Research Paper

WASH conditions in a small town in Uganda: how safe are on-site facilities?

J. G. Nayebare, M. M. Owor, R. Kulabako, L. C. Campos, E. Fottrell and R. G. Taylor

ABSTRACT

Inadequate hygiene coupled with the conjunctive use of the shallow subsurface as both a source of water and repository of faecal matter pose substantial risks to human health in low-income countries undergoing rapid urbanisation. To evaluate water, sanitation and hygiene (WASH) conditions in a small, rapidly growing town in central Uganda (Lukaya) served primarily by on-site water supply and sanitation facilities, water-point mapping, focus group discussions, sanitary-risk inspections and 386 household surveys were conducted. Household surveys indicate high awareness (82%) of domestic hygiene (e.g. handwashing, boiling water) but limited evidence of practice. WHO Sanitary Risk Surveys and Rapid Participatory Sanitation System Risk Assessments reveal further that community hygiene around water points and sanitation facilities including their maintenance is commonly inadequate. Spot sampling of groundwater quality shows widespread faecal contamination indicated by enumerated thermo-tolerant coliforms (TTCs) (*Escherichia coli)* ranging from 0 to 10^4 cfc/100 mL and nitrate concentrations that occasionally exceed 250 mg/L. As defined by the WHO/UNICEF Joint Monitoring programme, there are no *safely managed* water sources in Lukaya; ~55% of *improved* water sources comprising primarily shallow hand-dug wells show gross faecal contamination by *E. coli*; and 51% of on-site sanitation facilities are *unimproved*. Despite the critical importance of on-site water supply and sanitation facilities in low-income countries to the realisation of UN Sustainable Goal 6 (access to safe water and sanitation for all by 2030), the analysis highlights the fragility and vulnerability of these systems where current monitoring and maintenance of communal facilities are commonly inadequate.

Key words | hygiene, on-site, sanitation, urban, water supply

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INTRODUCTION

Urban areas in low-income countries are commonly characterised by informal settlements that lack basic amenities (Nakagiri *et al.* 2015). Water supply, sanitation and hygiene (WASH) conditions in these settlements are often inadequate due to low budgets, lack of capacity, unclear regulations and lack of feasible options to provide services by all branches of government (UNICEF 2015; Andersson *et al.* 2016). Further, there is often substantial

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dependence upon on-site water and sanitation facilities that exploit the shallow subsurface not only to contain faecal waste but also to provide potable water via wells and springs. In Kampala (Uganda), for example, ~90% of households (HHs) use on-site sanitation facilities, primarily pit latrines (Nakagiri *et al.* 2015) and traditional pit latrines without concrete slabs (WSP 2015). Such self-operated, on-site sanitation facilities are challenging to maintain, especially in densely populated areas where within informal settlements in Nairobi, 85% of latrine pit emptying is done by hand (O'Keefe *et al.* 2015). These conditions, combined with the tendency of low-income settlements to exist in low-lying areas prone to flooding, render on-site water supplies intrinsically vulnerable to contamination (WSP 2015).

Recent research continues to show the risk to human health posed by limited or impaired access to safe water and sanitation as well as inadequate hygiene. In Uganda where just 18% of the population nationally has access to a *basic* sanitation service (WHO/UNICEF-JMP 2019), a rise in unsafe modes of faecal matter disposal such as 'flying toilets' has been observed to facilitate the transmission of diarrhoeal diseases (MoH 2014). On Nsazi Island in Uganda, for example, 76% of respondents reported having no toilet with 48% of respondents also reporting ailments due to diarrhoeal diseases including dysentery (WaterAid 2011). In Angola, where 55% of the urban population resides in slums, cholera has been endemic with over 80,000 cases and 1,000 deaths in 2006 and a recurrence of cholera in 2013 (Buckley & Achilles 2016). In Benue State, Nigeria, children who failed to wash their hands regularly after toilet use showed a high prevalence (49%) of enteric infections (Atu *et al.* 2016). In Siaya County, Kenya, increased water fetching times and longer distances to water sources were found to result in an increased risk of diarrhoeal disease (Nygren *et al.* 2016).

Provision of WASH services is widely considered to be an essential requirement to control the occurrence of water-related diseases. There is, however, mounting evidence that *improved* water sources comprising a *basic* service following criteria of the WHO–UNICEF Joint Monitoring Programme (WHO/UNICEF-JMP 2017) may still be prone to faecal contamination in low-income settlements. According to Onda *et al.* (2012), 12% of sampled piped water supplies and 45% of other improved water sources including boreholes and protected springs and wells in Ethiopia were found to be contaminated by thermo-tolerant coliforms (TTCs). In Lilongwe, Malawi, faecal contamination was observed in 10% (59%) of improved sources in high-income (low-income) areas; the statistical difference ($p < 0.05$) between water quality in low-income and high-income areas was attributed to inadequate infrastructure and maintenance (Boakye-Ansah *et al.* 2016). In Benue State, Nigeria, private wells demonstrated the highest prevalence (52%) of contamination by faecal pathogens compared to boreholes and tank water facilities (Atu *et al.* 2016). In Ghana where over 70% of urban sanitation facilities are shared (Buckley & Achilles 2016), studies reveal these facilities are more likely to be unsanitary (Mazeau *et al.* 2012) and have an increased risk of diarrhoeal disease associated with their use (Heijnen *et al.* 2015).

To achieve sustainable and universal access to safe water and sanitation under United Nations (UN) Sustainable Development Goal (SDG) 6 requires an improved understanding of the status and risks posed by the use of on-site water and sanitation systems, which will feature centrally in most low-income towns and cities in realising UN SDG 6. Here, we assess the WASH conditions in Lukaya Town in central Uganda, a rapidly growing, small town using the shallow subsurface conjunctively as a source of safe water and repository of faecal matter. The specific objectives of this work were: (1) map and characterise water supply sources and sanitation facilities; (2) identify sources of pollution threatening potable water supply sources including on-site sanitation facilities; (3) assess water supply facilities and the quality of water used by the community; and (4) compare observed on-site water supply, sanitation and hygiene characteristics to the very limited, available evidence of morbidity from local health-facility records and self-reporting during household surveys.

STUDY AREA

Location

Lukaya is located in Kalungu District of central Uganda on the equator between latitudes 0°6′0″ and 0°11′0″S and longitudes 31°49′0″ and 31°56′0″E (Figure 1). The total

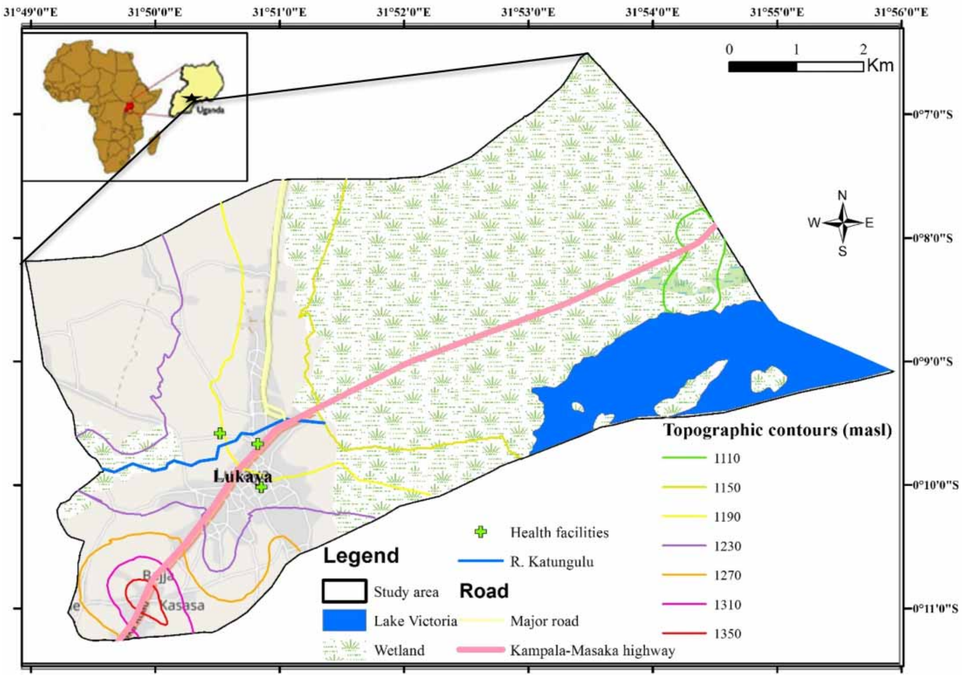

Figure 1 | Location of Lukaya Town (inset) and map of Lukaya Town based on Google OpenStreetMap™ showing topographic contours.

land area defined by the town council is 57 km^2 with a population density on inhabited land (38 km^2) of ~640 inhabitants per km^2 and population growth rate of 3% per annum (PDP 2017); remaining land (19 km^2) is occupied by wetlands adjacent to Lake Victoria. The region experiences a seasonally humid climate in which rainfall is bimodal with rainy seasons in March–April–May (MAM) and September–October–November (SON). Mean annual rainfall is ~890 mm with mean monthly peaks of 117 mm (April) and 102 mm (October) (Figure 2). Monthly minimum and maximum temperatures range from 10 to 16 °C and 16 to 25 °C, respectively; estimated potential evapotranspiration ranges from 1,350 to 1,750 mm $year^{-1}$ (NWRA 2013).

Physiographically, the town lies primarily within a lowland plain that is the result of downwarping during the Late Quaternary in the Upper Nile Basin associated with inter-rift tectonics (Taylor & Howard 1998). Depositional features which developed along valleys on the plateau and on the margins of Lake Victoria influence hydrology of local Rivers Katonga and Katungulu which flow into Lake Victoria. Mean elevation over the most eastern part of the town exceeds the mean lake level of 1,134 m above sea level (masl). The western part of the town is on relatively higher ground with an average elevation of 1,238 masl.

Water and sanitation

The water supplies of Lukaya derive primarily from groundwater abstracted from shallow wells using hand pumps and unprotected springs. A tiny minority of inhabitants is connected to a piped water system that is supplied by a borehole with a depth of 61 m below ground level (mbgl), equipped with a submersible pump in a neighbouring subcounty (Bukullula), and managed by the National Water Sewerage Corporation (NWSC). For the most part, sanitation facilities comprise partially lined, elevated pit latrines due to the shallow water table (0.5–5 mbgl) in low-lying areas. Other sanitation facilities include ventilated improved pit latrine, urine-diverting toilets and flushing toilets discharging into septic tanks. The town possesses neither a sewer network nor a wastewater treatment facility so faecal effluent is entirely contained in the shallow subsurface using on-site sanitation. Emptying of sanitation facilities is done by either digging another pit or transferring of the faecal matter to another pit. It also has been observed that

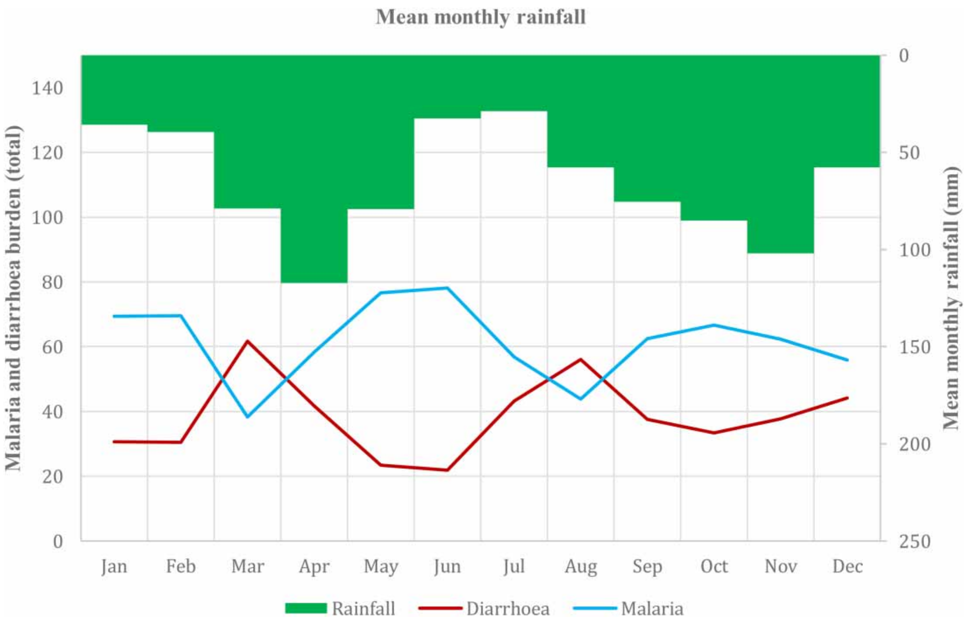

Figure 2 | Monthly incidence of malaria and diarrhoeal diseases based on 2,718 patients reporting in 2016 at the most frequently visited health clinic in Lukaya Town (Mukwano Medical Services); these are plotted alongside mean monthly rainfall (1942–2008) recorded at 6 monitoring stations in the vicinity of Lukaya Town.

dwellers leave an outlet on one side of the pit latrine housing so that when the pit latrine fills during the rainy season, faecal waste is flushed by surface runoff (focus group discussions (FGD), February 2017).

Water and sanitation legal and policy framework

Water and sanitation activities in Uganda take place within a set legal, policy and institutional framework (MWE 2007), which outlines the rights and responsibilities of different stakeholders and provides a basis for water resources management (WRM) and regulation. Key documents providing this framework in Uganda include The National Environment Management Policy (1994); The Constitution of the Republic of Uganda (1995); The Water Act (1995); The National Environment Act (1995); The Local Governments Act (1997); The Water Resources Regulations and Waste Water Discharge Regulation (1998); The Land Act (1998) and The Public Health Act (2000). Further, policies that provide the principles of action and rules of practices to be followed in the implementation of activities in the sector include The National Health Policy (1999); The National Water Policy (1999); The National Gender Policy (1999) and The Environmental Health Policy (2005). The institutional framework details the roles and responsibilities of key sector players which adopted the Sector Wide Approach to Planning (SWAP 2002). The four key sub-sectors of the water and sanitation sector include WRM; Rural Water Supply and Sanitation; Urban Water Supply and Sanitation; and Water for Production. In addition, Uganda has water quality standards formulated through Technical Committees comprising representatives from consumers, traders, academics, manufacturers, government and other stakeholders. The Ugandan National Bureau of Standards is a parastatal under the Ministry of Tourism, Trade and Industry that was established under Cap 327, of the Laws of Uganda and is responsible for enforcing standards for potable water (UNBS 2014).

Despite the existence of legal and policy frameworks in Uganda for water and sanitation, key limitations in these have been identified. For example, sanitation is not included at public service level; enforcement of stated regulations has been minimal; continuous provision of data on water and sanitation service delivery has been inadequate with a limited budget that affects the monitoring of services (MWE 2017). In small towns, low return on water and sanitation investments, a lack of feasible and cheap technological options to provide sanitation services, inappropriate infrastructure and poor coordination remain key challenges (MWE 2017). Conversely, water users lack power in fixing water charges for water in order to ensure affordability. For insistence, the introduction of 18% VAT on piped water in the 2012/2013 Financial Year National Budget affected many clients (NAPE 2012).

The legal and policy frameworks have instituted water management zones (WMZs) to facilitate sustainable development of water resources for the economic and social benefit of the people in the catchment and to implement the water management measures needed to protect and conserve the catchment and its water resources as well as to promote sustainability and resolve conflicts over resource use. Within the WMZs, town councils are responsible for the provision of water and sanitation services through the NWSC along with the protection of natural resources including water. Local councils and water user groups form water boards and water committees that are responsible for the maintenance of infrastructure and hygiene.

Observed health conditions

Commonly reported morbidity in Lukaya includes malaria and diarrhoeal diseases (Figure 2). Records from one of the most frequently visited health facilities indicate that disease incidence is dominated by malaria (81%) followed by diarrhoeal diseases (19%). The high incidence of malaria is associated with flooding during the rainy season when water levels in Lake Victoria are high thus draining the wetland area (see Figure 1) due to the close proximity of Lukaya Town to the lake. It is noteworthy that reported cases of diarrhoeal cases exceed malaria at the end of the dry seasons (March and August) when ponding is at a minimum.

Health legal framework

In 2010, Uganda developed the 2nd National Health Policy (NHP II) having been informed by the National Development Plan 2010–2015 and the 1995 Constitution of the Republic of Uganda. The NHP II priorities are health promotion and disease prevention with an emphasis on achieving universal access to a minimum health-care package as well as equitable and sustainable financing mechanisms. Several bills have been proposed to promote these policies but none have been finalised (MoH 2010). Kasimbazi & Kabwa (2013) argue that there is a need to enact new acts and amend existing ones in order to strengthen the existing Health Professions' Regulatory framework and develop robust monitoring capacity within the government and regulatory agencies. Currently, the country has made some reforms where the Ministry of Health developed the Health Sector Development Plan 2015/2016–2019/2020 to address the key challenges facing Uganda's health system such as information access and supporting health-care operations, management and decision making (MoH 2016).

MATERIALS AND METHODS

The study is cross-sectional in its design employing iterative quantitative and qualitative data collection methods; these included key informant consultations, FGD, field mapping of water supply points and sanitary facilities, sanitary inspections of the facilities, HH surveys, Rapid Participatory Sanitation System Risk Assessment (RPSSRA) and water-point sampling.

Water sources and sanitary facilities

To obtain data on water sources and sanitary facilities, consultation with Lukaya town council officials, and its health inspector was initiated in May 2016. This consultation was followed by field mapping of all existing water sources and sanitary facilities within the study area. All facilities were geo-referenced using a handheld Garmin eTrex®10 Global Position System. Water supply points were categorised according to WHO/UNICEF-JMP (2017, 2019) as 'safely managed', 'improved', 'basic', 'limited', 'unimproved' and 'no facility' depending on service level and structural classifications. Similarly, sanitary facilities were also classified as 'safely managed', 'basic', 'limited', 'improved', 'unimproved' and 'no facility' based on the mode of faecal matter containment, transport/treatment and disposal/use and facility structural integrity. Service levels for water sources are defined as: *safely managed* when water is from an *improved* water source that is located on premises, available when needed and free from faecal and priority chemical contamination; *basic* when drinking water is from an *improved* water source provided collection time is not more than 30 min for a round trip; *limited* when drinking water is from an *improved* source but collection time exceeds 30 min for a round trip including queuing; and *unimproved* when the water sources are not protected against contamination (e.g. unprotected dug well or unprotected spring). Likewise, for sanitation, a *safely managed* service employs an *improved* facility that is not shared with other HHs and where excreta are safely disposed of *in situ* or transported and treated offsite. *Basic* and *limited* services employ improved non-shared and shared sanitation facilities, respectively; an *unimproved* service may comprise pit latrines without a slab or platform, hanging latrines or bucket latrines. An *improved* service consists of flush and pour-flush toilets connecting to sewers, septic tanks or pit latrines and dry sanitation technologies, such as dry pit latrines with slabs and composting toilets.

To assess potential contamination risks to on-site water supplies, sanitary inspections of all the water supply points and latrines within a radial distance of 10 m from functional water points at the time of the visit was carried out during May 2017 using WHO (1997) Sanitary Risk Surveys tools. The survey tool had a set of questions with *Yes*/*No* responses which indicated presence/absence of a risk of contamination, respectively. The responses were awarded points so that '*Yes*' scored one point and '*No*' scored zero points. The risk score of each facility was obtained by summing up the *Yes* scores at the end of the inspection. A higher risk score represented a greater risk to drinking water quality and thus more likely to be contaminated by surrounding pollution sources (WHO 1997). Risk scores were plotted on a map using Arc GIS 10.3 software.

Household survey and environmental inspection

Household surveys were carried out using a pre-tested questionnaire in the months of July and August 2017. Two wards, Kaliro (highly populated) and Central (sparsely populated) (Figure 3), were purposefully selected in order to compare health risks resulting from differences related to population density. Using the Kish–Leslie formula, we obtained a total of 386 out of 4,930 HHs obtained from the Town Council Community Development Office which were randomly selected from across the two wards and their HH heads

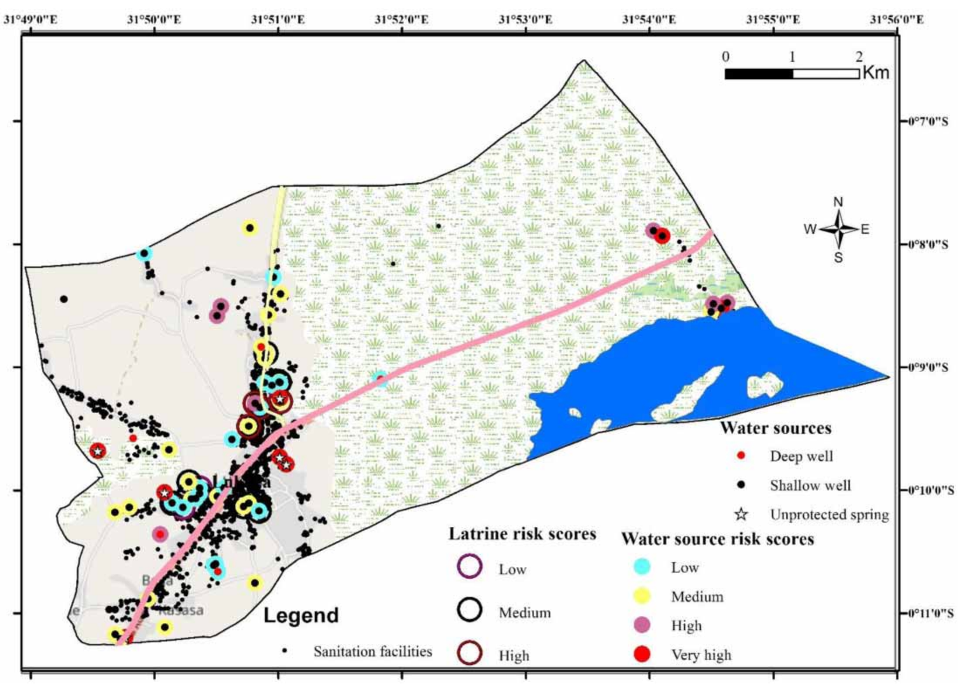

Figure 3 | Map of sanitary inspection results of on-site water sources and sanitation facilities in Lukaya in May 2017 overlaid on Google OpenStreetMap™.

interviewed. Detailed HH information on self-reported handwashing practices, domestic water sources and drinking water handling and sanitary infrastructure were collected in order to characterise through self-reporting the prevailing morbidity that may be related to prevailing WASH conditions. Only HH heads or their spouses who were present at the time of the visit were considered for the interview. At the same interviewed HH, environmental and sanitary inspections and observational spot checks of drinking water containers were carried out and evaluated.

Rapid participatory sanitation system risk assessment

Four half-day stakeholder risk assessment workshops were held in February 2018 with target communities (Kaliro and Central wards) at the Town Council Headquarters. Participants comprised a diverse group with representatives from the Village Health Teams, Local Council committee, Councillors, Youths, People With Disabilities and women who were selected with the help of a community development officer in the area. The risk assessment followed the RPSSRA methodology described by Campos *et al.* (2015). Each workshop had a group of 10–12 members who were further divided into small teams of 5–6 people. Participants were initially introduced to the F-diagram, which outlines pathways of disease transmission to humans related to fluids, fingers, flies and fields (Carr 2001) to help understand how different water and sanitation interventions reduce disease transmission by interrupting these transmission pathways. The scoring of risk indicators was followed by a discussion of their results. For the risk scoring, a set of 10 tokens was given to each group to indicate a proportional breakdown among low, medium and high-risk scores in each system component. The level of risk for all the risk indicators was calculated, averaged and graded into low, medium and high depending on severity as scores of 1, 2 and 3, respectively. To obtain overall risk scores, a mean of each indicator (hazardous events, exposure and vulnerability) was determined; results were then transformed to a scale of 0–100 of which 0–33 was low risk, 34–67 was medium risk and 68–100 was high risk (Campos *et al.* 2015). The results from the RPSSRA were used to validate the results from the HH surveys and sanitary inspection.

Water sampling

A snapshot of water quality was obtained by carrying out four periods of water sampling at an interval of 1 week during the wet season (April, 2018) when water quality is expected to deteriorate (Taylor *et al.* 2009). Water samples were collected from 37 commonly used water supply points by the community members previously reported during the HH surveys which included deep and unscreened hand-dug shallow wells equipped with hand pumps and unprotected springs.

Physico-chemical properties including temperature, pH, electrical conductivity (EC) and turbidity were determined in the field using a multi-parameter water quality meter (Hydrolab QUANTA) connected to a flow cell (where feasible) whereas nitrate concentrations were analysed using a HACH Calorimeter DR 890. Water samples assayed for *E. coli* were collected in sterilised plastic bottles, stored at 4 °C and transported to the Environmental Engineering Laboratory in Makerere University for analysis within 10 h. Chromocult® Coliform Agar was used as a culture medium whereas, the Colony counter aided in the enumeration of the coliform colonies. All analyses followed Standard Methods (APHA 2012).

Ethical considerations

Ethical approval to carry out the study was obtained from Makerere University School of Public Health, Higher Degrees, Research and Ethics Committee and the Uganda National Council of Science and Technology (SIR 150). Each participant provided written informed consent to participate in the study.

RESULTS AND DISCUSSION

Water source and sanitation facilities mapping

Sixty-seven water sources were identified in Lukaya Town and include 56 shallow hand-dug wells, 4 boreholes (deep wells) and 7 unprotected springs (Figure 3). Shallow, hand-dug wells vary in depth between 3 and 8 mbgl and are equipped with hand pumps. Most shallow wells (67%)

have static water levels that range from 0.5 to 5 mbgl and are vulnerable to flooding. Applying criteria of the WHO/UNICEF Joint Monitoring Programme (WHO/UNICEF JMP 2017), 60 (90%) of these water sources in Lukaya Town were *improved* (*i.e.* 56 shallow wells, 4 boreholes) and 7 (10%) were *unimproved*. Service levels of the *improved* water sources were either *basic* (67%) or *limited* (33%) due to waiting times; the 7 unprotected springs provide an *unimproved* service. No source was classified as *safely managed*. The significant proportion of *improved* water sources that are classified as providing a *basic* service is due primarily to the high number of self-supply shallow wells that are located close to user HHs (<30 min for a round trip) whose quality was perceived to be good (83%). Additionally, standpipes from a piped water supply network supplied by a borehole and operated by the National Water and Sewerage Corporation (NWSC), also provide a *basic* service but is estimated to be used by less than 40 (<1%) of the 6,349 HHs mapped in Lukaya Town (UBOS 2016) due to high costs of water tariffs that include the introduction of 18% VAT on piped water in 2012 (NAPE 2012). Each of the 66 on-site water sources, whether *improved* (vast majority) or *unimproved* (minority), is consequently shared by an average of 92 HHs. A total of 2,099 on-site sanitation facilities, primarily pit latrines, were also mapped. On average, this total suggests that each on-site sanitation facility is shared, on average, by 3 HHs. Based on WHO/UNICEF-JMP (2017) criteria, the majority of these facilities (51%) are pit latrines without slabs, providing an *unimproved* service. Of the remainder, 26% of the mapped facilities provide a *limited* service; 22% provide a '*basic*' service whereas <1% is *safely managed*.

Sanitary inspection

Sanitary-risk inspections of the water sources indicated ~74% of the water sources as having low- to medium-risk scores (0–6) (Figure 3); all these wells were either recently installed (<1 year) or privately owned. Communal wells and those owned by institutions showed high- to very high-risk scores (7–14). High-risk scores reflected lack of protection against contamination sources as well as structural integrity problems such as loose nuts and leaking standpipes which may feasibly permit surface runoff to enter wells. In the vicinity of these sources, stagnant water resulting from abstraction activities, surface runoff from rainfall within less than 2 m distance from the water supply point and littering of organic materials including food and faecal matter around the water sources were also common. The appearance of pink worms (e.g. *Chaoborus chironomus*) commonly associated with faecal waste during the wet season was observed and reported by some participants (FGD, February 2017) for wells ALW-24 and ALW-28. Inadequate treatment, operation and maintenance of water supply systems, as well as limited monitoring and supervision by regulators among other factors, have been reported to be the cause of non-compliance with WHO standards for *E. coli* in the 40% of the water supplies in small towns in Uganda (MWE 2018).

A small but significant proportion of the water sources (~16%) was found to have sanitation facilities within a radial distance of <30 m. Pit latrines within a radial distance of 10 m from water sources (Figure 3) had high sanitary-risk scores (77%) due primarily to poor structural integrity and hygiene. Inadequate hygiene was often observed in association with shared pit latrines. In addition, limited maintenance of on-site sanitation facilities explains, in part, important discrepancies in risk scores between water supply points and sanitary facilities. Generally, the majority (64%) of the people in Lukaya Town use *unimproved* sanitation facilities (e.g. pit latrines without slabs); *improved* sanitation facilities were observed to provide a *basic* service due to improper methods of faecal containment, conveyance and disposal.

HH surveys

Most respondents (85%) to HH surveys were women whose level of education was commonly at primary-school level (50%). 96% of the HHs had on-site sanitation facilities of which two-thirds of these were traditional latrines without slabs and classified as *unimproved* (WHO/UNICEF-JMP 2017); the remaining third comprises pit latrines with slabs and designated as *improved*. 4% had 'no facility' and practiced *open defaecation*. Many HHs (63%) shared a pit latrine with more than 4 other HHs. Seventy-one (71%) of the respondents emptied or dug new pits when their latrines became full. The common mode of emptying by the majority of the HHs (68%) was by transferring the content into another pit dug next to the latrine. Only 2% (flush toilets) used a safe method of faecal containment (septic tanks) but were not certain of treatment methods. Level of education has been argued to influence HH cleanness (Ezzati *et al.* 2004) and may explain the inadequate hygiene conditions observed in the study area. According to WHO/UNICEF-JMP (2017), latrines without slabs are considered 'unimproved' and unhygienic, posing a health risk to users. Although WHO/UNICEF JMP (2017) considers *in situ* excreta disposal or excreta emptied from storage facilities and buried on-site as 'safe management', such methods can be unsafe especially where the water table is shallow and the subsurface is composed of transmissive coarse sediments. When the faecal matter is not removed from the source when the latrine is full, it still poses risk to the users and such scenarios are considered hazardous to public health (Campos *et al.* 2015).

Nearly half of HHs (49%) reported having handwashing facilities placed near their latrines of which 87% had water but only 42% had soap. 80% of the participants reported washing hands after visiting the latrine as well as 70% before eating but only 38% before preparing food and just a few (14%) washing before feeding babies. However, the observational survey found that the majority (82%) of respondents did not possess a handwashing facility and 92% had no soap near the latrine handwashing facility (Figure 4). Of the existing latrines, 63% had very high-risk scores (7–14) primarily due to the absence of handwashing facility and soap and bad smell. These results may be explained by the fact that more than half (56%) paid for the water with two-thirds (67%) paying an average of about USD 0.04 per 20 L jerry can. From the observational surveys, Lukaya town has no handwashing service because most pit latrines lacked handwashing facilities and those that had facilities lacked either water/soap or both (WHO/UNICEF-JMP 2017). A large fraction of the participants (80%) possessed knowledge of handwashing after each latrine visit according to the survey yet most of them (92%) wash without soap based on spot-check observations. Previous studies (e.g. Kampf & Kramer 2004; Atu *et al.* 2016) suggest handwashing with soap can reduce microorganisms to near-zero levels and reduce diarrhoea risks by 48% (Cairncross *et al.* 2010). As observed by Bartram & Howard (2003), the location of the water source and cost of the water have implications on HH hygiene. Indeed, when a water source is outside the home, HH members tend to use less water than when it is within the home.

Almost all HHs (92%) reported that they treat their drinking water, the majority by boiling (99%). Seventy-seven percentage of HHs stored their drinking water in jerry cans and 54% cleaned their storage containers 3–5 times a week. Observational checks of drinking water storage showed that 67% of HHs kept drinking water containers on the floor and 42% of the containers had no lids (Figure 5). Although HH water treatment is one of the important means of controlling infectious disease transmission and the majority of people in East Africa

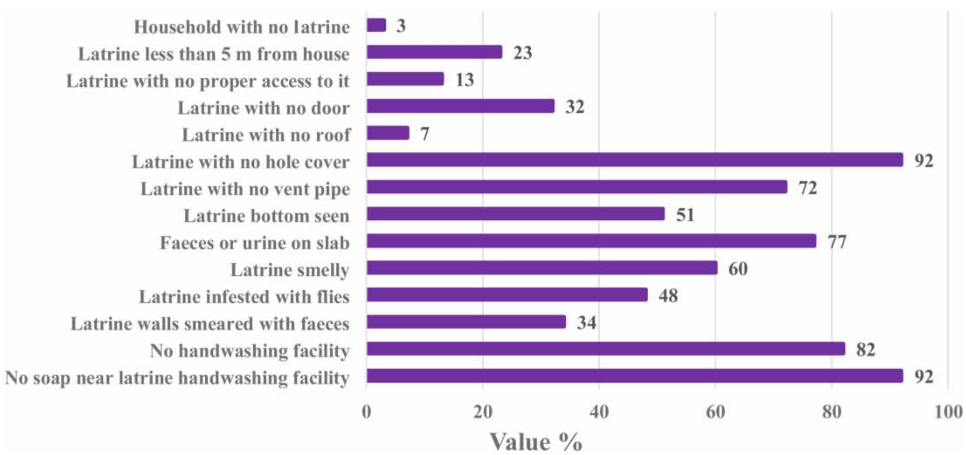

Figure 4 | Observed characteristics of pit latrines used by the members of the Lukaya community in May 2017.

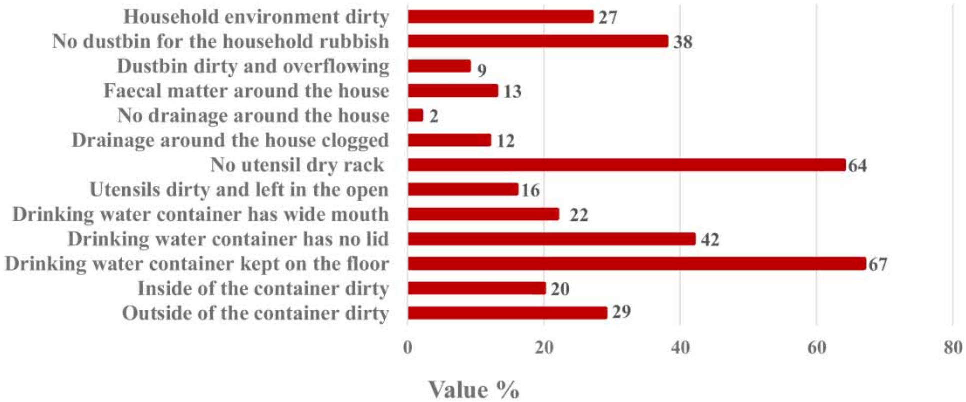

Figure 5 | Risk characterisation of drinking water containers and HH environmental hygiene.

including Uganda practice boiling drinking water as one of the HH treatment methods, safe storage of treated water is necessary to prevent recontamination (Clasen 2015).

Household environmental cleanness (Figure 5) indicated 28% of HHs have dirty compounds. 38% of HHs had no dustbin for HH rubbish collection and approximately 64% HHs had no utensil drying racks. Grey water and HH waste including children's faeces from the majority of the HHs (68%) were, for the most part, indiscriminately disposed of in open spaces around HHs resulting in ponding and menace of house flies leading to very high-risk scores (7–13) consistent with similar findings elsewhere in Uganda (Kitgum, Kampala) by Kulabako *et al.* (2009). Greywater accounts for 65–75% of the domestic water consumption in peri-urban areas of developing countries assuming per capita consumption of 20–30 L/day (Morel & Diener 2006). Most of the grey water ponds and acts as a potential source of contamination of groundwater. Poisson regression shows a significant association between malaria and HHs which left their dirty utensils in the open ($p = 0.014$) and HHs whose drinking water container had a wide mouth ($p = 0.001$). Wide-open water household containers and utensils left in the open collect rain water which can act as breeding places for mosquitoes. This risk of malaria is also exacerbated by flooding during the rainy season due to low relief, limited drainage and the proximity of Lukaya to Lake Victoria and its lakeshore wetlands. HHs with clogged (blocked by household waste) drainage channels had a high probability of reporting diarrhoea in the previous month compared to those HHs that did not have clogged drainage ($p = 0.003$).

Rapid participatory sanitation system risk assessment

The results of the RPSSRA categorise three major risk indicators (hazardous events, exposure and vulnerability) and showed medium risks (33–67%) for both wards. The factors that presented high-risk scores (>67%) are desludging, sharing of the latrine, solid waste collection, hygiene behaviour and housing conditions for Kaliro, the most densely populated ward. Because of the high population density, residents have challenges with desludging due to lack of space to place new pit latrines when the old ones are full. In fact, one of the participants reported during the focus group discussion that 'during the rainy season, we let faeces be flushed by runoff through a small hole left on the side of the latrine during construction' (FGD, February 2017). In the more sparsely populated ward (Central), high-risk scores are mainly due to desludging and hygiene behaviour where rubbish including children's faeces are indiscriminately disposed of in the environment around homes. The fact that desludging was scored high in both wards is not surprising as the commonly used practice is manual emptying of pit latrines in these settlements. Hygiene behaviour in the RPSSRA is linked to washing hands as well as the poor condition of latrines which means the faecal matter is not contained adequately; inadequately maintained latrines are more likely to be focal points for disease transmission and associated with insect vectors (flies) as per the F-diagram.

Compared to HH surveys and sanitary inspections, poor hygiene behaviour of latrines in the area cuts across all the survey results indicating high chances of contaminating water sources or direct ingestion of faeces. In urban areas where there is no safe desludging service to remove faecal sludge to an appropriate location, it can be dumped indiscriminately in the local environment via flying toilets, for example, that pose a health risk to people and potentially contaminate water sources. Shared latrines increase people's health risks as a result of increased contact with other people and dirty toilets. If solid wastes such as nappies (diapers) and plastic bags containing faeces are disposed of inappropriately with rubbish or at refuse collection points (Imam *et al.* 2008), they increase the risk of contamination of the groundwater sources during rainy seasons.

Water quality

The quality of 37 sampled water sources is summarised in Table 1; these include 30 shallow wells (SW), 3 boreholes or deep wells (DW) and 4 unprotected springs (US) – a proportionality in sources that aligns closely to the distribution of water sources surveyed across Lukaya Town. Acidity was high, often below a pH of 6, and likely a consequence of the decomposition of organic matter in the shallow subsurface. Acidity of this order can affect gastrointestinal mucous membranes, provide a bitter taste and cause corrosion of distribution pipes. Turbidity was also high (54%), similarly exceeding WHO guidelines. Higher levels of turbidity reduce the aesthetic quality and are an indication of pollution and affect the effectiveness of treatment (WHO 2017). Nitrate concentrations in 11 of 37 water sources exceed 10 mg/L and for 2 sources (ALW-8 & ALW-9) were grossly contaminated with concentrations exceeding 250 mg/L. These water sources with the highest nitrate concentrations, well above WHO guideline value of 50 mg/L, are located in the middle of the business centre with metal fabrications and sale of chemicals and surrounded by the highest number of latrines surveyed in Lukaya Town. Strong associations between the proximity of on-site sanitation facilities and nitrate contamination have been shown previously (e.g. Pujari *et al.* 2012; Cissé Faye *et al.* 2019).

Gross faecal microbiological contamination was indicated by very high counts of *E. coli* ($>10^3$ cfc/100 mL) in 57% (21/37) of the sampled sources. Of the 33 *improved* on-site water sources sampled, 18 or ~55% exhibited gross faecal microbiological contamination. Two of the three deep wells were safe (*i.e.* free of *E. coli*) whereas 17 of 30 (~57%) shallow hand-dug wells showed gross faecal contamination. Of the four *unimproved* water sources sampled (all unprotected springs), three demonstrated gross faecal contamination. Highest levels of faecal contamination by *E. coli* were recorded in shallow wells ALW-4 and ALW-24 (92×10^3 and 37×10^3 cfc/100 mL, respectively) which are proximate to, and downgradient from, several pit latrines. Water source ALW-13 derives from a deep (~60 mbgl) well or borehole that is chlorinated at source by NWSC and was found to be faecally contaminated due to the presence of *E. coli*. Contamination is presumed to have occurred either along the distribution line or at the source itself.

Based on the surveyed 67 water sources that exist in Lukaya Town, ~90% of the population is drawing its water supply from *improved* water sources as classified by WHO/UNICEF-JMP (2017). Critically, more than half (~55%) of the *improved* water sources sampled in the study area show gross faecal contamination despite their mode of construction and characteristics, which under the criteria of WHO/UNICEF-JMP (2017) are considered to provide access to a *basic* or *limited* water service. This outcome contrasts with evidence more widely from Ghana, reported by WHO-UNICEF-JMP (2015), in which the majority (57%) of *improved* water sources sampled was free of *E. coli.* It is, however, consistent with more recent, national-scale statistics reported by WHO-UNICEF-JMP (2019; Figure 53) relating access to *improved* water sources to the proportion of *improved* water sources free from contamination. Surveys of sanitary risks (WHO 1997) in Lukaya Town show that 23 (62%) of the sampled water sources scored high to very high risks. Of these, 14 (61%) showed gross faecal contamination whereas 9 (39%) water sources with high- to very high-risk scores were free of enumerated *E. coli*. Overall, the results reflect a conundrum regarding on-site water supply provision in urban areas. The low cost of shallow hand-dug wells promotes their development as a potential *improved* water source as shown by the high proportion (~67%) of these sources (e.g. self-supply) providing a convenient *basic* service (WHO-UNICEF-JMP 2017) but their shallow depths (3–8 mbgl) proximate to on-site sanitation facilities renders them vulnerable to

Table 1 | Water quality of sampled water sources in Lukaya Town

Source ID	Type	T (°C)	pH	EC (μS/cm)	Turbidity (NTU)	NO_3 (mg/L)	*E. coli* (cfc/100 mL)	Risk level (WHO 1997)	Facility type JMP (2019)
ALW-1	SW	24.6	4.6	166	24	21	33×10^3	Intermediate	Improved
ALW-4	SW	24.6	4.9	163	3	20	92×10^3	Intermediate	Improved
ALW-7	SW	24.3	5.2	92	1	11	12×10^3	Very high	Improved
ALW-8	SW	24.7	6.5	1,402	6	350	3.3×10^3	High	Improved
ALW-9	SW	25.4	5.9	771	7	270	2.8×10^3	Very high	Improved
ALW-10	SW	25.2	4.8	77	2	7	0	High	Improved
ALW-11	SW	24.4	5.0	170	2	24	0	High	Improved
ALW-12	SW	24.3	5.1	91	0	ND	9.5×10^3	High	Improved
ALW-13	DW	25.7	4.7	263	0	2	4.5×10^3	Intermediate	Improved
ALW-14	SW	24.4	5.2	78	18	4	9.1×10^3	Very high	Improved
ALW-15	SW	23.9	5.9	76	25	29	1.0×10^3	Very high	Improved
ALW-16	SW	25.1	4.7	150	0	29	0	Intermediate	Improved
ALW-17	DW	23.2	5.0	58	28	1	0	Low	Improved
ALW-18	SW	24.9	5.2	143	0	7	24×10^3	Low	Improved
ALW-19	SW	25.1	5.4	238	0	0.3	0	High	Improved
ALW-20	SW	24.2	5.0	291	0	24	0	Very high	Improved
ALW-21	US	24.5	5.4	269	29	20	1.8×10^3	Very high	Unimproved
ALW-22	US	24.4	5.4	306	28	18	0.3×10^3	Very high	Unimproved
ALW-23	SW	24.6	5.4	274	7	ND	0	Very high	Improved
ALW-24	SW	24	5.3	361	8	5.2	37×10^3	Very high	Improved
ALW-25	US	24.5	4.9	282	9	26	15×10^3	Very high	Unimproved
ALW-26	SW	25	4.9	67	0	6	0	Intermediate	Improved
ALW-27	SW	25	4.9	69	6	ND	5.5×10^3	Intermediate	Improved
ALW-28	SW	24.4	5.1	46	17	ND	4.5×10^3	Very high	Improved
ALW-29	US	24.8	5.1	55	12	7	0	Very high	Unimproved
ALW-30	SW	25.57	4.8	56	18	ND	12×10^3	Very high	Improved
ALW-31	SW	24.7	5.6	404	23	6	0	Very high	Improved
ALW-32	SW	25.5	5.5	126	9	ND	0	Very high	Improved
ALW-33	SW	23.72	5.4	208	0	15	0	Low	Improved
ALW-34	SW	24.3	5.1	79	3	6	0	Intermediate	Improved
ALW-35	SW	23.8	6.1	209	15	6	2×10^3	Low	Improved
ALW-36	SW	24.4	5.0	79	0	6	0	Intermediate	Improved
ALW-37	SW	24.4	6.3	480	0	ND	26×10^3	Very high	Improved
ALW-38	DW	24.5	5.4	154	12	7	0	High	Improved
ALW-39	SW	23.9	5.2	131	3	5	17×10^3	High	Improved
ALW-40	SW	24.7	5.1	177	1	3	0	Intermediate	Improved
ALW-41	SW	24.9	4.9	129	9	5	14×10^3	Low	Improved
WHO		NS	6.6–8	500	5	<50	0	Low	Improved

SW, shallow well; DW, deep well; US, unprotected spring; NS, not specified; ND, not detected.

contamination. The greater vulnerability of shallow hand-dug wells relative to deep wells observed in Lukaya Town is consistent with recent evidence from Ethiopia (MacDonald *et al.* 2019).

CONCLUSIONS

- Substantial dependence on the conjunctive use of the shallow subsurface for both a supply of safe water and a repository of faecal waste is demonstrated in a small but rapidly growing town in central Uganda (Lukaya).
- Construction and maintenance of commonly shared (communal) on-site water sources, primarily shallow wells and sanitation facilities (pit latrines) are inadequate as indicated by high-risk scores in sanitary-risk surveys.
- HH surveys indicate that awareness of basic hygiene (e.g. handwashing, boiling water) is high but basic hygiene is commonly not maintained in practice (e.g. absence of facilities, absent or unsanitary water containers).
- Community hygiene evaluated using WHO Sanitary Risk Surveys and Rapid Participatory Sanitation Systems Risk Assessments is often inadequate and may contribute to reported incidences of diarrhoeal diseases and malaria recorded by local health facilities and during HH surveys.
- Siting of on-site water and sanitation facilities, determined by convenience or preference, commonly disregards unenforced regulations.
- Gross faecal contamination by *E. coli* is observed in 55% of *improved* water sources, as defined by WHO/UNICEF-JMP (2017), that comprise primarily shallow hand-dug wells where the majority of on-site sanitation provision (pit latrines without slabs) is *unimproved*.
- Reliance on shallow wells as *improved* water sources providing a *basic* service in urban areas (*i.e.* self-supply) and their vulnerability to faecal contamination, shown here in Lukaya Town and reflected more widely in recent national-scale statistics (e.g. WHO-UNICEF-JMP 2019; Figure 53), merit urgent investment in the governance, regulation and research of on-site systems if low-income countries are to reach the UN SDG target of *safely managed* water supply and sanitation services by 2030.

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