization.[11,12] However, multiple challenges regarding its implementation, such as limited resources, a lack of coordination between those who collect data and a variety of surveillance systems, have been documented and identified.[13] Sharing data between different disease surveillance systems and across borders is crucial to recognise signals, respond where required and prevent outbreaks from spreading further and developing into a pandemic. Yet, obstacles exist such as a variety of legal frameworks that can significantly impede the integration of different data sources. This can be the case within countries, for example in federalised systems where states struggle to integrate data at national level or also between countries.[11] One area where the COVID-19 pandemic made the challenges to data sharing between countries visible was in the field of genomics and the use of genomic data in surveillance, as countries were tracking the emergence of new variants of the SARS-COV2 virus. WHO's Global genomic surveillance strategy for pathogens with pandemic and epidemic potential 2022–2032[14] highlights the need to harmonize across systems and countries to be able to use and compare the data effectively.

The COVID-19 pandemic overall brought the challenges and limitation in infectious disease surveillance at national level into stark focus. It revealed the need to better understand these in order to strengthen public health systems at national level around the world. To better understand these challenges, including the 'messy realities' of how systems' work in practice, this qualitative case study examined national level disease surveillance in five countries, focusing on how data was collected, analysed and where possible shared, and how it did (or did not) enable decision-making. Specific attention was on the role of National Public Health Institutes as central actors within this system, on genomic surveillance, and on how to strengthen capacities including through training.

Methods

We undertook an exploratory review of the current state of disease surveillance, in five countries (Côte d'Ivoire, Ecuador, Madagascar, Namibia and the Kingdom of Saudi Arabia). The study objectives were to: 1) identify challenges and opportunities to improve disease surveillance at national level with a focus on NPHIs, 2) identify core areas where disease surveillance capacity needs to be strengthened to enhance epidemic and pandemic preparedness and response and 3) assess how different national level actors collaborate on disease surveillance activities. This was a qualitative study consisting of interviews with key actors in the five countries, a scoping review and document review.[15] Overall, the research was designed around six interconnected domains relating to disease surveillance: human resource capacity, tools and technology development, data sharing and analytic services, normative functions, support for collaborative environments, and policy setting and advocacy. These six strategic domains mirror the strategic objectives of the newly established WHO Hub for Pandemic and Epidemic Intelligence,[16] and were selected for this reason. The study design was additionally informed by a set of initial key informant interviews with disease surveillance experts at international public health organisations.

In total, researchers conducted fifty-seven in-depth interviews across the five countries between June and November 2022. Countries were selected for feasibility, as the Robert Koch Institute has established links through previous projects and meetings with all five countries, and to cover a range of different geographic settings, as well as different surveillance systems. Interviewees were identified using a snowballing methodology starting with key actors at national level recommended by the key informants at global level. Potential interviewees were contacted by phone or email. Informed consent was obtained by all interviewees. All interviews were recorded by hand-written notes. Twenty-four in-depth interviews were additionally recorded and transcribed. Transcripts were coded and thematically analysed, the notes further informed the findings according to the themes that emerged but were not coded systematically. Our study used thematic analysis according to Braun and Clark.[17] Codes were derived both inductively from the data and deductively from the pre-identified topics. Throughout the analysis, analytic memos were created to inform codes, concepts and themes.[18] In order to enhance the validity and reliability of analysis, transcribed interviews were coded by at least two researchers. We used the consolidated criteria for reporting qualitative research (COREQ) checklist to guide the reporting of our methods and results (Supplement 1).

Results

Interviewees have various professional backgrounds, the most common being public health and/or epidemiology 25/57, 43.9%, followed by medical laboratory science 12/57, 21.1% (Table 1). Namibia did not have a NPHI established at the time of the interviews. Overall, 6 interviewees were employed by a NPHI at the time of the interview but other interviewees reported previous employment with a NPHI, consultancy work for a NPHI or employment by a national reference laboratory, hence there was good knowledge about the role of NPHIs across interviewees. Countries included in our study varied in terms of their disease surveillance structures and capacities. Four core themes arose from the interviews as priority areas for capacity strengthening: training and capacity building, data collection and tools, data sharing and genomic sequencing.

Training and capacity building

Adequately building and training the public health workforce in disease surveillance was of great importance to interviewees in all study countries. One of the main challenges raised by multiple interviewees was a limited number of trained personnel at national level, a senior public health official in Namibia highlighted:

> *The challenges we face as a country generally is capacity (…). We have only usually one or two people who are qualified and*

Table 1
Professional background of interviewees.

		Interviewees
Professional background	Public health/epidemiology	25
	Clinical medicine	3
	Politics/health system analysis	6
	Medical laboratory science	12
	Data science	4
	History	1
	Veterinary medicine	6
Total number		57

experienced in a particular space (…) and when they go on leave we are very short staffed. So, capacity is the biggest challenge.

Another challenge raised by multiple interviewees were budget restrictions at national level to expand the public health surveillance workforce and particularly attract people trained in computer or data science as reflected by a public health professional from Madagascar:

[The public health field] is not interesting for computer scientists (…). It's just self-interest (…) because it is less paid.

Moreover, multiple interviewees reported the lack of a training agenda at national level according to countries' priorities as a key challenge to ensures sustainability in disease surveillance capacity building and longer-term planning. Most interviewees reported that countries complement their national training programmes with those offered by international actors including academic institutions, non-governmental organisations or regional and multilateral organisations. These trainings offered, while addressing an obvious need were often reported as fragmented, ad-hoc planned and of varying quality. This identified lack of sustainability in terms of capacity building at national level arising from irregular external funding was highlighted by a public health veterinarian from Côte d'Ivoire:

[The training for veterinary surveillance in the community] is funded on some external project (…) it's why we want to put in place something which is very regular that is fund[ed] on a national budget (…).

Multiple opportunities to overcome these challenges were suggested, with the increase of budget allocated for the expansion of the public health surveillance workforce and the definition of a training agenda at national level which is developed according to the countries' needs to help guide donor funded training offers as the central factors. In Namibia specifically, it was mentioned that capacity building in disease surveillance needs to be prioritized by decision-makers to help with the establishment of a NPHI as highlighted by a member of staff of the Ministry of Health:

One of the important lessons that we learned during [the COVID-19 pandemic] was that we need to establish a Public Health Institute (…) An institute that (…) will not only respond to the current epidemic, or the current pandemic, but future epidemics and pandemics. So, for that to happen, we need to build capacity.

Another point emphasized aiding the improvement of analytical capacities was the advancement of Field Epidemiology Training Programs (FETP). These were highlighted to have created capacity at both the local and central level in Madagascar, Ecuador and Namibia for example. In all three countries the programme depended on external funding.

Data tools and technology

In all countries with the exception of the Kingdom of Saudi Arabia the majority of surveillance data was collected manually and often processed manually due to a lack of efficient software for data management. As illustrated by a senior Ministry of Health staff member in Madagascar, manual wrangling and management of data is still widespread and it creates a large burden on the public health workforce, slows down data transfer and generates errors.

So, for me it's especially [the] speed of the information (…). Because we really used the internet, but- we don't have efficient software for data processing (…). It's always related to this software, because [data management] it's done manually.

Furthermore, training on the different software tools when introduced is often lacking and there is a need to generally advance data analysis and interpretation skills at national level as highlighted by a senior public health professional from Madagascar:

Yes, there are epidemiologists but (…) it's the actual informatics training that is needed (…) so maybe to improve [data analysis] we just need that specific training (…) in informatics for health care personnel.

The interviewees also highlighted two opportunities to overcome these challenges. First, the introduction of software tools to help with the manual data management. Second, the need to strengthen data analysis skills, for example by incorporating FETP programmes within core budgets, indicating that there is room for policy and advocacy in this area.

Data sharing

Internationally, national surveillance data are shared through WHO as well as through regional structures and cross-border collaborations. The interviewees highlighted the role that regional structures play in the creation of collaborative environments and enhance their trust to share data with neighbouring countries. For example, most of participating countries highlighted that information on outbreak alerts are often shared through local structures such as West African Health Organization (WAHO), La Commission de l'Océan Indien (COI), Southern African Development Committee (SADC), and Organismo Andino de Salud - Convenio Hipólito Unánue (ORAS CONHU). For example, in Namibia, it was pointed out that data were shared with neighbouring countries like South Africa; in Madagascar it was reported that the COI played a key role in sharing data; in Côte d'Ivoire data were shared with neighbouring countries like Guinea as reflected by the quote from a medical laboratory expert:

Neighbouring countries always share this kind of information [outbreak alerts];

and in Ecuador, ORAS COHNU was highlighted as a venue for sharing research and disease interventions experiences.

Two challenges were mentioned for international data sharing. First, while regional collaborations provided a space to share experiences, it was pointed out that these communications are largely dependent on personal initiatives. As a consequence, there are irregular data sharing intervals and standards, which in turn cause a lack of comparability and difficult data quality assessments. Second, countries also pointed out to the negative consequences of sharing data, which may deter countries from engaging in sharing

practices. Specifically, countries mentioned South Africa as an example which faced travel bans after reporting the detection of the SARS-CoV-2 Omicron variant. The interviewees saw a potential facilitator in the support of collaborative environments, such as regional structures, to share data and experiences. Depending on the interviewee, these experiences ranged from epidemic intelligence activities conducted in the countries, to joint efforts to contain disease outbreaks by sharing data and experiences, and to research initiatives to build capacity. NPHIs and equivalents were identified as the central institution in their disease surveillance system to engage and foster these. Another facilitator mentioned was the creation of norms and standards to facilitate data sharing practices, specifically mentioned genomic data, and thus incentivise, guide and increase trust to share such data.

Genomic sequencing

In all five countries, the capacities to use molecular diagnostics was reported to be strong at the capital and in larger cities. Additionally, the use of sequencing to guide policy has been increasing throughout the last years of the COVID-19 pandemic. Depending on the country, laboratory activities were carried out by government, private laboratories, the Institute Pasteur, universities in various collaborative endeavours among national and international institutions. While genomic sequencing capacities have increased in all countries over the past years, there remain substantial inequities to monitor the spread of new pathogens or pathogen sub-lineages. Furthermore, strategies to address challenges experienced with increasing sequencing capacities and operationalise genomic surveillance at national level were lacking in most countries. Another challenge reported were the limited trained workforce to undertake genomic sequencing as highlighted by a public health professional in Namibia:

> *[There is an] inadequate number of technical experts who are trained in genomic sequencing (…) And so, that I think would be, for me, an area of opportunity to train more of our people.*

No sustainable funding and a lack of material (in particular issues with the procurement of reagents) were also mentioned as a key challenge to expand sequencing capacity, as reflected by a public health professional in Madagascar:

> *(…) right now, we don't have enough reagents to operate, to do the sequencing.*

And reflected by a senior public health laboratory expert from Côte d'Ivoire:

> *This is a problem! (…) it's the cost of the machines, and the cost of the reagents (…) This is a problem in sub-Saharan Africa. We wanted to buy tests for screening.*

It was also raised that the selection of samples to be sequenced and lacking guidance on the number of sequenced samples were key obstacles, hence more national guidance needed as reflected by a senior laboratory professional in Namibia:

> *This is always a question that I keep on asking my colleague from the Ministry of Health to say, "But can you please have then, I call it, a research agenda (…). Can you give us those pathogens of interest for Namibia?" Because (…) if you ask me, surely TB would be number one, (…) HIV, cancer (…) At least I will have those three. Then malaria is still in Namibia. But then, I also don't want to live out, I think the One Health approach is quite very important.*

Furthermore, discrepancies on the number of sequences uploaded to international data platforms such as GSAID due to a lack of guidelines for reporting sequencing data might cause data duplication and error as reflected by a laboratory professional from Namibia:

> *There is GISAID and I think there's also Nextstrain, if I'm not mistaken. But then when you compare the number of sequences that, for instance, Namibia put there, there's discrepancy between these two database[s].*

The need to have standardized guidelines for sequencing data was pointed out as an opportunity towards better standards for sharing sequencing data internationally as highlighted by a laboratory professional from Namibia:

> *And some of the question I had, which until now, WHO can't answer for me, if I use this essay, then I got to know that, okay, we pick up this variant, where do I report them? Until today, there's no way you can report this.*

Discussion

Our study identified important challenges, opportunities and priority areas for capacity building in disease surveillance at national level. While five very different countries in terms of geographical location, economic development and capacity of disease surveillance system were included, mutual priority areas in terms of capacity building were identified. These included training and capacity building, data tools and technology, data sharing and genomic sequencing. Building capacity in these areas was identified as being significant to establish and strengthen NPHIs.

We found that multiple training opportunities for the public health surveillance workforce exist but training opportunities are fragmented, which contrasts with other key health-related occupations such as medicine and nursing.[19] Moreover, training opportunities are often supported by international donors on short-term funds in low- and middle-income countries which makes it difficult to ensure sustainable capacity building, in particular if the training offers are not implemented according to a training agenda addressing country needs. This lack of a whole-system approach is not new to the public health profession.[20,21] Our study identified the design of a training agenda at national level as one of the central opportunities when building a well-trained public health surveillance workforce sustainably. Through this agenda, donors would pledge to the agenda priorities, facilitating financial assignments and ensuring longer-term planning and coordination at national level. A similar approach is used to finance humanitarian interventions through the Humanitarian Response Plan.[22] Borrowing methodologies from other disciplines might aid in streamlining international efforts while increasing national capacities with a long-term outlook. In order to establish such a training agenda, competencies for a public health surveillance workforce need to be defined. Efforts to define competencies for a public health workforce have been increasing in recent years.[23–26] Yet, core competencies for a national public health surveillance workforce that focuses on infectious disease surveillance, risk assessment, and emergency response are lacking in most countries. This corresponds with WHO and the International Association of Public Health Institutes and partner organisations who launched a roadmap for scoping, defining, and building the capacity of the public health and emergency workforce to deliver the essential public

health functions tailored to country needs.[27] NPHIs as a central actor within countries' public health system could take the lead in drafting such a training agenda according to countries' needs. Our study also found that increasing country's FETP capacity is important to expand the disease surveillance workforce as a whole. This is supported by a large body of literature on the programme which highlights its relevance in disease surveillance and outbreak response generally.[15,28,29]

Our study found that a key challenge is that the majority of data within a countries' surveillance systems is collected and processed manually, creating a large burden on the public health workforce, slows down data transfer and generates errors. New technologies may support collecting and analysing large volume of complex data sets.[16] This was also supported by our study findings as the introduction of software tools was mentioned as a major opportunity to overcome manual data management. While generally the introduction of software tools was seen as positive, there is a need to be mindful of the benefit of introducing different software running in parallel.[30] The mapping of objectives of a given software tool could help decision-makers with the selection of a tool that would best address the country need, avoiding an uncoordinated integration of new software tools and help clarify their best use. Furthermore, establishing evaluation cycles to assess surveillance systems regularly if the system addresses the public health needs of a country is crucial.[31] Our findings reflect the current situation of a wide span of development and digital transition that public health systems currently undergo, with many countries trying to digitalize their surveillance system and at the same time considering the integration and leveraging the potential of emerging computing sciences such as in genomics and artificial intelligence.[32] We found that these processes are often uncoordinated and are faced with infrastructure gaps, which aligns with challenges identified from a recent scoping review on the development of digital public health interventions.[33] Another recent systematic review identified six use cases for involving artificial intelligence in pandemic preparedness and response with one of them being 'surveillance and outbreak detection', underlining the opportunity of artificial intelligence in disease surveillance.[34] At the same time, the authors also identified that few of the current machine learning based solutions have been optimized for practical public health applications early in a pandemic reflecting that surveillance data remains underutilized for action possibilities with artificial intelligence.

Opportunities and priority areas for capacity building that our study identified, included the creation of clear standards and norms to facilitate data sharing practices, specifically for genomic data. The provision of a set number of indicators to ensure best practices, i.e. definition of priority pathogens, periodicity, % of samples to sequence, and data sharing platforms is needed. In November 2022, the WHO published guiding principles for pathogen genome data sharing which align with the findings of our study and call on institutions within the global system of pathogen genome data sharing that operate different sharing platforms to collaborate on identifier systems and data reporting standards to increase interoperability and relevance for decision-makers.[35] Furthermore, pathogen genomic experts recently called for an investment in a federated data-management system for genomic epidemiology across Africa to address the lack of data management infrastructure within individual countries across the continent.[36] Our study also found that collaborative environments were seen as an important opportunity to help build trust among actors and provide a space for sharing experiences and outbreak-specific data. Our findings also highlight the important role of NPHIs as key actors engaging in regional structures (e.g. COI, WAHO, SADC, ORAS CONSU, Gulf Center for Disease Prevention and Control) that foster collaborative environments. This finding aligns with current literature body on the importance of investing in NPHIs to strengthen public health system and disease surveillance.[37] Strengthening genomic surveillance capacities was seen as a key priority area to strengthen disease surveillance at country level, yet national strategies to overcome many of the infrastructural, funding and workforce challenges that countries face were lacking. WHO published recently a guiding document for the development of national genomic surveillance strategies that could support countries with the establishment and discussion of key considerations.[38] Nevertheless, it is important to be mindful of recommending investments particularly in resource scarce settings. While evidence for cost-effectiveness of genomic sequencing in the surveillance of pathogens that are foodborne or cause healthcare associated infections has been identified in high-income settings, there remain gaps for economic evaluations to assess resource scarce settings and for the development of economic evaluation frameworks to increase comparability of such evaluations across countries.[39] Ideas for mitigating the cost of operationalising genomic surveillance across Africa include using functional networks of multipathogen genomic facilities, high-level multiplexing, centralised bulk purchasing, and price negotiations with manufacturers.[40] Additionally, the WHO suggests countries to undertake stakeholder mapping to identify new funding sources with multisectoral engagement that aim to narrow funding gaps identified by countries.[38]

The potential of integrated disease surveillance while not a specific focus of our study findings, should be taken into considerations when discussing strengthening disease surveillance capacities. While this concept has existed for decades to ensure efficient and coordinated responses to disease outbreaks,[12] the findings of our study align with key challenges identified by a recent synthesis report that assessed the state of integrated disease surveillance across seven countries, such as that funding for strengthening of their public health surveillance workforce is often driven by donor's interest rather than countries' needs in countries relying on external support.[11] Importantly, the authors suggest that NPHIs could act as catalysts and system leaders for integrated disease surveillance reinforcing the significance of strengthening NPHIs.

Limitations

The representativeness of the countries selected for interviews were a limitation in our study. While we covered three different geographical regions, consultations were limited to five countries. While this approach brought challenges in comparing diverse surveillance systems and geographical regions, it allowed us to have an overview of an array of disease surveillance efforts by identifying opportunities and protracted challenges at national level.

Conclusion

Strong disease surveillance capacities at national level can contribute to prevent future epidemic and pandemics. Our study adds to the current body of literature that identifies the need for a training agenda at national level to ensure sustainable capacity building and guide donor funded training offers; mapped objectives of software tools to help decision-makers select the best tool to address countries' identified need; establishment of norms and standard for national to international data sharing, the support of collaborative environments; and the need for national genomic surveillance strategies and reporting guidelines as priority areas for capacity building to strengthen disease surveillance at national level. Furthermore, it highlights the significance of NPHIs in building these capacities. Our findings may help to guide decision-making on prioritising disease surveillance capacity building needs

particularly at national level and to understand the potential role and significance of strengthening NPHIs.

Author statements

Ethical approval

This project obtained ethical approval from Ärztekammer Berlin in Germany (N.: Eth-24/22), and was approved by the data protection department of the Robert Koch Institute in Germany. Ministries of Health of the included countries were contacted prior to the interviews by email about the project with the information sheet and all five ministries indicated their support and approval to conduct the study.

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Competing interests

None.

Contributors

AM, LK, CG and JH conceptualised the project. AM, LK, CG and JH designed the methodology. Data was collected by AM, LK, JB, VB and CLCM. The formal analysis was performed by AM, LK, CG and JB and discussed with JH. AM and CG prepared the original draft and all authors reviewed and edited the documents and approved the final version.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2024.04.040.

References

1. World Health Organization (WHO). Surveillance in emergencies [Available from: https://www.who.int/emergencies/surveillance.
2. Lee LM, Thacker SB. Public health surveillance and knowing about health in the context of growing sources of health data. *Am J Prev Med* 2011;**41**(6):636–40.
3. World Health Organization (WHO). *WHO's global health emergency appeal, 2022*. 2022.
4. World Health Organization (WHO). Mpox (monkeypox) outbreak 2022 Available from: https://www.who.int/emergencies/situations/monkeypox-oubreak-2022.
5. World Health Organization. *Strengthening the global architecture for health emergency preparedness, response and resilience*. 2022. May.
6. Morgan OW, Aguilera X, Ammon A, Amuasi J, Fall IS, Frieden T, et al. Disease surveillance for the COVID-19 era: time for bold changes. *Lancet* 2021;**397**(10292):2317–9.
7. World Health Organization. *International health Regulations*. Third edition; 2016.
8. International Association of National Public Health Institutes (IANPHI). *National public health institutes core functions & attributes*. Available from: https://ianphi.org/_includes/documents/sections/tools-resources/nphi-core-functions-and-attributes.pdf.
9. The International Association of National Public Health Institutes (IANPHI). *Building global public health capacity*. 2023. Available from: https://www.ianphi.org/.
10. Centers for Disease Control and Prevention. *National public health institutes fact sheet*. 2023. Available from: https://www.cdc.gov/globalhealth/healthprotection/resources/fact-sheets/nphi-fact-sheet.html.
11. Lee ACK, Iversen BG, Lynes S, Rahman-Shepherd A, Erondu NA, Khan MS, et al. The state of integrated disease surveillance in seven countries: a synthesis report. *Publ Health* 2023;**225**:141–6.
12. World Health Organization (WHO). *Integrated epidemiological surveillance of diseases: regional strategy for communicable diseases (resolution AFR/RC48/R2)*. 1998. Harare, Zimbabwe.
13. Phalkey RK, Yamamoto S, Awate P, Marx M. Challenges with the implementation of an Integrated Disease Surveillance and Response (IDSR) system: systematic review of the lessons learned. *Health Pol Plann* 2015;**30**(1):131–43.
14. World Health Organization. *Global genomic surveillance strategy for pathogens with pandemic and epidemic potential, 2022–2032*. 2022.
15. Gotsche CI, Meierkord A, Baruch J, Körner-Nahodilová L, Weishaar H, Hanefeld J. Approaches, challenges, and opportunities to strengthen the epidemic intelligence workforce: a scoping review. *Publ Health* 2023;**225**:353–9.
16. Morgan O, Pebody R. The WHO Hub for Pandemic and Epidemic Intelligence; supporting better preparedness for future health emergencies. *Euro Surveill* 2022;**27**(20).
17. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol* 2006;**3**(2):77–101. https://doi.org/10.1191/1478088706qp063oa.
18. Saldana J. *The coding manual for qualitative researchers*. 3rd ed. ed. SAGE publishing; 2015.
19. Tao D, Evashwick CJ, Grivna M, Harrison R. Educating the public health workforce: a scoping review. *Front Public Health* 2018;**6**.
20. Usher AD. Health systems neglected by COVID-19 donors. *Lancet* 2021;**397**(10269):83.
21. World Health Organization (WHO). *Building health systems resilience for universal health coverage and health security during the COVID-19 pandemic and beyond: a brief on the WHO position*. Geneva. 2021.
22. United Nations Office for the Coordination of Humanitarian Affairs. *Humanitarian response plan 2023*. 2023. Available from: https://www.ochaopt.org/coordination/hrp-2023.
23. Olu O, Usman A, Kalambay K, Anyangwe S, Voyi K, Orach CG, et al. What should the African health workforce know about disasters? Proposed competencies for strengthening public health disaster risk management education in Africa. *BMC Med Educ* 2018;**18**(1):60.
24. Bhandari S, Wahl B, Bennett S, Engineer CY, Pandey P, Peters DH. Identifying core competencies for practicing public health professionals: results from a Delphi exercise in Uttar Pradesh, India. *BMC Publ Health* 2020;**20**(1):1737.
25. Bornioli A, Evans D, Cotter C. Evaluation of the UK public health skills and knowledge framework (PHSKF): implications for international competency frameworks. *BMC Publ Health* 2020;**20**(1):956.
26. World Health Organization (WHO) Regional Office for Europe. *WHO-ASPHER competency framework for the public health workforce in the European region*. 2020. Copenhagen.
27. World Health Organization (WHO). *National workforce capacity to implement the essential public health functions including a focus on emergency preparedness and response: roadmap for aligning WHO and partner contributions*. 2022. Geneva.
28. Parry AE, Kirk MD, Durrheim DN, Olowokure B, Colquhoun SM, Housen T. Shaping applied epidemiology workforce training to strengthen emergency response: a global survey of applied epidemiologists, 2019-2020. *Hum Resour Health* 2021;**19**(1):58.
29. Wilson K, Juya A, Abade A, Sembuche S, Leonard D, Harris J, et al. Evaluation of a new field epidemiology training program intermediate course to strengthen public health workforce capacity in Tanzania. *Publ Health Rep* 2021;**136**(5):575–83.
30. Katherine W, Vanessa M, Mikael G-M, Jenny R, Julia J. Software tools to facilitate community-based surveillance: a scoping review. *Glob Health* 2023;**11**(5):e2200553. Science and Practice.
31. Calba C, Goutard FL, Hoinville L, Hendrikx P, Lindberg A, Saegerman C, et al. Surveillance systems evaluation: a systematic review of the existing approaches. *BMC Publ Health* 2015;**15**:448.
32. Donelle L, Comer L, Hiebert B, Hall J, Shelley JJ, Smith MJ, et al. Use of digital technologies for public health surveillance during the COVID-19 pandemic: a scoping review. *Digit Health* 2023;**9**:20552076231173220.
33. Iyamu I, Gómez-Ramírez O, Xu AX, Chang HJ, Watt S, McKee G, et al. Challenges in the development of digital public health interventions and mapped solutions: findings from a scoping review. *Digit Health* 2022;**8**:20552076221102255.
34. Syrowatka A, Kuznetsova M, Alsubai A, Beckman AL, Bain PA, Craig KJT, et al. Leveraging artificial intelligence for pandemic preparedness and response: a scoping review to identify key use cases. *NPJ Digit Med* 2021;**4**(1):96.
35. World Health Organization. *WHO Guiding principles for pathogen genome data sharing*. 2022. Geneva.
36. Christoffels A, Mboowa G, van Heusden P, Makhubela S, Githinji G, Mwangi S, et al. A pan-African pathogen genomics data sharing platform to support disease outbreaks. *Nat Med* 2023;**29**(5):1052–5.
37. Myhre SL, French SD, Bergh A. National public health institutes: a scoping review. *Global Publ Health* 2022;**17**(6):1055–72.
38. World Health Organization (WHO). *Considerations for developing a national genomic surveillance strategy or action plan for pathogens with pandemic and epidemic potential*. 2023. Geneva.
39. Tran M, Smurthwaite KS, Nghiem S, Cribb DM, Zahedi A, Ferdinand AD, et al. Economic evaluations of whole-genome sequencing for pathogen identification in public health surveillance and health-care-associated infections: a systematic review. *The Lancet Microbe* 2023;**4**(11):e953–62.
40. Inzaule SC, Tessema SK, Kebede Y, Ogwell Ouma AE, Nkengasong JN. Genomic-informed pathogen surveillance in Africa: opportunities and challenges. *Lancet Infect Dis* 2021;**21**(9):e281–9.