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Translating pathogen knowledge to practice for sanitation decision-making

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ABSTRACT

Sanitation planners make complex decisions in the delivery of sanitation services to achieve health outcomes. We present findings from a stakeholder engagement workshop held in Kampala, Uganda, to educate, interact with, and solicit feedback from participants on how the relevant scientific literature on pathogens can be made more accessible to practitioners to support decision-making. We targeted Water, Sanitation and Hygiene (WASH) practitioners involved in different levels of service delivery. Practitioners revealed that different sanitation planning tools are used to inform decision-making; however, most of these tools are not user-friendly or adapted to meet their needs. Most stakeholders (68%) expressed familiarity with pathogens, yet less than half (46%) understood that fecal coliforms were bacteria and used as indicators for fecal pollution. A number of stakeholders were unaware that fecal indicator bacteria do not behave and persist the same as helminths, protozoa, or viruses, making fecal indicator bacteria inadequate for assessing pathogen reductions for all pathogen groups. This suggests a need for awareness and capacity development around pathogens found in excreta. The findings underscore the importance to engage stakeholders in the development of support tools for sanitation planning and highlighted broader opportunities to bridge science with practice in the WASH sector.

Key words | decision-making, knowledge translation, pathogens, sanitation, stakeholder engagement, tools

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INTRODUCTION

In order to meet Sustainable Development Goal 6 (SDG6) on universal access to safe water and sanitation, access to scientific data, such as on the occurrence, persistence, inactivation, and removal of pathogens in excreta and wastewater to support evidence-based sanitation decision-making, is needed (Rose & Jiménez-Cisneros 2019). Unsafely managed excreta and untreated wastewater degrade surface and groundwater quality, posing a significant public health and environmental risk (UN 2018). The United Nations (UN) SDG report shows that most countries, especially in Africa and Asia, are missing or have insufficient wastewater treatment and poor databases on their sanitation systems. Of the 22 countries with data, less than 50 per cent of all household wastewater is safely treated (UN 2018). The discharge of

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unsafely treated wastewater or fecal sludge into the environment threatens public health by introducing pathogens into surface and ground water (WWAP 2018). Populations in low- and lower-middle-income countries have the greatest exposure to environmental pollutants due to larger populations, rapid economic growth, and a lack of wastewater management (WWAP 2018). Diarrheal disease occurrence in low-income countries has been linked to a wide variety of fecal pathogens, such as rotaviruses, pathogenic strains of *Escherichia coli*, *Vibrio cholera*, *Shigella* spp., *Salmonella enterica* serotype Typhi, Hepatitis E virus, and soil-transmitted helminths (Schwarzenbach *et al.* 2010; Afema *et al.* 2016; Freeman *et al.* 2017). The World Health Organization (WHO) Guidelines on Sanitation and Health include a chapter focused on excreta-related pathogens to broaden the spectrum on how sanitation-related interventions could contribute to improved health outcomes (WHO 2018).

This paper outlines what knowledge and tools are currently available, and what is needed by sanitation planners to support improved evidence-based decision-making on safe sanitation. Specifically, it outlines the methods used to engage and solicit feedback from stakeholders, so that the scientific literature can be made more accessible to practitioners. The engagement of stakeholders, including engineers, managers, policymakers, and NGOs, in the development of tools that ease access, understanding, and use of scientific data for sanitation planning is critical for achieving safely managed sanitation and reducing exposure to excreta. A study on integrated fecal sludge management (FSM) cities in Burkina Faso showed that the involvement of stakeholders in the selection of sanitation options ensured that the designs of fecal sludge treatment plants were adapted to local conditions (Bassan *et al.* 2013). In a study on the engagement of stakeholders in the development of a theory of change for handwashing and sanitation behavior change, authors point out that stakeholders are important in providing the context in which programs are implemented (De Buck *et al.* 2018). Additionally, stakeholder involvement is crucial for the planning and implementation of sanitation infrastructure and services as it helps to promote sustainability and improved operation and maintenance (Lüthi *et al.* 2011).

Unlike the Millennium Development Goals that focused only on access to improved water and basic sanitation, the SDG sanitation indicators provide a more holistic approach to the entire sanitation service chain (containment, emptying, transportation, treatment, and disposal/use) (WHO/UNICEF 2017). However, to achieve 'safely managed' sanitation as defined in the SDG targets, it is crucial to identify pathogens present in excreta and wastewater, understand their persistence, and determine their removal or inactivation along the sanitation chain. This knowledge can provide defined targets which can be used to limit the population's exposure to the vast array of excreta-associated pathogens and ultimately achieve improved health outcomes (Murphy 2017; Schmitz *et al.* 2018). Achieving safely managed excreta along the full-service chain necessitates that sanitation planners have access to scientific data that support decision-making, policy development, project development, implementation and evaluation, and advocacy (Mitchell *et al.* 2016; Rose & Jiménez-Cisneros 2019). The recent large body of evidence on pathogens in wastewater and excreta published by the Global Water Pathogen Project (GWPP) as an open-source online book provides crucial access to scientific data (www.waterpathogens.org) (Rose & Jiménez-Cisneros 2019). However, this information is largely understood by academics and scientists and has not directly involved those who deliver Water, Sanitation and Hygiene (WASH) services. It is important that these data on pathogens be translated and simplified for practical use by WASH practitioners to inform decision-making. The body of pathogen evidence could also be utilized to enrich existing manuals, tools, and other documents used by WASH practitioners for better sanitation planning. For example, chapter six of the World Health Organization Guidelines on Sanitation and Health is based on the GWPP database (WHO 2018).

To bridge the gap between science and practice, the knowledge to practice (K2P) team is developing a safe sanitation decision support application (App) that contains two tools to support sanitation decision-making. These K2P tools will build off and supplement existing safe sanitation planning (SSP) approaches or frameworks such as the Eawag compendium on sanitation technologies (Tilley *et al.* 2014), the WHO sanitation safety planning manual (WHO 2016), and the shit flow diagrams (SFDs) (tools that help to visualize the flow and treatment of excreta and wastewater in an urban system) (Peal *et al.* 2014). Uganda is the first implementation country, and a coalition of national and local stakeholders is being assembled and engaged in the development of these analytical tools. The primary outcome of the K2P agenda is to improve accessibility to the existing body of evidence on pathogens in excreta and sewage through scientific tools that WASH professionals can use to apply an evidence-based approach to water and sanitation planning.

This paper shares findings from stakeholder engagement workshops in Uganda that aimed to provide answers to the following questions that are broadly applicable to global sanitation planning.

Key questions included:

1. What is the level of knowledge of WASH practitioners regarding the variety of pathogens in excreta and wastewater?
2. What are the sources of information and tools WASH practitioners use for sanitation decision-making and what are the existing gaps?
3. How can the pathogen flow and emissions mapping tools (currently under development through the K2P agenda) link with these existing tools, align with stakeholder needs, and facilitate the use of scientific information to better support policy, decision-making, resource allocation, and advocacy around the safe management of excreta, sewage, and sludge?

METHODS

Two single-day workshops were held at the National Water and Sewerage Corporation (NWSC) International Resource Centre (IREC) on 4 July 2018 and 5 July 2018. Participants represented a variety of organizations working in the WASH sector, including the national government in Uganda. Seventy-four stakeholders from organizations actively involved in the WASH sector in Uganda were invited to participate in the workshops and consisted primarily of members of the National Sanitation Working Group (NSWG) organized by the Ministry of Water and Environment (MoWE) that supports benchmarking and tracking of sanitation investments in the country. The NSWG brings together government partners responsible for WASH services delivery, including MoWE, The Uganda Parliamentary Forum for WASH (UPF-WASH) services, the NWSC, the Ministry of Health (MoH), Kampala Capital City Authority (KCCA), and the National Environment Management Authority (NEMA). Additionally, stakeholders in the NSWG include bilateral donor agencies, UN agencies, and NGOs. Of the 74 stakeholders who were invited to attend the workshop, only 41 could attend (government = 29, non-government = 12). To facilitate interactive discussions and cross-disciplinary exchanges, the workshop sessions were composed of (1) overview and background knowledge presentation on pathogens and the project, (2) small group (marketplace) stations, (3) interactive clicker surveys, (4) small group breakout sessions, and (5) the mapping of stakeholder interests and levels of engagement.

Overview/background knowledge presentation

The first part of the workshop was devoted to providing an overview of the K2P approach, including presenting baseline knowledge on the variety of pathogens found in excreta and sewage and their importance, exposure routes for contamination in the environment. Concepts regarding the removal and inactivation of pathogens in wastewater treatment were also presented. The goal of the session was to orient the participants to key concepts. Throughout the session, the team used anonymous clicker surveys to gage the level of knowledge and the understanding of participants. The survey questions included familiarity with pathogens, familiarity with fecal indicator microorganisms, the definition of fecal coliforms, and why in the water/wastewater sectors we typically measure indicator organisms instead of specific pathogens.

Marketplace stations (~1.5 h (30 min per station))

Following the overview presentation, participants were randomly assigned to groups to engage in small discussions with experts at three different stations. This approach, referred to as a marketplace, rotates through the stations. Each station was equipped with illustrative posters and two facilitators to guide and engage stakeholders in detailed discussion. At each station (4–10 participants), a brief overview was provided along with key questions that the facilitators wanted to address with most of the station time devoted to stakeholder discussion and feedback.

The stations were broken up into three key themes:

Station 1: Understanding and compiling existing tools and information for Ugandan sanitation planners and gaps in these tools.

Station 2: Developing a tool that models pathogen flow (fate and transport) in excreta and wastewater throughout the sanitation service chain.

Station 3: Developing a pathogen mapping tool to visualize modeled excreta-associated pathogens emissions and concentrations in the environment.

Rapid anonymous clicker surveys to solicit feedback on the stations and K2P agenda (~30 min)

The goal of this session was to understand stakeholder interests and the level of future engagement in the K2P agenda and tool development. Interests in the pathogen emission mapping and the pathogen flow safe sanitation decision support tools and their perceived value for decision-making were assessed. Participants were asked to answer a series of structured questions on their level of agreement on a seven-response scale from very strongly agree to very strongly disagree.

Small group sessions (~1 h)

After the clicker surveys, stakeholders were split again into small group breakout sessions (different group members) to discuss how the K2P tools (the sanitation app and mapping) link with or fill gaps in tools currently used by stakeholders for sanitation planning. Stakeholders also discussed how the K2P agenda and knowledge on pathogens could be better aligned for utilization by practitioners. The stakeholders were challenged to think of all levels of the sanitation service chain where the tools could help support planning, design, resource prioritization and allocation, advocacy, and implementation of sanitation services. The group-work session was followed by a plenary in which selected leaders from each group presented summaries of their discussions.

Identification of areas for future engagement (~30 min)

The workshop ended by asking participants to identify areas of where they would like to have future engagement in the development of the K2P agenda. The areas of engagement were broken up into the following: (1) developing the pathogen emission mapping and scenario tool, (2) developing the pathogen flow tool (PFT), (3) integrating data into K2P tools, (4) attending other workshops, (5) training or testing of the tools, and (6) developing pilot case studies. A poster board organized into the six themes was put in the center of the meeting room. Participants were asked to put their name, organization, and contact information on sticky notes and place them under the areas of engagement where they would like to be involved.

RESULTS AND DISCUSSION

Background knowledge of participants

During the first session of the workshop, participants anonymously responded to questions regarding pathogens and indicator organisms to gage their knowledge. Four groups of pathogens (bacteria, e.g. *Vibrio cholera*; helminths, e.g. *Ascaris*; protozoa, e.g. *Giardia*; and viruses, e.g. rotavirus) and indicator organisms were introduced to participants and their important differences concerning size, persistence, potency, and resistance to treatment (see Figure 1 for illustrations).

Despite initially reporting a high level of knowledge regarding pathogens or fecal indicator microorganisms, a number of stakeholders were unaware that fecal indicator bacteria do not have the same behavior and persistence traits as helminths, protozoa, or viruses, making fecal indicator bacteria inadequate for assessing pathogen reductions for all pathogen groups. This suggests a need for awareness and capacity development around pathogens found in excreta (Table 1).

Marketplace station 1: stakeholder engagement to understand current tools used for sanitation safety planning

Table 2 shows a range of documents used by stakeholders to make sanitation decisions. These range from crosscutting

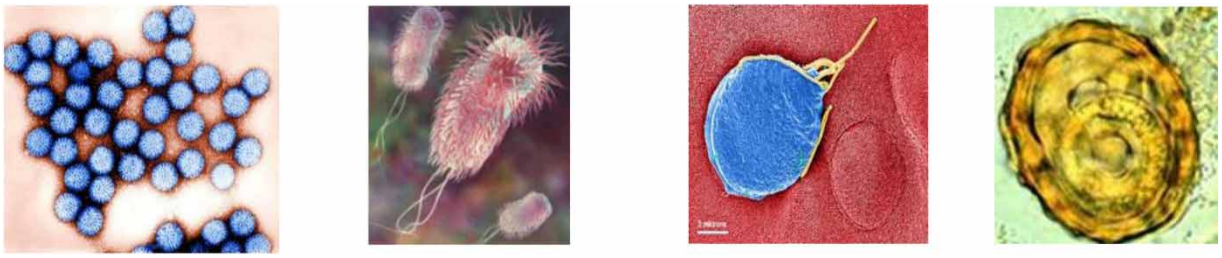

Figure 1 | Viruses, bacteria, protozoa, and helminths (image credits left to right: CDC/ Dr. Erskine Palmer; US EPA (2016); CDC Parasitology).

Table 1 | Participants' knowledge of pathogens and indicator microorganisms

Question	Totals, *n* (%)
How familiar are you with pathogens?	$n = 25$
Not familiar at all	3 (12)
Slightly familiar	2 (8)
Somewhat familiar	3 (12)
Moderately familiar	11 (44)
Extremely familiar	6 (24)
How familiar are you with fecal indicator organisms?	$n = 28$
Not familiar at all	4 (14.3)
Slightly familiar	2 (7.1)
Somewhat familiar	2 (7.1)
Moderately familiar	11 (39.3)
Extremely familiar	9 (32.2)
Fecal coliforms are	$n = 28$
A. Bacteria	2 (7.1)
B. Indicator microorganisms	9 (32.2)
C. Pathogens	4 (14.3)
D. A and B	13 (46.4)
Why we measure indicator organisms instead of specific pathogens?	$n = 28$
A. Less expensive	0 (0)
B. Easier than measuring individual pathogens	4 (14.3)
C. Occurrences in the environment correspond really well with pathogens	7 (25)
D. A and B	4 (14.3)
E. A, B, and C	13 (46.4)

n = number of participants who participated in the clicker survey and % = percentage. Not all participants utilized the clickers on both days, which is why n does not equal 41.

tools used by many organizations to organization-specific documents.

Stakeholder responses (Table 2) indicated that most of the sources of information they use are not necessarily tools but generic documents, frameworks, or approaches that may not be user-friendly enough to support decision-making. Limitations with existing information sources (Table 3) relate to (1) limited awareness, (2) limited dissemination and capacity building, and (3) limited evidence-driven data on specific technologies and management strategies to support stakeholders in making informed sanitation decisions.

Surprisingly, no reference was made to more quantitative and design-related tools, such as the Eawag compendium on sanitation technologies (Tilley *et al.* 2014) or the WHO guidelines for the safe use of wastewater, excreta, and graywater in agriculture (WHO 2006). The tools cited by the participants were largely frameworks and did not seem to support their needs in terms of sanitation technology selection and resource prioritization around sanitation. This is supported by previous research that found that utilities and government agencies mainly relied on information from water consumers, guidelines for water quality standards, and self-monitoring data from utilities for decision-making (Amjad *et al.* 2017). Interestingly, the study by Amjad *et al.* (2017) also found that while water utilities applied a mix of information sources for decision-making, government agencies relied more on intelligence gathering (e.g. self-reported data) than evidence-based data. An example of intelligence gathering is when government agencies rely on self-reported data collection by water utilities as opposed to conducting their own water quality testing to verify the adequate performance of treatment systems.

The K2P agenda includes increasing access and adding the value to existing tools and documents that inform sanitation decisions. Nearly all currently used sanitation tools lack health-based data on pathogens in wastewater and

Table 2 | Stakeholders' information sources for sanitation decision-making

Information sources
Government: ***WHO sanitation safety plans***, Public Health Act, sector performance reports, district implementation plans, financing strategy for improved sanitation and hygiene promotion, town sanitation plans, and manuals (such as implementation manual for water and sanitation development facilities, design manual for water supply, population data, MoWE sanitation manual – under development, and manuals for water quality indicators and standards). Other sources of information mentioned include internet, books, documents on handwashing and waste disposal, bacteriological test certificates from laboratories on the quality of water sources, regulations on sanitation and water quality standards, the construction of lined pit latrines, and FSM.
University: National water and sanitation policies, geographic information system (GIS) maps, sector performance reports, ***community-led total sanitation (CLTS)***, health risk awareness for schools, questionnaires on perceptions and trends, ArcGIS for mapping survey areas, and population data.
Water and sewerage utility: Wastewater loads produced, information on area population, topography and cost of establishment, conversion and non-conversion technologies, effluent discharge standards manual, standard operating laboratory procedures, and academic training in treatment plant operations.
City authorities: *WHO sanitation safety plans, FSM toolbox*, *SFD*, World Bank sanitation toolbox, ***CLTS***, child hygiene and sanitation training (CHAST), and participatory hygiene and sanitation transformation (PHAST). Authority specific documents include the ordinance for sewage and FSM, minimum standards for sanitation technology specifications for the containment of waste in communities and institutions, inspection tools for the assessment of fecal sludge transporters, monitoring and evaluation data, health inspection checklists, onsite sanitation guidelines, drainage sanitation legislations, and solid waste management ordinance.
Non-government organizations: Community-led urban environmental sanitation planning approach (CLUES), *CLTS*, water quality analysis, PHAST, area-specific data, data on costs, SFDs, Uganda National Bureau of Standards (UNBS), *WHO guidelines*, joint monitoring program (JMP) for drinking water and sanitation standards, ***FSM toolbox***, community sanitation maps, national sanitation data collection tools, latrine and water coverage data for community entries, human-centered designs, nudging/behavioral guide, ***WHO sanitation safety plans***, bylaws, and minimum onsite sanitation standards.

Notes: Common tools used for decision-making mentioned more than once are indicated in bold and italic font. Others are specific to the organization.

excreta. Generic documents and frameworks used by WASH practitioners for sanitation planning can be supported with tools developed with data from the GWPP (Rose & Jiménez-Cisneros 2019). Thus, instead of creating a new set of tools, the K2P project seeks to link with the SSP manual, SFDs, the FSM toolbox, and Eawag's compendium for sanitation technologies among other existing tools (WHO 2006, 2016; Peal *et al.* 2014; Tilley *et al.* 2014). Additionally, participants expressed the need for capacity building regarding the microbial risks and hazards associated with inadequate management of wastewater and excreta, access to data, and user-friendly tools for using the data. Participants also suggested that the tools should have short user manuals, because the current guidance documents and tools available are too long and difficult to use. This concurs with previous research that found that the use of process guides for comprehensive urban sanitation decision-making is not common practice due to difficulties in comprehension and inadequate dissemination (Ramôa *et al.* 2017).

Table 3 | Gaps in existing tools or information sources used for sanitation decision-making

Government: Awareness, capacity building, and occupational risk/hazards, proper waste management, statistics on improved sanitation methods, and practices in communities; cost–benefit analysis, accessibility and data user-friendliness; sanitation technology standards, operation and maintenance mechanisms for sustainability, quality monitoring of effluent and water supplied, sanitation levy, and framework to regulate sanitation services.
Water and sewerage utility: Information on technologies.
City authorities: Sanitation standards for safe reuse of fecal sludge, citizen engagement in awareness creation, and sludge/pellet safety for agriculture use.
Non-government organizations: Information/tools on safe excreta management and national tools on sanitation levels from health facilities and schools.

Marketplace station 2: the development of a concept for a PFT

In this station, stakeholders were presented with preliminary concepts for a tool (Figure 2) that would determine pathogen flows throughout the sanitation service chain, using information about the design, management, and performance of the different components of the sanitation system with respect to pathogen containment and reduction.

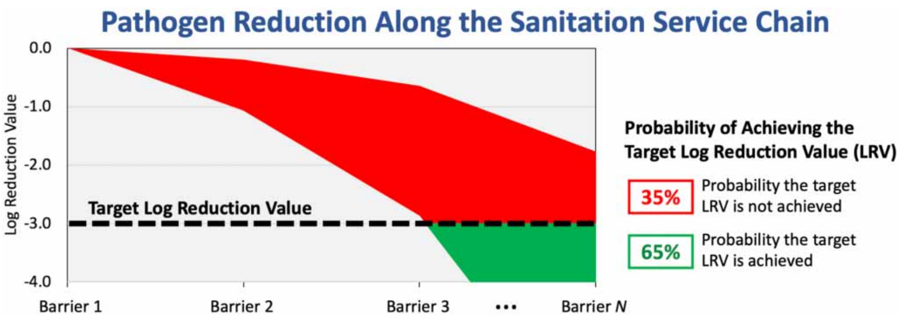

Figure 2 | Original draft concept for the visualized output of the PFT. (*Note*: This figure is showing a concept. It is not based on real data, but the proposed concept was to produce a similar figure (using real data) by defining a distribution of log reduction values for each barrier in the sanitation service chain and then using Monte Carlo simulations to forecast the likely range of overall log reduction values (represented as the spread between upper and lower values shown) for the entire treatment chain, which may consist of multiple barriers in series.)

The design of the tool builds off the SFD approach regarding the proportion of unsafely managed excreta in a given context. The main difference is that instead of mapping the flow of excreta, the tool maps the flow of pathogens throughout the sanitation chain. The tool will complement design standards as it will be able to help sanitation planners and engineers select technologies based on anticipated pathogen reductions achievable for onsite sanitation and centralized sanitation technologies used in their particular context. The tool will predict the log reduction of pathogens throughout the sanitation service chain (using data from the GWPP) as the fecal sludge moves through several treatment barriers (Figure 2). The tool will output an overall log reduction achieved and will show the variability and uncertainty in the data using prediction intervals. The probability of achieving a target overall log reduction value that is established at the beginning by the user is then calculated based on the local context, priorities, and health targets. The results will be shown as the percentage probability of achieving versus not achieving the target. The K2P team hypothesizes that this form of communicating uncertainty (i.e., showing a binary output based on the comparison between a prediction interval and a user-selected target value) will (1) be more intuitive for practitioners (rather than simply showing the predicted value with its respective prediction interval) and (2) empower practitioners by allowing them to view predictions within the context of their own targets and goals. This approach resonated with stakeholders as some users mentioned that the output was 'easy to interpret.'

The stakeholders also shared feedback on the utility of the tool and its application that have contributed to improve the current version of the tool. Some stakeholder suggestions were specific to Uganda, while others centered on several key themes (Table 4). First, stakeholders suggested that the tool should be explicit in providing additional treatment barriers that could be added into the system to increase overall pathogen reductions. This has been addressed by predicting pathogen flows in both liquid and solid fractions of onsite and centralized sanitation system components. We are also developing short factsheets that highlight the ability of onsite and centralized sanitation technologies to inactivate and remove pathogens from waste streams.

Second, stakeholders suggested incorporating other potential causes of pathogen exposure such as solid waste that is often dumped into pit latrines and not safely managed when pit latrines are emptied. This suggestion to incorporate the management of solid waste that is often disposed of in onsite sanitation systems is an important consideration. However, the assessment of exposures is outside of the scope of the PFT, which is mostly focused on predicting the fate of the hazard (pathogens). Risk is the product of hazard and exposure, so the exposure component is very important and can be addressed using other tools such as the SaniPath tool (Robb *et al.* 2017). Third, participants recommended that the tool incorporates costing features or links to a costing tool that could further support decision-making regarding the selection of technologies. However, since the goal of the K2P agenda is to develop a tool that is broadly and globally applicable, incorporating the cost of constructing, operating, and maintaining different sanitation technologies is challenging as it can vary greatly

Table 4 | Collection of stakeholder suggestions on the development of a PFT

Themes	Stakeholder responses
How to establish a meaningful log reduction value	Stakeholders liked the per cent or probability safe versus unsafe as it was easy to interpret. However, they requested guidance on how to establish meaningful target log reduction for their particular system. Some sanitation systems might be considered safe if they achieve an overall 3-log reduction of pathogens, while for others, this log reduction value might still be considered 'unsafe.' They suggested improvement strategies, such as the provision of additional barriers to demonstrate to users how to achieve an appropriate log reduction value for their particular context.
Solid waste addition to onsite sanitation systems	Stakeholders mentioned that households use onsite systems such as pit latrines as dumping sites for solid waste. During the pit emptying process, solid waste needs to be separated from human excreta before conveyance to the treatment facility. This practice can result in a potential flow of pathogens back into the environment and thus needs to incorporate it in the tool.
End use or disposal	Burying sludge at the treatment facility and reusing treated biosolids in agriculture were highlighted as two potential end users of the solid products from a sanitation system. Stakeholders requested that the tool clarifies the appropriate log reductions needed under different end-use scenarios. The application of fecal sludge on farms is of great importance to users and requires adding the exposure risk into the models. Essentially, the users requested that the tool incorporates exposure into the hazard assessment to enable the use of risk assessment methods.
Cost of different treatment technologies	Many individuals are involved in the design and construction of onsite sanitation systems, e.g. pit latrines and septic tanks, but normally provide different quotes. The App should have a feature to estimate the cost of materials used in relation to various sizes (dimensions) of onsite sanitation systems. The design life of a facility in this case should also be included.
Retention time	The log reduction or percentage removal of pathogens achieved when waste stabilization ponds are used for wastewater and fecal sludge treatment depends on flow rates, volume, depth of ponds, and total retention time. The greater the retention time, the more pathogen reduction/inactivation obtained. Key factors, such as the number of sunshine hours (UV radiation) or the number of sunshine days received for the total retention time, should be included to improve the predictability or accuracy of results produced by the App.
Treatment facility or no treatment facility	The tool should have scenarios that indicate the impact or change in surface or ground water quality in the presence or absence of a wastewater/fecal sludge treatment facility with existing or proposed additional barriers. This is important in the planning and advocacy process to justify the need for a treatment facility in a given community/area.

between and within countries. Due to this complexity, it is outside the current K2P scope. In the future, investigating what costing tools exist that could be linked to the current tool under development is warranted.

Lastly, to justify the need and advocate for improved treatment efficiency within certain communities or areas, it was suggested that the tool incorporates the use of scenarios to demonstrate anticipated changes in surface or ground water quality in the absence or presence of a particular set of sanitation barriers. Future versions of the tool will allow users to select additional treatment barriers to achieve suggested pathogen reduction values if the current configuration is not achieving the desired goals. These modifications will allow users to track improvements in the performance of the sanitation systems with respect to planned expansions or upgrades to facilities.

From the clicker survey feedback on the PFT, the majority of the stakeholders (94.2%, $N = 35$) either agreed (25.7%, $n = 9$) or strongly agreed (68.5%, $n = 24$) that they wanted to learn more about the tool moving forward (Figure 3). Nearly half of the stakeholders (44%, $n = 15$) were interested in learning more about the tool through future workshops and contributing to the design of the tool, 27% ($n = 9$) were only interested in helping with the design, and 24% ($n = 8$) were only interested in learning through the training workshops. Six per cent of the participants did not express interest in the tool. In addition, 85.3% ($N = 29$) of the stakeholders either strongly agreed

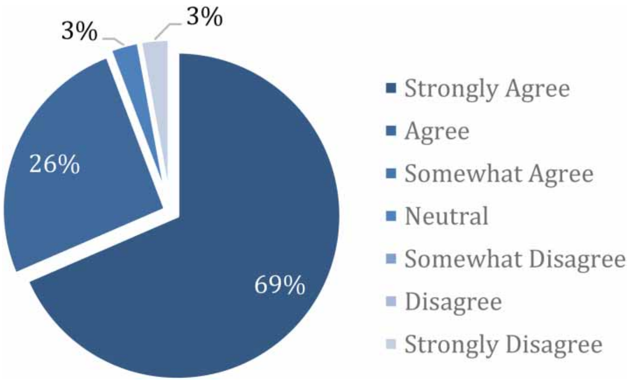

Figure 3 | K2P stakeholder interests in learning more about the PFT (the total number of workshop respondents = 35).

(35.3%, $n = 12$) or agreed (50%, $n = 17$) that the tool could help support their sanitation decision-making (see Supplementary Data, Table S1). Studies have found the use of information communication technology tools influential in stimulating public participation in improved water resource governance and planning, as well as in improving the delivery of health services (Pereira *et al.* 2003; Mukhtarov *et al.* 2018). Based on participants' feedback, we felt that this could also be true for the PFT in that it could enable stakeholders to use scientific evidence to support sanitation decision-making, such as in resource allocation, technology selection, the development of policy guidelines, and advocacy. Stakeholder feedback led to the incorporation of several changes in the revised concept of the tool.

Marketplace station 3: the development of a pathogen mapping tool (PMT) for the visualization of modeled pathogen emissions and concentrations in the environment

Stakeholders were presented with a preliminary mapping tool that can visualize pathogen emissions to surface waters based on the population density and sanitation coverage, among other inputs. The mapping concepts and tools were presented to stakeholders, so they could visualize the role of sanitation facilities on surface water contamination by quantifying and visualizing the different pathways pathogens use to reach surface water. Ultimately, modeled pathogen emission outputs can inform SSP and guide decision-making for areas lacking monitoring data, such as in Sub-Saharan Africa, and identify hotspots and key sources of pathogen emissions resulting from inadequate excreta management (Okaali & Hofstra 2018). During the session, the facilitators walked the participants through a demo of the pathogen emission mapping tool and maps developed previously for Uganda on the distribution of rotavirus emissions in surface waters based on access to sanitation across the country (Figure 4). The waterborne pathogen modeling approach used in the mapping tool has evolved through several studies (Hofstra *et al.* 2013; Vermeulen *et al.* 2015). The modeling framework requires the literature and data on rural and urban population, sanitation types and their percentage coverage, disease incidence, pathogen excretion rates, and wastewater treatment efficiency to estimate pathogen loading. The population is divided into different age groups, and the simulated model output is plotted on a gridded population density map as shown in the example of Figure 4. In Figure 4, two hypothetical scenarios are presented. These scenarios are not intended to be realistic or desirable, but served the sole purpose of illustrating the potential for scenario analysis in understanding the impacts of sanitation coverage on pathogen loading to surface waters. According to the 2030 projections, the population is expected to increase by 76% for both scenarios (Okaali & Hofstra 2018). In Scenario 1, everyone in Uganda was given a sewer connection, but the treatment capacity did not increase, while in Scenario 2, 10% of the population had a sewer and 90% of this waste was treated, and 3% practiced open defecation. It should be noted that emissions from pit latrines and septic tanks are omitted from these calculations and will be incorporated in future versions of the model (Okaali & Hofstra 2018). The areas in red in Figures 4(d) and 4(e) indicate districts with high pathogen emissions, while the blue regions include districts with reduced emissions when compared to the baseline. Emissions and changes in the emissions are largest in the capital city Kampala, mostly because this is the area with the largest population.

During the workshops, stakeholders discussed the importance of visual maps, what improvements could be made, and what should be added to make them more useful. They mentioned that emission maps can help identify 'hotspots' with high pathogen emissions, make decisions on appropriate sanitation interventions, monitor hotspot areas

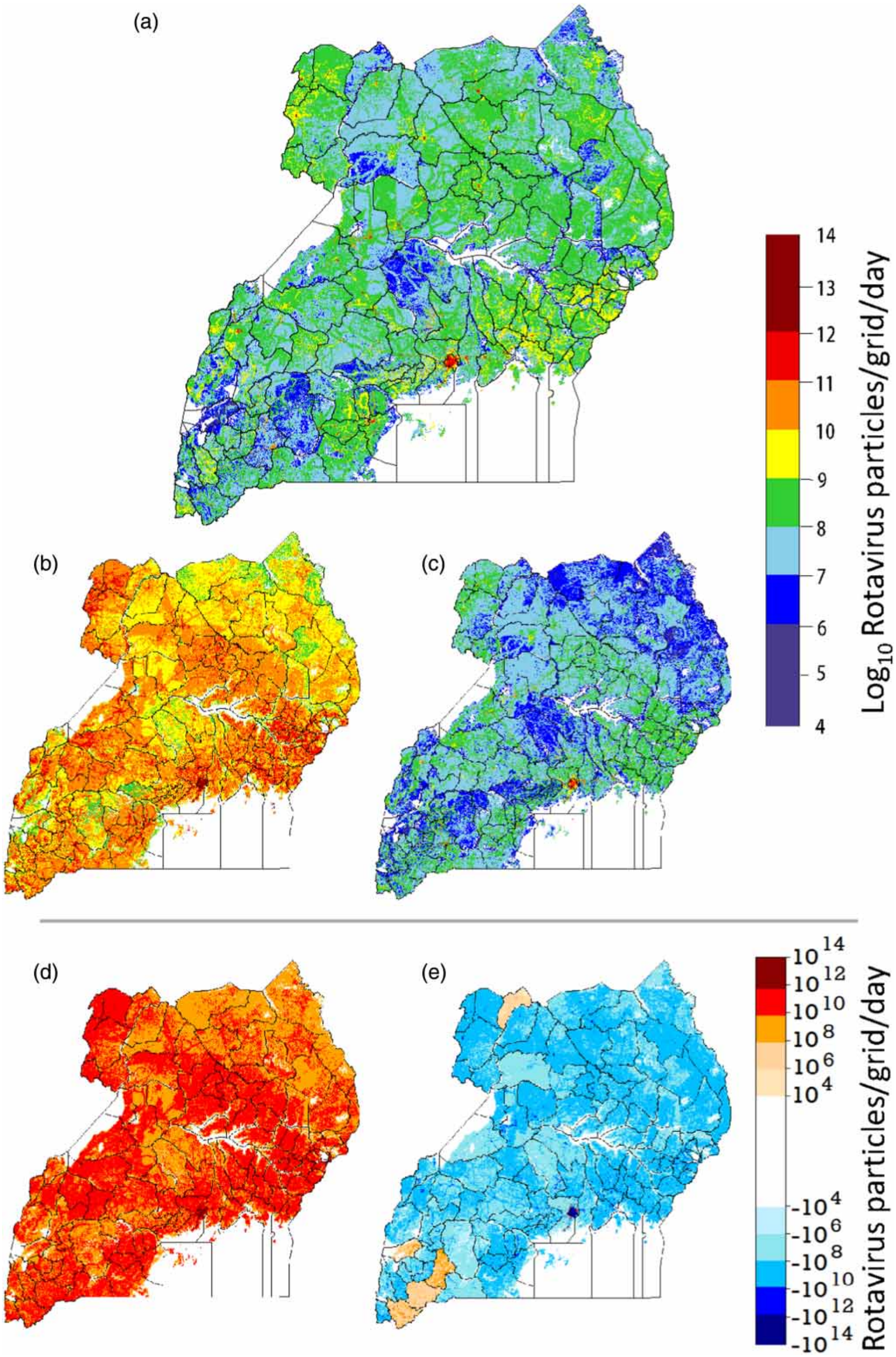

Figure 4 | Demo results output from the pathogen mapping tool showing rotavirus emissions reaching surface water in Uganda from different sanitation sources for the baseline year 2015: plot (a); and for two scenarios in 2030: plots (b) and (c). Plots (d) and (e) are the differences between the respective scenario ((b) and (c) and the baseline year. These maps are produced using the global waterborne pathogen model adapted for human rotavirus emissions (GloWPa-H1) (Okaali & Hofstra 2018). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wh.2019.151.

for resource prioritization and potential disease outbreaks, and identify locations for implementing preventive interventions and help with health education.

Stakeholders were also critical about the omission of pit latrines and septic tanks in the model, and they emphasized that the scenarios were not realistic. Additionally, stakeholders suggested including socio-demographic inputs like population growth, as well as data on sanitation technologies and seasonal variations. Suggested outputs included health impacts and disease burden. While the latter outputs would be an asset, they are not currently a part of the project and will need to be integrated in future. Moreover, stakeholders will get the opportunity to develop their own scenarios that could, for example, include socio-economic development, climate change, and management interventions.

From the clicker survey feedback, the majority of the stakeholders (90.7%, $N = 29$) either agreed (31.3%, $n = 10$) or strongly agreed (59.4%, $n = 19$) that they wanted to learn more about the pathogens emission mapping tool (Figure 5). Similarly, they also either agreed (38.2%, $n = 13$) or strongly agreed (41.2%, $n = 14$) that the mapping tool would be useful for sanitation decision-making or planning (see Table S1). Stakeholders expressed learning more about pathogen emissions mapping through future workshops and helping in designing the tool (58%, $n = 19$), followed by more than a third (36%, $n = 12$) who were only interested in future workshops. Only three per cent were expressed not interested in future participation in workshops and engagement in the development of the mapping tool. Previous studies underpin the growing need and importance to use system methodologies and approaches in environmental and public health decision-making (Carey *et al.* 2015; Pongsiri *et al.* 2017; Currie *et al.* 2018). System approaches provide the behavioral understanding of complex systems and align well with the K2P agenda to evidence-based science translated into knowledge understandable and usable by a wide range of WASH practitioners (Carey *et al.* 2015; Pongsiri *et al.* 2017). The emissions mapping tool is a visualization tool that uses a system approach to help stakeholders visualize scenarios for pathogen distribution in the environment. In a study of scenario planning, authors underscore the importance of combining qualitative and quantitative scenario planning approaches to generate robust scenarios (Amer *et al.* 2013). One of the next steps in the mapping tool development includes hosting a scenario analysis workshop, whereby stakeholders can help identify scenarios that would be most representative of their needs and contexts utilizing both qualitative and quantitative data.

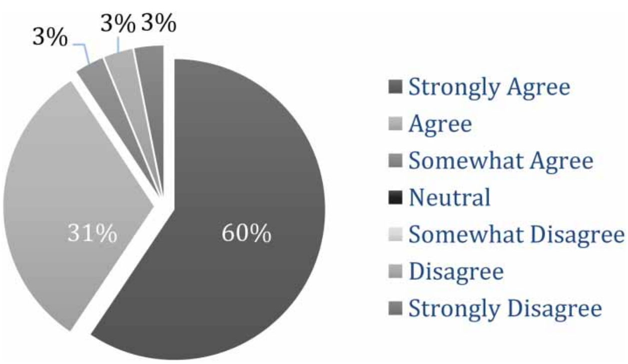

Figure 5 | K2P stakeholder interests in learning more about the mapping emissions tool (the total number of workshop respondents = 32).

Utility of the K2P tools in existing sanitation planning strategies

Although several approaches on sanitation and health risks have recently been developed, they fall short in their ability to predict fecal pathogen flows that can be connected with exposure to estimate risks associated with existing sanitation services and to compare expected health improvements (Mills *et al.* 2018). The tools under development through the K2P agenda seek to fill these gaps while also providing stakeholders with interactive tools to use in decision-making processes for appropriate technology selection and ultimately improved health outcomes. Stakeholders in the workshops engaged in discussions and provided feedback on existing tools used for sanitation planning, gaps in available tools, the K2P pathogen mapping, and the pathogen flow sanitation decision support tools. Stakeholders provided recommendations on the integration of the K2P tools with existing WASH tools/activities as well as identified improvements to better align the tools with practitioner needs. Overall, the vast majority of stakeholders (87.9%, $N = 33$) either agreed (27.3%, $n = 9$) or strongly agreed (60.6%, $n = 20$) that they wanted to learn and engage more in the K2P agenda as it moves forward (Table S1). Only six per cent expressed no interest.

Stakeholders identified how the K2P agenda could link with existing tools and other information sources used for sanitation planning, and how K2P tools aligned to support stakeholder needs (Table S2). In addition, during the small group discussions, participants were challenged to reflect on the value of using pathogen data in sanitation planning. In these discussions, stakeholders mentioned that the K2P tools were good for targeting and allocating resources to priority areas, technology selection, designing of treatment facilities, the selection of appropriate technologies, advocacy – through mobilization and lobbying for funds, and providing direction for planning, implementation, and evaluation of sanitation projects (Table S2). Participants identified the following gaps and areas for improvement, including the development of tools for informing decisions on smaller onsite sanitation technologies, such as pit latrines, incorporating the design and life span of sanitation technologies as well as costing information, and the inclusion of a compliance component.

Lastly, stakeholders identified several case studies where the tools could be tried in Uganda including the implementation of town sanitation plans, fecal sludge reuse on land, decision-making around upgrading existing wastewater treatment facilities across the country, as well as the mapping of pathogen emissions in informal settlements in Kampala. At the close of the workshop, stakeholders identified areas where they wanted to engage more with the K2P project team in moving forward. Participants said that they wanted to be involved in case study development (27%; 11/41 participants), the provision of data (17%; 7/41), contributing the pathogen emissions mapping tool (32%; 13/41), contributing the sanitation system PFT (44%; 18/41), testing of the tools (93%; 13/41), and/or future workshop participation (58.5%; 24/41). Stakeholder engagements, such as those undertaken in the K2P agenda, have been found, in both research and practice, crucial in achieving health outcomes (Reed 2008; Aranda-Jan *et al.* 2014). The study by Aranda-Jan *et al.* (2014) found that strong stakeholder collaboration was among the key factors associated with the positive health-related outcomes. The other success factors identified were accessibility, acceptance and low cost of the technology, effective adaptation to local contexts, and government involvement (Aranda-Jan *et al.* 2014). In order to achieve safely managed sanitation, researchers and tool developers need to collaborate with end users and co-create tools that will work to support practitioners in the field in their daily decision-making. This integration of local and scientific knowledge through stakeholder participation can provide a more comprehensive understanding of the complexity of systems and processes and enhance decision-making (Reed 2008). These studies highlight the importance of stakeholder input for the success in any tool development, uptake, and use in practice.

CONCLUSIONS

Uganda, like other UN member states, is committed to the 2030 SDGs agenda, among which is the aim to achieve 100% access to safe water and sanitation. Achieving this target calls for more consolidated, evidence-based, and readily accessible information on the treatment performance and appropriateness of sanitation technologies to inform decision-making. Often, the data present in the academic literature have not been translated to a form that is usable and accessible to practitioners. In order to move to a science and risk-based framework, the first step is to translate scientific knowledge to practitioners. The K2P agenda with assistance from stakeholders seeks to fill this gap by providing accessible tools, so that sanitation practitioners can use scientific evidence to move up the ladder from 'basic' to 'safely managed' excreta when planning and implementing sanitation projects. The findings presented in this paper underscore the need for evidence-based support tools for sanitation planning and the potential for communicating scientific data through digital Apps and visualization tools to bridge science with practice.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at http://dx.doi.org/10.2166/wh.2019.151.

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