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Rapid Wastewater and Environmental Surveillance Informed Precautionary Public Health Action Following the 2024 Kiteezi Landfill Disaster in Uganda

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Abstract

Background

Wastewater and environmental surveillance (WES) has been used to detect pathogen signals during pandemics and mass gatherings, yet its role in sudden-onset environmental disasters remains poorly understood. Following the catastrophic August 9, 2024, Kiteezi landfill collapse in Kampala, Uganda, which caused fatalities, displaced communities, destroyed sanitation infrastructure, and contaminated the surrounding environment with leachate and sewage, the Ministry of Health rapidly deployed WES to assess infectious disease risks and guide emergency public health action.

Methods

Between 10 and 12 August 2024, with sampling initiated within 72 hours of the collapse, we conducted a purposive cross-sectional assessment at five high-risk sites: a leachate-floodwater interface, a flowing leachate stream, two stagnant wastewater pools, and a community borehole. Moore swabs were collected at Sites A-D, and a 500 mL grab sample was collected at Site E. Concentrated extracts were qualitatively tested using commercial qPCR or RT-qPCR assays for selected enteric, respiratory, and zoonotic pathogens. The borehole sample was also cultured for Escherichia coli as an indicator of fecal contamination, and field observations documented potential exposure pathways.

Results

Nucleic acids from Shigella spp., Salmonella spp., non-O1/non-O139 Vibrio cholerae, enteric adenovirus 40/41, selected enteroviruses, SARS-CoV-2, and rotaviruses A-C were detected in one or more leachate or wastewater samples. We did not detect influenza A and B viruses, respiratory syncytial virus, or mpox virus. In the single borehole sample, Escherichia coli and all molecular targets were not detected; this single grab-sample result does not establish that the water source was safe. Field observations identified potential exposure pathways, including unprotected contact with contaminated water, children's proximity to polluted pools, livestock access to leachate, and inadequate protection of a community borehole. The response team reported implementing precautionary measures, including water-source restrictions, household water treatment, access controls, WASH activities, animal-control measures, and enhanced clinical surveillance. These measures were implemented within the broader disaster response, with environmental surveillance findings informing risk assessment and decision-making alongside field observations and other operational information.

Conclusions

Rapid deployment of WES after the Kiteezi landfill disaster was operationally feasible and produced site-specific evidence of environmental microbial hazards. When combined with field observations and routine disaster-response information, these findings informed precautionary public health decision-making, including drinking-water protection and exposure-reduction measures. Although the assessment did not establish the effectiveness of these interventions in preventing infections, it demonstrated the potential value of integrating environmental surveillance into early disaster-response frameworks. Future applications should incorporate repeated environmental sampling, linked clinical surveillance, and systematic documentation of public health actions and outcomes.

Background

Natural and human-induced disasters increasingly overlap with public health crises, particularly in low- and middle-income countries where rapid urbanization, informal settlements, and climate change intersect (1, 2). Beyond causing trauma and displacement, these disasters often disrupt water, sanitation, and waste management infrastructure, creating conditions that greatly amplify the spread of infectious diseases (3, 4). In particular, floods, landslides, and waste-related disasters often trigger

outbreaks of enteric, vector-borne, and environmentally transmitted pathogens within days to weeks of the precipitating event (2, 5).

Traditionally, disaster response efforts prioritize critical life-saving operations such as trauma care and search-and-rescue, with environmental health assessments often limited to basic water quality indicators, such as turbidity and chlorine levels (6). Although clinical surveillance is usually initiated after a disaster, it remains heavily reliant on patient healthcare-seeking behavior and symptom reporting, factors that are often compromised in disrupted communities with overburdened or inaccessible health services (7, 8). This creates a critical surveillance gap between environmental contamination and clinical detection, allowing pathogens with longer incubation periods or those transmitted asymptomatically to spread unchecked.

Wastewater and environmental surveillance (WES), the detection of pathogens in sewage and other impacted water matrices, has emerged as a vital, non-invasive complement to traditional public health surveillance systems (9). By providing near-real-time, anonymized, population-associated pathogen signals in wastewater, where connected catchments and sampling conditions permit inference, WES reduces reliance on individual case reporting (10, 11). The COVID-19 pandemic decisively demonstrated WES's global utility by providing early warnings of SARS-CoV-2 surges. It evolved from its use in polio eradication programs to become a cornerstone for monitoring pathogens of epidemic and pandemic potential (11, 12). Despite the expanding utility of WES in mass gatherings (13) and AMR surveillance (14), its operational use for real-time public health risk assessment following a major disaster has rarely been documented, a critical blind spot in current emergency response frameworks (9).

The August 2024 collapse of Uganda’s Kiteezi landfill, a waste disposal site in Kampala, offers a case study for exploring WES's utility after a catastrophic disaster. This landfill was established in two phases: initially in 1996 on 29 acres of land with funding from the World Bank, and expanded by 6 acres in 2007 as a temporary measure to extend its lifespan until 2010 (15, 16). However, it remained operational well beyond its intended and forecast lifespan, receiving approximately 28,000 tons of garbage per month, which accounted for about 40% of Kampala's total waste (17). This created substantial environmental and health threats, including methane-driven air pollution, leachate-induced water contamination, and a heightened risk of infectious disease outbreaks following storm overflow after heavy rains and poor sanitation infrastructure. On August 9, 2024, heavy rainfall triggered a catastrophic garbage slide at a section of the landfill. The slide caused significant loss of life and displaced many people. The Office of the Prime Minister reported 24 fatalities and 92 people accommodated in a temporary shelter as of August 14, 2024. It also led to the demolition of the landfill’s leachate treatment plant (18). Blocking natural drainage channels left the area flooded with stormwater and toxic leachate mixtures, creating widespread stagnant pools. This overlapping matrix of hazards vividly underscored One Health vulnerabilities in this rural-urban fringe.

Following the August 2024 Kiteezi landfill collapse, Uganda's Ministry of Health incorporated WES into the initial disaster response (19, 20) alongside clinical outreach, water, sanitation and hygiene interventions, and multisectoral coordination. Although environmental surveillance is increasingly used to monitor infectious disease threats, evidence on its operational implementation during sudden-onset environmental disasters in resource-limited urban settings remains limited. This study aimed to describe the feasibility of rapidly deploying WES after the Kiteezi disaster, characterize microbial hazards at selected high-risk environmental sites, identify potential human and animal exposure pathways, and document how the resulting environmental information contributed to precautionary public health decision-making. The findings provide operational lessons for integrating laboratory-based environmental risk assessment into future disaster preparedness and response frameworks.

Methods

Study design and operational setting

This purposive, cross-sectional environmental assessment was conducted at the Kiteezi landfill, approximately 13 km north of Kampala City Center in Wakiso District, Central Uganda (latitude: 0° 25' 0" N, longitude: 32° 34' 00" E), as shown in Fig. 1 (16). This landfill is located within Nangabo sub-county. As the premier and largest waste disposal site, it serves the five divisions of Kampala (Kampala Central, Nakawa, Rubaga, Makindye, and Kawempe) as well as the nearby peri-urban areas of Wakiso District (21, 22).

Kiteezi landfill is surrounded by Bamba, Kasangati, Kawempe, Tula, Nangabo, Namalere, Bulambiro, Buye, Lusanja, Kitetika, and Kalerwe (16, 21). A wetland borders it, through which the Kitetika stream flows; the stream is used for domestic water abstraction and downstream livestock consumption. Cattle farms and residential houses are located within 200 meters of the landfill perimeter (23, 24). The waste composition at the landfill is about 90% organic material (food waste, market residuals, and vegetation), with the remainder composed of plastics (~ 3.7%), small fractions of paper and packaging items (~ 1.62%), textiles (~ 0.50%), and broken glass (~ 0.68%) (23, 25). The region has a tropical climate with bimodal rainfall from March to May and September to November, and two dry seasons from December to February and June to August (22, 24). Notably, weeks of intense rainfall preceded the August 2024 disaster and destabilized the garbage slopes.

Sampling-site selection and field deployment

Five high-risk sampling sites (Fig. 2) were purposively selected based on: (a) proximity to submerged homes, pit latrines, and septic tanks; (b) observed human and animal exposure and contact pathways; (c) risk of community water source contamination; and (d) safety and accessibility for sample collection. Site A was the primary leachate-floodwater interface at the heart of the slide (the highest-concentration point of contamination); Site B was a flowing leachate stream to evaluate downstream pathogen transport; Sites C and D were stagnant secondary wastewater pools within residential areas to assess community exposure and environmental seeding of pathogens; and Site E was a community borehole adjacent to Site C to test for potential drinking-water contamination via subsurface leachate migration (27, 28). Because we purposively selected sampling locations based on perceived exposure risks and operational accessibility, the resulting observations were intended for rapid environmental hazard characterization rather than for statistical inference. Only one sampling event was conducted at each site, and the selected sites were not considered representative of all potentially affected environmental matrices or communities surrounding the landfill. Consequently, comparisons between sites were descriptive and did not estimate pathogen prevalence, environmental contamination intensity, or population-level infection risk.

Uganda's MoH, through the NHLDS, activated an emergency environmental surveillance response to conduct a rapid microbiological risk assessment of the contaminated environment. A multidisciplinary rapid assessment team, comprising MoH epidemiologists and environmental health officers, Kampala Capital City Authority (KCCA) sanitation engineers, and laboratory scientists from the Central Emergency Response and Surveillance Laboratory (CERSL) and the National Microbiology Reference Laboratory (NMRL), conducted the field investigation.

Pathogen-panel selection

The diagnostic panel targeted high-priority, public health-relevant pathogens in post-disaster and flood-associated settings. We prioritized waterborne enteric bacteria and viruses associated with fecal contamination or flood-related exposure, as well as respiratory and zoonotic pathogens established in Uganda's outbreak profile and in the Ministry of Health's routine WES pathogen portfolio (20, 29–32). Including multiple pathogen groups enabled simultaneous assessment of fecal contamination, environmental detection of selected viral targets, and broader environmental health risks in disaster-affected communities.

Environmental sample Collection

All sample collection personnel wore full PPE during collection activities, including Tyvek suits, N95 masks, face shields, double nitrile gloves, gumboots, and disposable laboratory coats. Moore swab sampling was used at the leachate pools (Sites A, C & D) and the stream (Site B); grab sampling was used at the community borehole (Site E). Each Moore swab was folded into an 8-ply pad, secured with a string long enough to reach the wastewater influent, autoclaved, and sealed in a Ziploc® bag. At each site, a swab was tied to a fixed object and fully submerged in the wastewater for 24 hours. Swab installation and retrieval took place between 7:00 a.m. and 9:00 a.m. After 24 hours, each swab was retrieved and placed in a clean Ziploc® bag for transport. The grab sample was collected by manually drawing water from the borehole spout and transferring 500 mL into a sterile container. Retrieved samples were double-bagged in Ziploc® bags, their external surfaces were disinfected with 70% ethanol, and they were

transported at 2–8°C in a secondary bio-bottle. This analysis represents one sampling event per site. All field sampling (swab installation and retrieval, and borehole grab sampling) was conducted between 10 and 12 August 2024.

Sample transport and initial processing

Samples were transported to the Central Emergency Response and Surveillance Laboratory (CERSL) and the National Microbiology Reference Laboratory (NMRL), approximately 13.6 km and 22.2 km from the sampling area, respectively. At CERSL, samples were processed within one hour of arrival. We aseptically squeezed the liquid from each Moore swab into a sterile bag and then transferred it to a sterile flask, recovering approximately 250 mL per swab. The borehole grab sample and the expressed Moore-swab liquids then underwent the concentration workflow described below.

Concentration, capture and Nucleic Acid Extraction/Purification

A magnetic bead–based method was used for concentration. Briefly, 35 mL of each sample was mixed with 100 µL of Nanotrap® Enhancement Reagent 2 (ER2) and 525 µL of Nanotrap Magnetic Virus Particles, then incubated at room temperature for 10 minutes. Captured particles were pelleted using a DynaMag™-15 magnet and eluted in 1 mL of Nanotrap Buffer 2. The workflow was adapted from published Nanotrap® Microbiome A particle methods for wastewater and passive environmental samples (33). We did not independently evaluate the applicability and recovery efficiency of this workflow for each bacterial and viral target in the disaster matrices. Eluted pathogen particles were lysed and nucleic acids were purified using the Qiagen Viral DNA Minikit (Qiagen, Germantown, MD, USA) or the Qiagen Viral RNA Isolation Kit (Qiagen, Germantown, MD, USA), as applicable. Nucleic acid extracts were eluted in a final volume of 60 µL. A negative extraction control was included in each extraction batch.

Molecular assays

The extracted nucleic acids were tested with eight commercial real-time PCR (qPCR) or reverse-transcription real-time PCR (RT-qPCR) assays, as applicable to the pathogen, manufactured by Jiangsu BioPerfectus Technologies Co., Ltd. Amplification was performed on a CFX96 Dx Real-Time PCR Detection System. Table 1 summarizes assay names, analyte coverage, and manufacturer-reported limits of detection. Limits of detection are expressed in assay-specific units (copies/reaction, copies/mL, CFU/reaction, or CCID50/0.1 mL) and are therefore not directly comparable across assays. Assay-specific reagent compositions, cycling parameters, controls, and interpretation criteria are provided in Supplementary Table S1.

RT-qPCR was used for rotaviruses A-C, SARS-CoV-2, influenza A and B viruses, respiratory syncytial virus, and the selected enterovirus panel. qPCR was used for mpox virus, Salmonella spp., Shigella spp., Vibrio cholerae with O1/O139 differentiation, Clostridioides difficile, and enteric adenovirus 40/41. When target genes were not publicly disclosed, we described them as proprietary assay targets. Detection of a nucleic acid target was not interpreted as evidence of organism viability, infectivity, or clinical disease (34).

Commercial assays were used with nucleic acid extracts from concentrated environmental specimens, including leachate, floodwater, wastewater, and borehole water. Manufacturer-reported analytical performance characteristics for these matrices were not independently verified. In addition, target-specific recovery efficiencies and the potential effects of co-extracted environmental inhibitors were not systematically evaluated. Therefore, positive results were interpreted as qualitative evidence of target nucleic acid detection, whereas negative results were interpreted cautiously because assay sensitivity could have been affected by matrix composition, sample processing, or nucleic acid recovery.

Reaction setup and thermal cycling

Reactions were prepared in a designated pre-amplification area using nuclease-free consumables and aerosol-resistant filter tips. Reagent composition, reverse transcription, activation, cycling, fluorescence acquisition, and channel interpretation followed the lot-specific manufacturer's instructions. Each reaction contained 5 µL of extract in a final volume of 25 µL.

We initially tested each environmental extract in a single technical reaction. Reaction plates were sealed before transfer to the amplification area and were not reopened after amplification. Repeat testing occurred only when the assay interpretation algorithm required it.

Quality assurance and result interpretation

Each extraction batch included a negative extraction control. Each amplification run included the kit-supplied positive control, a no-template (negative amplification) control, and the relevant assay internal control. We accepted a run only if the positive control met the manufacturer's criteria, the negative controls showed no target-specific amplification, and the required internal controls were valid.

Runs were rejected and repeated when the positive control failed, or target-specific amplification occurred in a negative control. A sample was classified as invalid when neither the target nor the required internal control produced an acceptable signal. Invalid or inconclusive results were retested from the existing extract or after repeat extraction.

Fluorescence data were analyzed using CFX Manager v3.1. Manufacturer-specified baseline and threshold settings were applied consistently within each assay run, and amplification plots were visually reviewed for a characteristic sigmoidal profile. A target was classified as detected only if its amplification curve crossed the manufacturer-defined threshold within the accepted Cq range and all controls were valid.

Analytical scope and reporting

Targets without valid amplification were reported as not detected only when the required internal control was acceptable. Results outside the manufacturer's interpretation range were classified as inconclusive and managed through repeat testing. No standard curves or quantified calibrators were generated (35).

Accordingly, Cq values were not converted to genome copies, organism concentrations, or pathogen loads. Manufacturer-reported limits of detection were not independently verified in concentrated leachate, floodwater, wastewater, or borehole water. Findings were therefore treated as qualitative environmental surveillance signals rather than as estimates of infection prevalence or individual clinical diagnoses.

Table 1
Commercial molecular assays used for pathogen detection

Commercial assay	Analyte(s)	Manufacturer-stated target/coverage	Manufacturer-reported LoD
Rotavirus A/B/C Real Time PCR Kit	Rotavirus A, B, and C RNA	Gene regions not publicly disclosed	5 copies/reaction
Allfastra SARS-CoV-2/FluA/FluB/RSV Real Time PCR Kit	SARS-CoV-2, influenza A, influenza B, and RSV RNA	SARS-CoV-2: ORF1ab/N/E; influenza A: M; influenza B: NS; RSV: N	200 copies/mL
Enterovirus Real Time PCR Kit	Selected enterovirus RNA	EV71, CoxA9, CoxA16, CoxB2, CoxB5, and Echo30; gene region not publicly disclosed	2.0×10^{-2} CCID50/0.1 mL
Monkeypox Virus Real Time PCR Kit	Mpox virus DNA	F3L	5 copies/reaction
Salmonella & Shigella Real Time PCR Kit	Salmonella and Shigella DNA; multiplex qPCR	Proprietary target regions not publicly disclosed	500 CFU/reaction
Vibrio Cholerae Real Time PCR Kit	V. cholerae, O1, and O139 DNA	Species-level V. cholerae plus O1 and O139 channels; gene regions not publicly disclosed	5 copies/reaction
Clostridioides difficile Real Time PCR Kit	C. difficile DNA	Proprietary target region not publicly disclosed	5 copies/test
Enteric Adenovirus Real Time PCR Kit	Enteric Adenovirus DNA	Hexon; adenovirus types 40 and 41	5 copies/reaction

Enumeration of Escherichia coli in the Community Drinking Water Source

For the community borehole (Site E), *E. coli* was enumerated as an indicator of fecal contamination using the membrane filtration technique in accordance with ISO 9308-1 (36). Briefly, we vacuum-filtered 100 mL of borehole water through a sterile 0.45-µm membrane, then cultured it on MacConkey agar and incubated it at 37°C for 24 hours. Presumptive identification of E. coli was based on characteristic colony morphology (dry, flat, pink colonies) and Gram stain, and was confirmed by MALDI-TOF mass spectrometry (BD™ Bruker MALDI Biotyper® CA System) —MALDI-TOF confirmation applies only when presumptive colonies are present.Colonies meeting confirmation criteria were enumerated and reported as colony-forming units per 100 mL (CFU/100 mL). Quality controls, including sterile blanks, media sterility checks, and E. coli ATCC 25922 positive controls (Culti-Loops™, Thermo Scientific), were included in each batch. Results were interpreted against the WHO drinking water quality guidelines (37). This method was applied exclusively to the borehole water because the high organic load and expected saturation of leachate and floodwater samples (Sites A–D) make membrane filtration unsuitable and redundant, given the direct pathogen detection achieved through qPCR. In addition, grab samples collected from Site E underwent the same nanoparticle-based pathogen capture and concentration, nucleic acid extraction and purification, and the qPCR workflow described above to enable direct molecular detection of the target pathogens.

Field observations, public health actions, and data analysis

During sampling and sample retrieval, the multidisciplinary response team documented environmental conditions and potential human and animal exposure pathways, including contact with contaminated surface water, livestock access to leachate, and the physical protection of community water sources. The response summarized public health interventions alongside the environmental findings to illustrate the operational relationship between hazard identification and precautionary action. Because these interventions were implemented within a broader multisectoral emergency response, we could not attribute their initiation solely to WES findings. The assessment did not systematically collect intervention implementation dates, population-level health outcomes, or post-intervention exposure measurements; therefore, the effectiveness of the reported actions was not evaluated.

Field and laboratory data were compiled in Microsoft Excel 2021 and analyzed descriptively in R v4.5.1 (38). Basic descriptive statistics and visualizations were generated using R's base functions, with figures created using the ggplot2 package (39) and

further annotated using the ggpubr package (40). Because we purposively selected sites and matrices and sampling methods differed, we did not perform inferential analyses or interpret site-level detection proportions as prevalence.

Results

Pathogen Detection in Environmental Matrices

Qualitative molecular testing detected nucleic acid from several bacterial and viral pathogen targets in leachate and wastewater collected from the disaster-affected area (Fig. 3). Detected targets included *Shigella* spp., *Salmonella* spp., non-O1/non-O139 *Vibrio cholerae*, enteric adenovirus 40/41, selected enteroviruses, SARS-CoV-2, and rotaviruses A–C. *Shigella* spp., *Salmonella* spp., enteric adenovirus, and SARS-CoV-2 were each detected at three of the five sampled sites (a count of sampling sites, not an estimate of prevalence), as shown in the detection matrix in Fig. 3. Influenza A, influenza B, respiratory syncytial virus, mpox virus, and *Clostridioides difficile* were not detected by the assays used. No molecular targets were detected in the single community borehole sample (Site E), and *E. coli* was not recovered from the 100-mL portion tested by culture (0 CFU/100 mL). These findings describe target detection at selected environmental sites and should not be interpreted as estimates of pathogen prevalence, organism viability, or community disease burden.

Environmental pathogen detections varied across the five sampling locations, with multiple bacterial and viral targets identified at the leachate-associated sites. Of particular public health relevance was the proximity of Site C, a contaminated wastewater pool in which *Shigella* spp. and *Salmonella* spp. nucleic acids were detected, to Site E, a community borehole in which the selected molecular targets and cultured *E. coli* were not detected. Despite these negative findings, contaminated surface runoff surrounded the borehole, and it lacked adequate physical protection. These observations supported a precautionary risk assessment because a single negative sample could not exclude intermittent contamination or future contaminant ingress. However, the study did not establish a hydrological connection between the wastewater pool and the borehole or demonstrate groundwater contamination.

Spatial Risk Mapping and Exposure Observations

Field observations during sampling documented multiple concurrent exposure pathways that amplified the public health risk identified by WES. Direct human exposure was widespread; salvage workers and community members were observed wading through contaminated floodwaters without personal protective equipment to retrieve belongings. A high zoonotic risk was also apparent, with domestic goats and pigs drinking directly from leachate pools, some of which showed signs of diarrhea. Childhood exposure was evident, as children played barefoot near contaminated pools with observed hand-to-mouth contact. Furthermore, the community borehole (Site E), despite testing negative, was visibly compromised, surrounded by contaminated surface runoff, and lacked basic protective infrastructure (no sanitary sealing and no protective berm).

These field findings contextualized the pathogen detections within a converging risk landscape: environmental contamination was not contained but actively intersected with human and animal behavior, creating numerous potential transmission points.

Discussion

This study demonstrates the operational feasibility of integrating wastewater and environmental surveillance into the early response to a major environmental disaster in a resource-limited urban setting. Within 72 hours of the Kiteezi landfill collapse, Uganda's public health laboratory and environmental health teams initiated a rapid assessment of selected high-risk sites and subsequently identified bacterial and viral nucleic acid targets of public health relevance. When combined with observations of human and animal exposure pathways, these findings contributed to the environmental risk information available to the multisectoral response team. This study's principal contribution is demonstrating how existing laboratory surveillance capacity can be adapted to support precautionary environmental health decisions during emergencies. Unlike studies designed to evaluate intervention effectiveness, this assessment did not establish whether surveillance findings reduced exposure, prevented transmission, or changed clinical outcomes.

Our environmental findings showed microbial target detections in selected leachate-associated environmental sites. The detection of classic enteric pathogens, *Shigella spp.*, *Salmonella spp.*, and Enteric Adenovirus, in leachate and floodwater is consistent with established models of diarrheal disease risk following flooding and infrastructure damage (41). The spatial pattern of these results was also informative when interpreted alongside field observations. The detection of *Shigella* and *Salmonella* in a wastewater pool (Site C), directly adjacent to a pathogen-negative community water source borehole (Site E), presented a practical decision problem for responders. Traditional post-disaster water quality testing, often limited to basic physical, chemical (6), and microbiological indicators such as thermotolerant coliforms (37), might have deemed the borehole safe for use based solely on a negative result. In contrast, interpreting the negative borehole result alongside contamination detected in the adjacent pool and the observed lack of wellhead protection supported a precautionary decision to close the borehole. This precautionary approach is consistent with reducing the risk of subsequent leachate ingress (27, 42) although this study did not directly measure post-closure outcomes. This illustrates a key advancement WES offers in disasters: contextual environmental intelligence rather than isolated point measurements of water quality.

Multisector coordination and One Health

The operational feasibility of this deployment was fundamentally underpinned by multisectoral coordination. Collaboration among the MoH's NHLDS, the environmental health department, and KCCA enabled rapid field assessment and allowed municipal response decisions to consider laboratory findings alongside field observations. This model aligns with the growing consensus that effective surveillance requires embedded pathways to public health action, not merely data generation (43). Additionally, the integration of systematic field observations of scavengers, livestock, and children at risk with molecular data embodies a practical One Health approach to disaster assessment. This transformed an abstract laboratory detection into a tangible zoonotic transmission risk, reinforcing the necessity for concurrent animal and human health measures, an integration often missed in siloed disaster responses (44).

Toward a precautionary disaster response

This study also illustrates how WES might be positioned earlier in the disaster response timeline. Although operational observations at the time of sampling did not indicate an ongoing acute diarrheal outbreak in the affected community, this study did not systematically collect them. Therefore, they should not be interpreted as study findings but rather as contextual information; the clinical timing of infections relative to environmental detection could not be assessed. This information supported a precautionary, risk-reduction approach rather than reliance on reactive outbreak containment, an orientation disaster risk reduction frameworks call for but rarely achieve in practice (45). The precautionary measures reported are consistent with the WHO "prepare, prevent, detect, respond" paradigm as applied to the environmental phase of a disaster (46).

Public Health Interventions Implemented During the Multisectoral Disaster Response

The multisectoral response to the Kiteezi landfill disaster reviewed environmental surveillance findings alongside field observations and other operational information. The response team reported implementing several precautionary public health measures to reduce potential exposure to contaminated water and improve community preparedness for infectious disease threats. These included drinking-water protection, access restrictions, WASH interventions, animal-control measures, community health outreach, and enhanced clinical surveillance. Although WES findings contributed to the available risk information, we could not independently establish the relative contribution of environmental surveillance to individual response decisions. The actions described below should therefore be interpreted as part of the broader disaster response rather than interventions directly caused by WES findings.

1. **Precautionary Protection of Drinking Water Sources**

Despite a negative test result from the community borehole (Site E), enteric pathogen target detections at the adjacent surface pool (Site C), together with the borehole's lack of physical protection, indicated a potential contamination risk. This spatial risk assessment supported a precautionary approach to water security. According to response-team reports, the borehole and two identified shallow wells were sealed, and chlorine tablets were distributed to 156 households, accompanied by demonstrations of

correct water treatment practices. Concurrent public health sensitization advised against using any unprotected groundwater sources until a comprehensive safety assessment could be finalized.

1. **Containment of Environmental Contamination and Human Exposure**

Detection of enteric pathogen targets at multiple surface-water sites (A–D) was considered alongside field observations in planning source containment and exposure reduction. Access to the landfill and the most heavily contaminated zones was restricted by the Kampala Capital City Authority (KCCA), with entry permitted only to licensed waste management personnel equipped with appropriate personal protective equipment. Temporary fencing and warning signage were erected around major leachate pools and flooded areas to deter entry. In addition, households living directly near flowing leachate channels were relocated to a temporary settlement to eliminate direct residential exposure.

1. **Scale-Up of Water, Sanitation, and Hygiene (WASH) Infrastructure**

In parallel with containment measures, an emergency WASH scale-up was initiated to address the underlying vulnerabilities exposed by the disaster. The MoH deployed handwashing stations at strategic points within the affected communities. Daily disinfection of communal sanitation facilities was also instituted, and hygiene promotion teams conducted door-to-door messaging on safe water storage and handwashing practices.

1. **Mitigation of Zoonotic and Occupational Transmission Risks**

Environmental pathogen detections were considered alongside direct field observation of livestock consuming leachate in a One Health-informed strategy. KCCA veterinary teams restricted the movement of stray animals, including by isolating visibly ill livestock. To address occupational hazards, personal protective equipment (gloves, gumboots) was provided to authorized salvage workers, along with mandatory hygiene briefings. Targeted daily community inspections and engagement, led by environmental health officers, were also conducted in areas where children were observed playing near contaminated water, with an emphasis on risk-reduction behaviors.

1. **Community Health Screening and Medical Outreach**

A medical camp was established at the Kiteezi disaster site to provide immediate clinical services to the affected population. The camp offered voluntary testing for HIV, malaria, syphilis, hepatitis B, sickle cell disease, and non-communicable conditions such as hypertension and diabetes. Symptom screening for acute watery diarrhea, fever, respiratory illness, and skin infections was conducted, with on-site stabilization and referral protocols activated for suspected cases.

1. **Enhanced Surveillance and Clinical Preparedness**

Detection of enteric pathogen targets was considered in planning enhanced monitoring for diarrheal illness, and the response team reported a move from passive to active monitoring. An alert threshold for diarrheal diseases was established at nearby health facilities, and oral rehydration solution (ORS) and zinc supplements were prepositioned at the parish health center. The existing Village Health Teams (VHTs) were mobilized to implement community-based symptom reporting, focusing on the early identification of clusters of diarrhea and fever in the affected population.

Implications for Public Health Emergency Preparedness

The Kiteezi experience has implications for public health emergency preparedness in rapidly urbanizing settings where informal settlements, inadequate sanitation infrastructure, and environmental hazards intersect. Sudden disruption of waste-management and sanitation systems may create conditions for human and animal exposure to contaminated water before routine clinical surveillance can adequately characterize emerging health risks. Integrating rapid environmental surveillance into initial disaster assessments could complement established WASH inspections, drinking-water quality monitoring, and syndromic surveillance by providing additional microbiological information to support precautionary decisions. However, this approach's value depends on laboratory capacity, validated methods, timely communication of findings, and clear procedures for translating environmental results into proportionate public health action. Future implementation studies should assess the feasibility, costs, timeliness, and measurable health outcomes of incorporating WES into disaster-response systems.

Study Limitations

This assessment has several limitations. First, five purposively selected sites and a single reported sampling event cannot characterize the full spatial or temporal distribution of contamination or provide prevalence estimates. Second, Moore-swab and grab-sample results are not directly comparable because the sampling methods and effective sampled volumes differ. Third, we had no pre-disaster baseline, repeated post-disaster sampling, or hydrogeological assessment. Fourth, assays were qualitative, initially performed as single technical reactions, and the manufacturer-reported limits of detection were not verified in the tested matrices. Field blanks, whole-process recovery controls, matrix-inhibition assessments, and target-specific recovery efficiencies were not documented (35). Fifth, nucleic acid detection did not establish viability or infectivity, and genomic sequencing was not performed. Sixth, field observations were contextual rather than systematically quantified. Furthermore, the environmental findings could not be linked to individual clinical cases, population-level disease incidence, or subsequent outbreak occurrence. Although several precautionary interventions were reported, the study did not independently verify their implementation through a standardized evidence-to-action assessment, nor did it measure their effectiveness in reducing exposure or preventing infection. Consequently, this study provides descriptive evidence of operational feasibility and environmental risk characterization rather than causal evidence of improved population-health outcomes. Future studies should integrate longitudinal environmental sampling, clinical surveillance, validated analytical methods, and prospective documentation of intervention implementation and effectiveness.

Conclusions

Rapid WES was operationally feasible during the acute response to the Kiteezi landfill collapse and provided site-specific qualitative information on microbial hazards and exposure pathways. When interpreted with field observations and routine response information, the findings supported precautionary environmental-health decision-making. They do not establish that WES prevented disease. Future implementation should incorporate predefined sampling plans, repeated measurements, field and process controls, matrix-specific method evaluation, linked clinical surveillance, transparent evidence-to-action documentation, and outcome assessment.

Integrating these elements into existing national laboratory and disaster-response systems would permit more rigorous evaluation of WES as a component of initial rapid assessment and WASH response.

Abbreviations

CERSL Central Emergency Response and Surveillance Laboratory.

NHLDS National Health Laboratory and Diagnostic Services.

KCCA Kampala Capital City Authority

q-PCR Quantitative Polymerase Chain Reaction.

RT-PCR Reverse-Transcriptase Polymerase Chain Reaction.

WASH Water, Sanitation, and Hygiene

WES Wastewater and environmental surveillance

Declarations

Ethics approval and consent to participate

This assessment was conducted by Uganda's Ministry of Health under the National Health Laboratory and Diagnostic Services disaster-response mandate and involved environmental samples only; no individual participant data or human biological specimens were collected. Formal research ethics review was not required under the emergency-response determination made

by Prime Minister's Office in charge of Disaster Response. Access to the landfill and community sampling sites was authorized by the Kampala Capital City Authority.

Consent for publication

Not applicable

Availability of data and materials

The data generated or analyzed during this study are included in this manuscript.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization: AN, SN, JBK

Methodology: AN, SN, JK

Investigation: GMB, JM, RK, VN, IM, HK, SZ

Data curation and validation: JK, GMB

Formal analysis: JK, IM

Supervision: SS, VN, RK, GN

Resources: SN, AN, VU, HN, HK

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Figures



Figure 1

Satellite image of the Kiteezi landfill disaster site (Kampala, Uganda, August 9, 2024), showing the area affected by the garbage landslide. Image credit: Google Earth. Reproduced from Petley D., The Landslide Blog, Eos, American Geophysical Union (2024), with attribution to the original imagery providers (26).



Figure 2

Map of the Kiteezi Landfill disaster site with the five WES Sampling Points (A–E) indicated

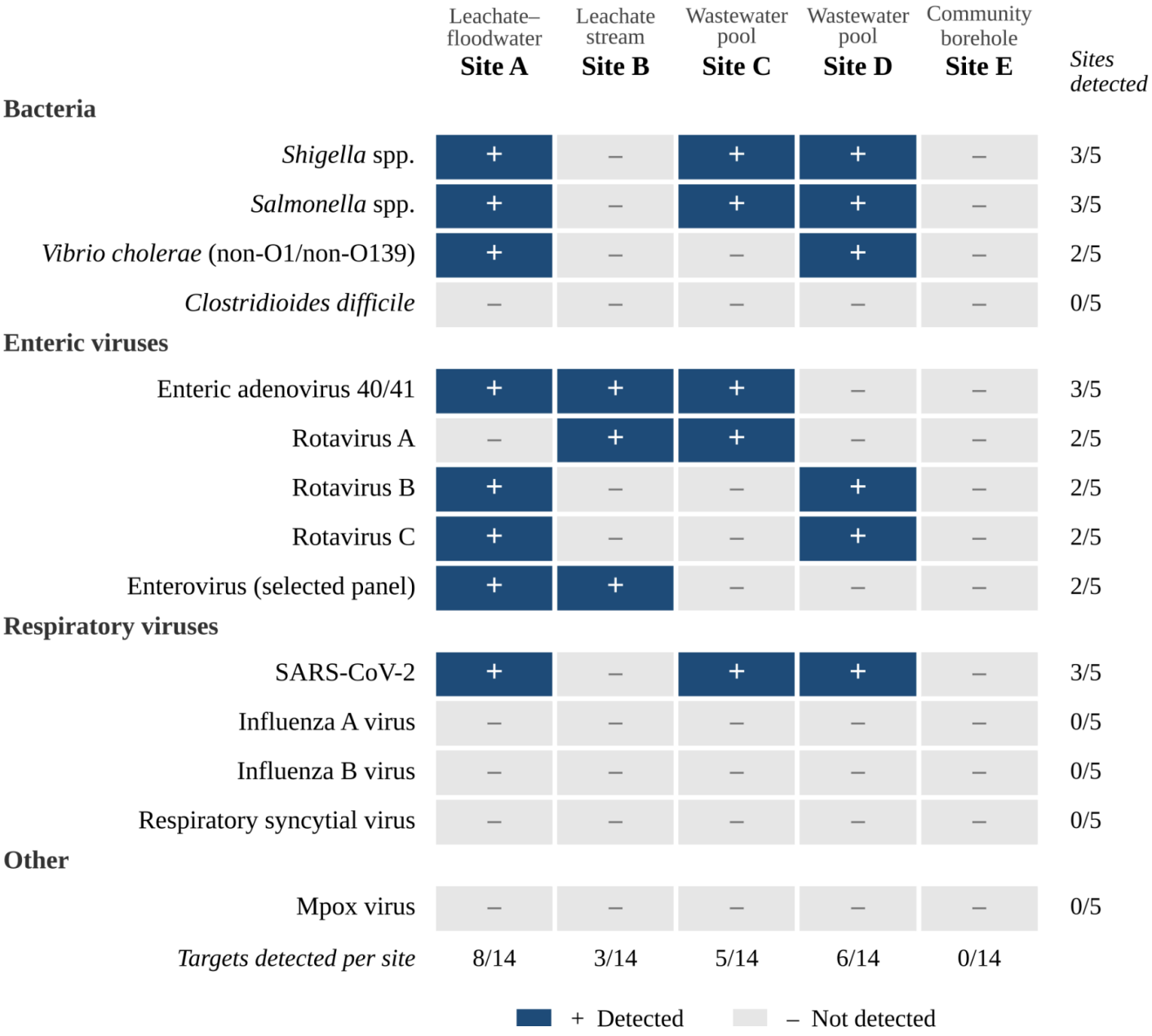


Figure 3

Qualitative detection of 14 bacterial and viral assay outputs at five environmental sampling sites following the Kiteezi landfill disaster, Uganda (sampled 10–12 August 2024). Dark cells (+) indicate detection, and grey cells (–) indicate no detection. Values on the right give the number of sites (of five) at which each target was detected; values at the bottom give the number of targets (of 14) detected at each site. Vibrio cholerae is shown at the species level, with the O1 and O139 channels not detected. Sites A–D were sampled using Moore swabs, and Site E using a single borehole-water grab sample. Results represent one sampling event per site and do not indicate pathogen concentration, infectivity, or environmental prevalence.

Supplementary Files

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- KiteeziSupplementaryTableS1.pdf