# Training Needs for Emerging Infectious Diseases Research, Surveillance and Control in High-Risk and Resource-Constrained Settings: Findings and Recommendations for Uganda

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## Abstract

# Background

Uganda is prone to Emerging Infectious Diseases (EIDs) which can cause serious epidemics and pandemics. Uganda's capacity for EID research, surveillance and control is improving but still low partly due to inadequate highly knowledgeable and skilled human and animal health workers. To inform the design of training programs that can address Uganda's health workforce capacity gaps, we conducted a training needs assessment.

# Methods

A qualitative study involving a desk review, 25 key informant interviews and a 1-day consultative workshop to review study findings.

# Results

The majority of infectious disease research, surveillance and control in Uganda focuses on HIV/AIDS, Tuberculosis, Malaria and viral hemorrhagic fevers *e.g.*, Ebola and Marburg. Health workforce capacity for surveillance and control is robust compared to many other resource-constrained settings but research capacity and output are relatively low, especially for EIDs. Public and private tertiary institutions in Uganda predominantly offer training in primary health care and population studies through problem-based learning, community-based education and services, and Blended Learning (BL). There are several training programs in advanced clinical and epidemiological sciences, but few opportunities in biomedical sciences (*e.g.* virology, immunology, bioinformatics and predictive modeling), social sciences, One Health and leadership. To address the gaps, the following interventions were recommended: 1) advanced graduate and/or post-graduate training in basic biomedical sciences; 2) short-term training for continuous knowledge and skills development in multidisciplinary/One Health approaches; and 3) pedagogy and mentorship through BL, networking and experiential training programs that effectively leverage North-South collaborations. Training and mentorship should be achieved by (a) conducting most of the in-person didactic and experiential training at Southern tertiary and research institutions, (b) utilizing electronic-learning for didactic training and mentor-mentee interactions with subject-matter experts at Northern institutions, and (c) well-orchestrated placements at Northern institutions for hands-on experience using the latest advances in science and technology.

# Conclusion

Inadequate health workforce capacity for EID research was identified as a priority gap that requires long and short-term multidisciplinary training interventions. Efficiently leveraging North-South collaborations for e-learning, short-term placements and mentorship will enable Uganda to remain abreast with latest advances in science and technology for EID research, surveillance and control.

## Background

Uganda is a low-income country that is at high risk of emerging infectious diseases (EIDs) including HIV and high consequence pathogens such as Ebola and Marburg given its geographic location, biodiversity, and climate [1,2,3,4,5]. EIDs in Uganda *e.g.* the recent Anthrax (26 May 2022) and Yellow Fever (23 March 2022) outbreaks [6] can be transmitted locally and internationally via porous borders and international travel causing epidemics and pandemics which cripple socioeconomic systems and pose serious existential threats as evidenced by coronavirus disease 2019 (COVID-19) [7,8,9,10,11].

One of the most important steps in eliminating EIDs in Africa is strengthening the human and animal health workforce including researchers and scientists [12]. Several public and private tertiary institutions in Uganda *e.g.* Makerere University (Mak), Mbarara University of Science and Technology (MUST) and Gulu University (GU) offer training in courses that are relevant to EID research, surveillance and control; however, few students matriculate at graduate-level and even fewer develop into independent researchers who can significantly contribute to Uganda's efforts to prevent and respond to EIDs [13,14,15]. This is largely due to a number of structural barriers, limited access to funding, lack of training and mentorship approaches and programs that are abreast with Uganda's context-specific health needs and latest advances in science and technology [16,17,18,19,20].

To adequately and sustainably address EIDs, we conducted a training needs assessment (TNA) to identify competency, essential knowledge and skills gaps, and identify training approaches to address the gaps in Uganda.

# Methods

### Study Design

The TNA was performed using qualitative methods including a desk review and 25 key informant interviews (KIIs) among purposively selected professional cadres who are actively involved in EID research, surveillance and control in Uganda. A 1-day consultative workshop was held to review and verify the collected data and brief key stakeholders.

### Data Collection

Desk review: Following a pre-designed desk-review guide (refer to Supplemental File 1), we performed a PubMED and Google Scholar search for peer-reviewed articles and abstracts in EID using combinations (and/or) of key words including emerging, infectious, diseases, research, surveillance, control, health, training, capacity, needs, gaps and Uganda. This generated relevant search terms/queries including: 1) '(emerging) and/or (infectious) and (diseases) and (capacity) and (Uganda)'; 2) '(emerging) and/or (infectious) and (diseases) and (training) and/or (needs) and (Uganda)'; 3) '(emerging) and/or (infectious) and (disease) and (research) and (capacity) and/or (needs) and (Uganda); and 4) '(health) and (training) and/or (needs) and (Uganda)'. We selected articles and abstracts for analysis based on key words in titles and setting-specific focus on Uganda. We also selected grey literature (short-term and graduate-level curricula) from premier tertiary institutions in Uganda *i.e.* Makerere University College of Health Sciences (MakCHS), Makerere University College of Veterinary Medicine, Animal Resources and Biosecurity (MakCOVAB) and Makerere University College of Humanities and Social Sciences (MakCHUSS) based on the relevance of the title to EID research, surveillance and control. The researchers also selected websites of institutions involved in tertiary training, and infectious disease research, surveillance and control in Uganda *e.g.* The Uganda Ministry of Health (MoH), Mak, MUST, GU, Uganda Virus Institute (UVRI) and Makerere University Walter Reed Project (MUWRP) based on the availability of Uniform Resource Locators (URL)/links/page titles with either (1) various combinations of the aforementioned key words or (2) title pages with direct relevance to EIDs and health education. Lastly, we searched the NIH RePORTER for relevant past and present funded activities using only select combinations of the key words *i.e.* Uganda, emerging, infectious, diseases, research, and training. Identifiable information including title, digital object identifier (DOI), citations and URLs of articles, abstracts, grey literature and websites that were selected for further review and analysis were summarized in tables in Microsoft Office Word™.

Key informant interviews: We purposively selected key informants who are actively involved in EID research, surveillance and control in Uganda and contacted them by email and/or phone call to schedule a private interview at their preferred location. Using a pre-designed semi-structured KII guide and notetaking forms (refer to Supplemental File 2), and 3) we conducted 25 KIIs (including 23 face-to-face interviews and 2 virtual interviews using Zoom) in English and recorded the interviews using an Olympus voice recorder. The KIIs lasted 30 to 60 minutes and all Key Informants provided written informed consent.

### Data Analysis and Management

Desk review: We performed content and thematic analysis of the selected articles, abstracts, and websites/webpages largely focusing on reviewing the methods, results/findings and conclusion/key message to identify relevant concepts and themes including: 1) current capacity for EID research, surveillance and control; 2) relevant training in EID research, surveillance and control; 3) knowledge and skills gaps in Uganda; 4) present and future training approaches. We also conducted thematic and content analysis of the selected grey literature focusing on training program description, objectives, curriculum and learning outcomes to identify content and themes including pedagogy approaches and course units relevant of EID research, surveillance and control (*e.g.* research methods, statistical analysis, epidemiology, virology *etc*). Finally, we reviewed all search terms/queries including various combinations of key words, selected literature and websites, and summary findings for completeness and accuracy and stored all data files on password protected computers.

Key informant interviews: We reviewed all audio recordings for completeness, anonymized, and transcribed them verbatim. Data was coded and reviewed for consistency and consensus. We subsequently performed content analysis to categorize participant demographics including gender, education and expertise; and thematic analysis to identify the 4 concepts/themes mentioned above. We summarized the findings in Microsoft Excel™ (Refer to Supplemental File 4). All audio files, transcripts and summary findings did not contain personal identifiers to ensure privacy and confidentiality

Consultative Workshop: We held a 1-day consultative workshop to share findings through PowerPoint presentations and open-ended discussions with subject-matter experts and stakeholders in Uganda (Refer to Supplemental File 5 for Workshop Agenda).

# Results

### Study Participants Demographics

All 25 Key Informants were at least 18 years old and 84% (n=21) were males. Only 18% (n=5) of the key informants were heads of academic or research institutions, 40% (n=10) were trainers at tertiary institutions (*i.e.* professors or lecturers), 52% (n=13) were EID researchers including 7 senior and 4 early-career researchers, 28% (n=7) were government officials, 16% (n=4) were in-service professionals *i.e.* consultants or employees of non-government organizations involved in EID research, surveillance and control. A majority 88% (n=22) had graduate-level training (*i.e.* 10 masters and 12 PhDs or MDs), 48% (n=12) of key informants were public health specialists and 32% (n=8) were basic biomedical scientists practicing either microbiology, immunology, virology, genomics or bioinformatics. Only 28% (n=7) of key informants were medical doctors and 11% (n=3) were veterinarians.

### Current Capacity for EID research, surveillance and control

The reviewed literature revealed that the vast majority of Uganda's capacity for infectious disease research, surveillance and control is centered around HIV/AIDS, TB, Malaria and viral hemorrhagic fevers *e.g.* Ebola and Marburg [21,22,23,24,25,26,27]. In 2001, Uganda adopted the World Health Organization's Integrated Disease Surveillance and Response (IDSR) and the Uganda Ministry of Health (MoH) coordinates most of the on-going activities which largely focus on surveillance and control to meet the 2005 International Health Regulations (IHR) core capacities to prevent, detect and respond to infectious disease threats [28,29,30,31,32]. The Global Fund Project and the U.S. President's Emergency Plan for AIDS Relief (PEPFAR) fund and provide technical support for most of the on-going surveillance and control activities in HIV/AIDS, TB and Malaria [33,34], and the few on-going research activities mainly involve clinical or community-based studies and a limited number of pre-clinical studies [35]. In 2020, the Essence on Health Research ranked Uganda as having Upper Medium Research Capacity based on the number of clinical trials, international grants (World RePORT), publications (PubMED) and training institutions offering PhDs[36]. However, research output is still low mainly due to structural barriers including inadequate funding and government support and coordination [37,38,39,40,41].

Evidence from the desk review was further corroborated by a majority of key informants. All key informants mentioned that Uganda has some capacity for infectious disease research, surveillance and control with particular strengths in field epidemiology. Fourteen informants mentioned that there is limited funding especially for EID research; 12 mentioned a lack of adequate laboratory capacity, especially in detecting new pathogens and developing interventions such as diagnostic tools, vaccines and therapeutics; 9 highlighted the lack of adequate multisectoral coordination and/or One Health approach. Below are quotes from some key informants highlighting the gaps in EID research, surveillance and control capacity in Uganda:

*The research component* [of EIDs] *is very weak, but surveillance and control is okay*. (KI_06).

*They* [EIDs] *are only taken seriously if they emerge, if they are not there, no one listens so that is a challenge in itself. There is no funding.* (KI_09)

*So, when you are as a nation, you don't have that first-line of capacity to be able to detect any emerging disease or characterize a pathogen, or develop a diagnostic, then you are too dependent on other people* [countries with better capacity]. (KI_20)

*The most challenging* [aspect of EID research, surveillance and control] *is working with different partners that have got different interests and managing those interests.* (KI_10)

### Relevant Training in EID Research, Surveillance and Control

In Uganda, Mak, MUST, GU and a few other public and private tertiary institutions are the predominant source of the health workforce including medical, veterinary and social scientists [42,43,44,45,46,47]. However, many Ugandan tertiary institutions have a limited capacity to offer training in the latest advances in science and technology to address Uganda's challenges with EIDs [48,49,50,51,52,53,[54]. Makerere University is the premier human and animal health training and research institution in Uganda with MakCHS, MakCOVAB and MakCHUSS offering about 33 undergraduate programs and 66 graduate (Masters and/or PhD) programs that are relevant to EID research, surveillance and control [55,56,57]. All masters programs at Mak are classroom-based and involve 1 to 1.5 years of didactic lectures and 1 year of research. A majority of the PhD programs are research only programs where students only need to (1) conduct independent research and publish set-required peer-reviewed articles, and (2) enroll in select cross-cutting core course units (*i.e.* advanced research methods; philosophy of method and scholarly writing communication skills) and electives (*i.e.* information competence and management, advanced gender research methodology, advanced quantitative data analysis, advanced qualitative data analysis and clinical epidemiology) at MakCHS[58]. There are only a handful of fully-taught PhD programs that offer didactic classroom-based training in advanced courses that are relevant to EID research, surveillance and control including PhD in bioinformatics and genomics[59], PhD in Health Sciences[60] and PhD in Public Health[61]. A majority of the advanced training and research are affiliated with or hosted at MakCHS [62,63,64] with a few schools dominating the space *i.e.* the Makerere University School of Public Health (MakSPH), Makerere University School of Medicine (MakSOM) and Makerere University School of Biomedical Sciences (MakSBS) [65,66,67].

The vast majority of the advanced training programs in EID research, surveillance and control are donor-funded through North-South collaborations where foreign institutions provide placements/rotations for advanced knowledge, mentorship, and hands-on training in new technologies [68]. Recently concluded and on-going training programs include but are not limited to: 1) Uganda Public Health Fellowship Program (UPHFP)[69]; 2) Fogarty International Center Research Training Programs [70]; 3) Training of Ugandans in Basic and Translational Research on TB and Emerging Infectious Diseases [71]; 4) Research Training and Mentoring Program for Career Development of Faculty at Makerere University College of Health Sciences [72]; 5) Mbarara University Research Training Initiative [73]; 6) Makerere University/Uganda Virus Research Institute Centre of Excellence for Infection & Immunity Research and Training (MUII) [74]; 7) The Field Epidemiology Training Program (FETP); and 8) Fogarty Global Health Fellows, Northern Pacific Global Health Fellows consortium (Fogarty-NP) [75]; and 8) Swedish International Development Cooperation Agency (SIDA)[76].

## Knowledge and Skills Gaps in Uganda

Many of the basic and advanced training programs in Uganda that are relevant to infectious disease research, surveillance and control focus on knowledge and skills development in primary health care (including clinical/laboratory diagnosis and case management), public health courses (*e.g.* epidemiology), and community engagement [77,78]. Compared to other low- and middle-income countries (LMICs), Uganda has a relatively good number of knowledgeable and skilled professional health workers (*i.e.* doctors, pharmacists, nurses, midwives, clinical officers and medical laboratory staff): Uganda's IHR scores for health workforce in 2021 ranged between 3 and 4 which implies developed and demonstrated capacity especially in epidemiology and public health [79]. However, the ratio of professional health workers per 1000 population is still below WHO recommendations [80] and many of the past and present health workforce capacity building programs focus on increasing the number and quality of primary health care providers [81] and only a few (*e.g.* MUII) specifically develop cutting-edge knowledge and skills for researchers [82]. There are even fewer programs that support advanced training for veterinary and social scientists [83].

Lack of adequate advance research training programs has left significant knowledge and skills gaps among researchers in Uganda which are especially highlighted by the low quantity and quality of research outputs including innovations and scientific publications with high *h*-index journals [84]. Many scholars have documented the need for capacity in advanced laboratory/basic biomedical sciences (*e.g.* genetics and bioinformatics) social sciences, implementation science, research leadership, research ethics, mentorship and professional scientific writing [85,86,87,88]. Evidence from the desk review was corroborated by a majority of key informants. Fourteen key informants commented on the lack of an adequate pool of researchers, and a majority stated that Uganda requires cadres with advanced training in epidemiology (n=13) and laboratory/basic biomedical sciences (n=12) including virology, microbiology, genomics, bioinformatics, molecular biology, vaccinology, and immunology. Below are quotes from some key informants:

*The issue is most of the people* [health workers] *are not researchers and they are practitioners, but how do they apply research knowledge in their practice, that is power question*. (KI_13).

*Biostatistics, epidemiology, biological dynamics of the diseases and the sociological understanding of the* [disease]; *you have to understand them.* (KI_11)

*I would recommend a background in some basic science, actually going back to physics, but certainly chemistry. And some of the* [Ugandan] *students I worked with in Europe, it was really, it was surprising how little they really understood the methods they were using, they didn't, they could barely tell me how PCR* [polymerase chain reaction] *was working and what the chemical structure of the base-pair was or how that is influenced by salt or temperature and things like that*. (KI_18)

In addition, several key informants mentioned that multidisciplinary knowledge and skills are required including leadership (n=7), teamwork/interpersonal/soft skills (n=8), infection prevention and control (n=6), risk analysis (n=7), qualitative research and community engagement (n=7), and scientific writing (n=5). Sixteen key informants mentioned the relevance of knowledge and skills in research ethics. Below are quotes from some of the key informants:

*You must have managerial and administrative skills because you can't be head of those* [EID research, surveillance and control] *programs when you can't supervise people.* (KI_16)

*It is very important to have an understanding of the society, how it perceives and sees and understands the infectious diseases*. (KI_11)

*People being able to write well is a rare skill in our part of the world.* (KI_02)

*One of the issues we have had is that these* [EID] *outbreaks come very quickly; they don't give you time to write proposals, go to ethics and all that, we have to move very quickly. So, one of the, I think, approaches* [to navigate ethical processes during

EID outbreaks] *that has been used and we are also using it, is to have ready protocols. In case there are any outbreaks, we can have quick approvals* [if] *the protocols are ready.* (KI_23)

### Present and Future Training Approaches

Constructivist approaches to pedagogy *i.e.* Problem-based learning (PBL) and community-based education and services (COBES) were introduced at MakCHS in the 2003/2004 academic year to replace traditional instructor-led approaches [89,90,91]. PBL is an effective student-centered approach that encourages critical thinking and independent learning [92] whereas COBES develops competencies to handle setting-specific and community-level health challenges [93,94]. To augment PBL and COBES, Blended Learning (BL) was also adopted at Mak and other tertiary institutions in Uganda. BL (also known as hybrid learning) integrates traditional instructor-led classroom-based training with digital technology including electronic-learning(e-learning) [95,96,97]. E-learning (*e.g.* on-line lectures and simulation-based medical education) gained widespread application during the COVID-19 pandemic, however the approach has several key drawbacks in LMICs including high costs and unreliable power and internet [98,99].

BL is particularly applicable in North-South collaborations where Ugandan students can attend on-line lectures and learn from subject-matter experts and peers from across the world without the need for travel [100]. In Uganda, BL has somewhat overtaken Joint Degree (sandwich) programs (*e.g.* the Mak and Karolinska Institutet program) where students had most of their training at Mak but traveled to Sweden for specialized PhD courses, data analysis, thesis writing and supervision [101] because sandwich programs may be costly and have low output [102]. The aforementioned training approaches are augmented by experiential learning (*e.g.* clinic, laboratory and field placements), continuous medical education (CME), training workshops covering various topics, fellowships (e.g. MUII and FETP), mentorship and multidisciplinary training programs (*e.g.* One Health Institute at Mak) [103,104,105,106,107,108,109]

Evidence about current training approaches in Uganda was corroborated by nearly all key informants. Key informants further recommended BL training programs that offer either (1) advanced graduate and post-graduate education that is abreast with contemporary advances in scientific knowledge and technology and aligned to Uganda's setting-specific challenges with EIDs; or (2) robust short-term courses and experiential learning opportunities in multidisciplinary skills including data collection and leadership. Eleven key informants suggested that formative skills development should be achieved through long-term advanced graduate training *i.e.* masters, PhD and post-doctoral programs, 5 key informants recommended short-term didactic courses for in-service professionals who may need advanced training but may not be able to commit to full-time training programs. 5 key informants recommended that novel training programs should be aligned to target audiences and specific knowledge and skills required in Uganda. Below are quotes from some of the key informants:

*Science is dynamic, things keep on changing. So, what we knew in the past is not exactly the same today. So because of that, we need to train people in conducting research because it is through research that we are able to understand things* [EID outbreaks] *better.* (KI_03)

*Masters* [degree] *is good but masters is not so transformative. But if you want to have a sustainable impact, then you have to train Ugandans at PhD level in that area* [of EID research, surveillance or control] *and in use of contemporary technologies to tackle them* [EID outbreaks]*. You rather train two or three PhD* [students] *and train them properly, say in USA, and tell them you go and come back* [to Uganda] *where we don't have capacity than train fifteen masters, we will have the numbers but we won't have an impact.* (KI_09)

*I guess different components* [of EID research, surveillance or control] *will require different things* [trainings]*, but I think it will be very good to have people* [health workers] *in master's laboratory training* [and at] *PhD level, because then, there you know people can do* [the work]*. At that level they can possibly develop either vaccines, or drugs and all that. But also, being able to manage* [patients] *and identify and understand the dynamics of the various infectious diseases in* [a] *given context* [of the]

*people. So, but again maybe one important point is that all this is not about, I think, people in medicine* [clinical and laboratory personnel]*, but also, we make sure we co-opt, we bring in multidisciplinary* [practitioners]. (KI_11)

*Don't only look at university training* [only]*, we may train a community health worker, may be for 3 months* [and] *we give them the necessary skills to collect information* [about EID outbreaks]*.* (KI_01)

# Discussion

A majority of key informants were males (n=23) probably due to the fact that the targeted cadres and career stages are dominated by males in Uganda [110]. We purposively selected key informants from subject matter experts and cadres *e.g.* professors, senior researchers, and professionals from renown institutions (*e.g.* Makerere University and Ministry of Health) that are actively involved in pedagogy and/or infectious disease research, surveillance and control to ensure targeted collection of relevant information about Uganda's capacity for EID research, surveillance and control.

Findings from the desk review and KIIs highlighted Uganda's strong capacity in HIV/AIDS, TB, Malaria and viral hemorrhagic fever (VHF) research, surveillance and control compared to many other LMICs. Laboratory infrastructure, surveillance systems, health workforce and other capacities for HIV/AIDS, TB and Malaria were and are leveraged to establish and strengthen capacity for research, surveillance and control of other EIDs including VHFs and COVID-19[111]. According to the U.S. Centers of Disease Control and Prevention (CDC), HIV/AIDS, TB and Malaria are among the top 5 causes of death in Uganda whereas VHFs (*e.g.* Ebola and Marburg) are high consequence pathogens which pose serious global health security threats [112,113]. This prompted the Government of Uganda, donors (*e.g.* Global Fund and PEPFAR) and public and private tertiary institutions to logically adopt targeted resource-allocation (including health workforce and funding) to address the challenges posed by the aforementioned diseases in our resource-limited setting.

Despite the health workforce capacity strengths in surveillance and control (largely due to programs at MakCHS, MakCOVAB and MoH), Uganda's capacity for EID research, One Health and animal health remains low. Since the quality and quantity of the health workforce is directly correlated to research productivity [114], there is a need for tailored training programs to address the priority gaps that were identified in basic biomedical sciences, epidemiology and social sciences. However, many Ugandan tertiary institutions do not have adequate capacity to produce the required pool of highly knowledgeable and skilled health professionals [115,116]. Given the existing capacity gaps, it may be prudent and cost-effective to leverage existing North-South collaborations and follow KII recommendations and either: (1) prioritize designing advanced graduate-level training in biomedical sciences to generate a small pool of highly knowledgeable and skilled individuals who are able to conduct cutting-edge independent EID research; or (2) sustain and/or improve existing health workforce capacity in-line with contemporary EID challenges and advances in science and technologies through multidisciplinary and/or One Health short-courses, CME and experiential training.

Designing such multidisciplinary programs will require improvements to existing short-course, graduate and post-graduate training (including expedited curricular approval processes) to include (1) more e-learning opportunities with multidisciplinary subject-matter experts from across the world; (2) experiential training in the latest technologies through well-orchestrated short-term placements at resource-rich tertiary institutions; and (3) ongoing mentorship and career guidance by matched mentors in the North-South collaboration. E-learning is already available at Mak and its drawbacks *e.g.* requirements for steady power and internet supply are steadily being addressed in Uganda [117,118], therefore adoption of novel technologies and remote learning approaches is no longer far-fetched as evidence by widespread use during the early phases of the COVID-19 pandemic. Such an approach may generate the required critical pool of professionals who can (1) independently address the context-specific needs of human and animal health in Uganda in-line with contemporary advances in pedagogy and science, (2) improve Uganda's research outputs (including quality and quantity) and hopefully (3) contribute meaningfully to science.

### Study Limitations

Data collection occurred during the early phases of the COVID-19 pandemic in Uganda when there were various restrictions to public gatherings and travel. Since many of the key informants were involved in the national response, some interviews were rushed because key informants had little time to spare. In such instances, the researchers ensured that the key informants responded to all interview questions in brief to ensure complete data collection per study participant. Secondly, it is possible that the key informants' preference and recommendation for advanced training programs in epidemiology and basic biomedical sciences was observed because a majority were human health professionals *e.g.* medical doctors, public health specialists and/or biomedical/laboratory scientists. Since (1) all KIs were active practitioners and/or subject-matter experts, and (2) results from the desk review and KIIs were reviewed and verified for correctness during the consultative workshop with stakeholders, it is highly likely that the identified gaps and recommendations are factually relevant to Uganda, however future studies may need to collect data from a more diverse group of cadres especially animal health professionals.

# Conclusion

The TNA demonstrated health workforce capacity gaps in EID research. We recommend that the following training interventions should be designed and implemented: 1) advanced graduate and/or post-graduate training in basic biomedical sciences; 2) short-term training for continuous knowledge and practical skills development in multidisciplinary/One Health approaches and leadership; and 3) pedagogy and mentorship through BL, networking and experiential training programs that effectively leverage North-South collaborations by (a) conducting the bulk of in-person didactic and experiential training at Southern tertiary and research institutions, (b) utilizing electronic-learning for advanced didactic training and mentor-mentee interactions with subject-matter experts at Northern institutions, and (c) well-orchestrated rotations/placements at Northern institutions for hands-on experience using the latest advances in science and technology. This will enable Uganda's health workforce to remain abreast with latest advances in science and technology for EID research, surveillance and control.

# Abbreviations

BL: Blended learning; CDC: U.S. Centers of Disease Control and Prevention; CME: Continuous Medical Education; COVID-19: Coronavirus disease 2019; COBES: community-based education and services; DOI: Digital Object Identifier; EID: Emerging Infectious Diseases; E-learning: Electronic Learning; FETP: Field Epidemiology Training Program; GU: Gulu University; IDSR: Integrated Disease Surveillance and Response; IHR: International Health Regulations; KII: Key Informant Interview; LMIC: low- and middle-income countries; PEPFAR: The U.S. President's Emergency Plan for AIDS Relief; PBL: Problem-based learning; Mak: Makerere University; MakCHS: Makerere University College of Health Sciences; MakCHUSS: Makerere University College of Humanities and Social Sciences; MakCOVAB: Makerere University College of Veterinary Medicine, Animal Resources and Biosecurity; MakSBS: Makerere University School of Biomedical Sciences; MakSPH: Makerere University School of Public Health; MakSOM: Makerere University School of Medicine; MoH: Ministry of Health; MUII: Makerere University/Uganda Virus Research Institute Centre of Excellence for Infection & Immunity Research and Training; MUST: Mbarara University of Science and Technology; MUWRP: Makerere University Walter Reed Project; SIDA: Swedish International Development Cooperation Agency; TNA: Training Needs Assessment; UPHFP: Uganda Public Health Fellowship Program; UVRI: Uganda Virus Research Institute; VHF: Viral hemorrhagic fever.

# Declarations

### Ethical Approval and Consent to Participate

We obtained ethical approval to conduct the study from Makerere University School of Public Health (MakSPH) Higher Degrees Research Ethics Committee (HDREC) and the Uganda National Council of Science and Technology (REF Number: SS 4975) as part of a capacity building program titled *Addressing Emerging and Re-emerging Infectious Diseases Through International Partnerships and Multidisciplinary Training in Uganda* (ADEPT). All study methods were performed according to regulations and guidelines of the Makerere University Walter Reed Project (MUWRP), MakSPH-HDREC and UNCST. All Key

informants provided written informed consent, and all individuals who participated in the consultative workshop provided verbal informed consent.

### Consent for Publication

As part of the consenting process, all key informants approved to having the data and information collected during the study published. However, no personal identifying information is included.

### Availability of Data and Materials

The datasets generated and/or analysed during the current study are not publicly available because completely de-identifying some of the raw data (*e.g.* audio files and transcripts) may not be possible since the data was collected from a small pool of subject-matter experts and professionals at the few institutions that participate in infectious disease research, surveillance and control in Uganda, but the datasets are available from the corresponding author on reasonable request.

### Competing Interests

The authors declare that they have no known competing interests.


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### Authors Contributions

Lawrence Mugisha (LM), Fred Wabwire-Mangen (FWM), Francis Kiweewa (FK), Bannet Asingura (BA), Sheila Achabo (SA), Hannah Kibuuka (HK), Prossy Naluyima (PN), Jauhara Nanyondo (JN), Betty Mwesigwa (BM), Derrick Mimbe (DM) and Allan Tindikahwa (AT) participated in study design and funding acquisition; BA, SA, Molly McCoy (MM), Martha Kandole and FWM participated in project administration and supervision. FWM, BA, LM, FK, AT and David Kaawa-Mafigiri (DKM) designed the data collection methodology and tools. All authors participated in data collection, curation and formal analysis as follows: (1) the desk review raw data collection was conducted by BA, Allen Eva Okullo (AEO), Patricia Eyu (PE), PN, Justine Nalunga, JN and Grace Mirembe (GM); (2) DKM and BA reviewed and analyzed desk review data; (3) KIIs were conducted by FWM, BA, AEO and PE; (4) audio files were transcribed by Mathias Ssekitoleko, Josephine Nakakeeto, Jesca Nawatti, Daniel Kbirige, Winfred Nansalire, Grace Mirembe, Annet Namusisi, Sharon Namubiri and Stephen Mugamba; (5) BA and DKM reviewed and analyzed Transcripts. FWM, BA, LM, DKM, SA, MM, BM, HK, Dominic Travis, Robert Tweyongyere, Katey Pelican, Shailey Prasad, Alex Riolexus Ario and Denis Karuhize Byarugaba participated in the consultative workshop. BA, LM, DKM and FWM participated in original draft preparation; all authors participated in final review and editing.


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