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Water supply and sanitation services in small towns in rural–urban transition zones: The case of Bushenyi-Ishaka Municipality, Uganda

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Small towns lag behind cities in drinking water and sanitation access globally. Closing this gap requires developing service models for areas with both urban and rural characteristics. This study assessed Bushenyi-Ishaka, a municipality in Uganda situated at the rural–urban transition, with a focus on service ladder indictors. Data sources included household interviews ($n = 500$) and water quality samples from sources and storage containers. Households in more urban (as compared to rural) cells were more likely to use improved water sources (including piped water on-premises), make regular payments for water, rely on shared sanitation facilities, and make use of manual sludge emptying services. Most households (72%) used an unlined pit latrine not intended for emptying and reuse. These findings suggest that small town servicing models should prioritize non-sewered sanitation management, including incentives for safe excreta containment and disposal opportunities. This study also highlights a need for integrated services models to expand rural–urban water and sanitation coverage.

INTRODUCTION

During the last two decades, considerable progress has been made in extending access to water and sanitation services globally. From 2000 to 2017, the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene reported that the number of people accessing basic drinking water and sanitation services increased by 315 million and 700 million, respectively[1]. Over the same time period, 23 countries reduced their open defecation rates below 1%[1]. Despite these improvements, inadequate water, sanitation and hygiene still caused 829,000 diarrhoeal deaths in 2016, corresponding to about 60% of all diarrhoeal-related deaths that year[2].

The aforementioned estimates are derived from standard definitions of access provided by the JMP, which enable comparisons of progress toward universal targets within and across countries and regions. However, such definitions may provide a limited picture of service provision realities that households experience in everyday life[3]. For instance, criteria used in policy documents to define urban and rural areas are locally defined and vary extensively between nations[4,5]. This variability challenges the reporting of disaggregated data, which may lead to incomparable data sets and difficulties and inaccuracies in analyzing global trends in both rural and urban environments[1].

The urban–rural dichotomy in policy documents is even more complicated for small towns, which account for 20% of the world's urban population[6]. Small towns often combine urbanized centres with surrounding areas typical of rural settings within their administrative boundaries. The categorization of small towns may differ among countries and regions in terms of population size, administrative importance or economic structure[4]. For example, in

East and West Africa, around 30% of the urban population lives in small towns, but in Central Africa this proportion is only 13%[6]. Yet a common characteristic of small towns is their potential as local economic nodes that attract rural migrants from surrounding regions[6]. In Uganda, rural-to-urban migration has resulted in higher urban populations, with the most urban growth being among people below the age of 30[7]. Reasons for increased rural–urban migration ranged from traditionally agro-pastoral communities' displacement due to drought conditions, to youth relocating to cities for economic opportunities and access to better services[7].

Moreover, labelling small towns as urban or rural ignores a large proportion of the population in these towns living 'in between' environments with certain nuanced or mixed urban and rural characteristics[4]. In addition to having implications for the global monitoring of service delivery trends, categorization of small towns as urban or rural also determines the allocation of budgets and assistance programs, as well as the degree of autonomy granted for the implementation of civil infrastructure projects[8]. When it comes to water service provision, small towns are often considered "sufficiently large and dense to benefit from the economies of scale offered by piped water systems, but too small and dispersed to be efficiently managed by a conventional urban water utility"[9]. They typically include rural socio-economic characteristics while also requiring urban-type technologies for water provision[10].

This paper aims to contribute to a growing body of literature on water service provision in small towns to unravel the particularities and challenges of providing public services in such rural–urban environments[8,9,11–16]. We focus on the experience of Uganda's National Water and Sewerage Corporation (NWSC) and

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Table 1. Water, sanitation and hygiene service ladders as defined by the WHO/UNICEF Joint Monitoring Programme (adapted from www.washdata.org).

	Drinking water	Sanitation	Hygiene
Safely managed	Drinking water from an improved water source located on premises, available when needed and free from faecal and priority chemical contamination	Use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site	
Basic	Drinking water from an improved source, provided roundtrip collection time is <30 min	Use of improved facilities which are not shared with other households	A handwashing facility on premises with soap and water
Limited	Drinking water from an improved source for which roundtrip collection time exceeds 30 min	Use of improved facilities shared between two or more households	A handwashing facility on premises without soap and water
Unimproved	Drinking water from an unprotected dug well or unprotected spring	Use of pit latrines without a slab or platform, hanging latrines or bucket latrines	
No services	Surface water: Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal	Open defecation: Disposal of faeces in open spaces or with solid waste	No handwashing facility on premises

Table 2. Use of different source types among high, medium and low housing density cells.

Source type	All cells (%)	High density (>1000 people/km^2) (%)	Medium density (501–1000 people/km^2) (%)	Low density (<500 people/km^2) (%)	Chi-square test
Safely managed source	12	23	10	7	$X^2 = 4.98$, $P = 0.083$
Improved source located on premises	21	34	13	20	$X^2 = 17.17$, $P < 0.0001$
Any improved source	77	92	75	71	$X^2 = 21.80$, $P < 0.0001$
NWSC piped water to yard or home	18	32	11	14	$X^2 = 23.47$, $P < 0.0001$
Protected spring	48	46	52	47	$X^2 = 1.45$, $P = 0.485$
Unprotected spring	20	7	17	28	$X^2 = 23.09$, $P < 0.0001$

hypothesize that access and service modalities vary when moving from urban-like to rural-like areas of small towns. This paper analyses water supply, sanitation and hygiene coverage trends across a rural–urban transition zone in south-western Uganda, drawing on a survey of 500 households, water quality sampling, and complementary qualitative studies that were conducted in the same study area. We adopt the JMP's definitions of access along the service ladder, with specific focus on criteria for safely managed water supply and sanitation (Table 1).

RESULTS AND DISCUSSION

Household characteristics

The 500 survey participants were divided between three divisions of Bushenyi-Ishaka Municipality: 42% in Central, 29% in Ishaka, and 29% in Nyakabirizi. Seventy-two percent of the survey respondents were female and 28% were male, with the mean age being 43 and 48 years, respectively. Respondents' mean family size was 5.3 people, with about half (49%) having at least one child under the age of 5 residing in the dwelling. Respondents were asked to give their answers on behalf of the entire household, defined as the people who eat and sleep together in the home on a regular basis. The ethnicity of most households was Banyakore (95%), with the remaining share being Baganda, Bakiga or another ethnicity. Nearly half (47%) of survey respondents had completed primary school as their highest level of education, 25% had completed secondary school and 12% had a vocational or university education. Most respondents (83%) could read and write in at least one language, were living in a home that they owned (87%) and had an agricultural based occupation such as farming or livestock herding (62%). Over three quarters of respondents had been born in Bushenyi-Ishaka Municipality and

currently resided there to live and work for the entirety of the year. Taken together, these results show that households had education and literacy levels similar to urbanized areas of Uganda, but at the same time had a livelihoods strategy dependent on agricultural activities[17].

Water supply type and accessibility

The most common water sources reported as households' main drinking water supply were protected spring (48%), unprotected spring (20%), and a NWSC tap at the home or yard (18%). Boreholes, community taps, rainwater harvesting, and surface water (streams or rivers) were less commonly used (Supplementary Table 1). About one in five households ($n = 107$) had access to this water source on-plot, as determined by the reported one-way walk time being one minutes or less.

To probe whether water supply accessibility varied between more urban *versus* more rural areas of Bushenyi-Ishaka Municipality, cells were categorized according to their housing density, i.e., cells with <500 people/km^2 were defined as low density, cells with 501–1000 people/km^2 as medium density, and cells with >1000 people/km^2 as high density (Supplementary Table 2). A chi-square test of independence was performed to examine the relationship between indicators of access and density strata. Higher density cells had a significantly greater proportion of households using an improved source, an improved source located on premises, and a NWSC piped water connection, whereas lower density cells had a significantly greater proportion of households using unprotected springs (all $P < 0.0001$). However, there was no statistically significant relationship between the density strata and the use of protected springs or safely managed water sources (Table 2). These results suggest that across Bushenyi-Ishaka Municipality's rural–urban spectrum, meaningful

Table 3. Percentage of households practicing water treatment by source type.

Among	N	Boiling (%)	Filtration (%)	No treatment (%)
All households	500	95	1	5
Protected spring users	239	91	1	8
Unprotected spring users	99	99	2	1
NWSC household or yard tap users	89	98	1	1
Households with any improved source	386	94	1	5
Households with an on-plot improved source	107	98	1	2
Households with a safely managed source	14	100	0	0

Some rows exceed 100% because households could report practicing more than one treatment method.

differences exist in access levels for some, but not all, source types along the JMP's water service ladder. Such heterogeneity at local scales has implications for infrastructure planning and resource allocation[18].

In terms of the time households spent fetching water, the median one-way trip time to their main water source ranged from less than one minute for in-house connections to 20 min for boreholes and streams. Among all main sources, respondents reported a median of 3 min queue time per trip (Supplementary Table 1). Queue times were highest for protected springs, with a median of 8 min and up to 3 h for some respondents. Survey respondents attributed the longer wait time at springs to their slow recharge rates at the end of the dry season, when the survey team visited. One quarter of the respondents said their main source was not the source nearest to their home; most of these households travelled an average of 8 min further per trip to use a protected spring. These respondents said they did so because they preferred the taste of spring water or they perceived the source closest to their home to be unsafe or too costly.

Water supply availability and affordability
The survey probed the seasonal availability of households' water sources. During rainy months, most respondents said water from the main drinking water source was available all day, whereas services were reduced by an average of 3 h per day during dry months. Respondents also said they used a median of two water sources during rainy months (as compared to one source during dry months), which mainly refers to rainwater harvesting that was practiced by 56% of respondents.

In terms of water system functionality, only 1% of households said their main source was non-functional at the time of the visit. Ten percent reported that there had been a service interruption lasting more than 24 h in the past 3 months, with the average interruption lasting 5 days. Most (85%) households were confident that the necessary repairs for future interruptions could be completed in less than a week. Disputes over water were rare, with only 5% reporting a current conflict over water in their community.

Most (78%) respondents said they did not pay for water from their main source, and the rest said they either paid regularly (15%) or when repairs were needed (7%). Among those paying, half said it was too expensive, 31% said the cost was appropriate, and 16% said it was cheap. When examining payment rates across density strata, the proportion of households paying for water in high density cells was significantly higher at 46%, as compared to 11% and 19% in medium and low density cells, respectively (X^2 (1, $N = 500$) = 48.36, $P < 0.0001$). Among those using NWSC piped water sources, 93% of users paid a median of UGX 5515 (US $1.50, based on 25 June 2019 exchange rate) per cubic meter. By comparison, only 4% of users of protected springs paid for water. Taken together, these results show a continuum of service models from low to high density areas of Bushenyi-Ishaka Municipality.

That is, nearly half of the households located in densely populated urbanized cells were paying for (mainly piped) water services on a volumetric basis, whereas the vast majority of households residing in more sparsely populated rural cells were relying on free water sources such as protected springs.

Microbial safety of drinking water
Households generally perceived the quality of their main drinking water source to be good, with only one in ten survey respondents saying their drinking water was bad or very bad. Nearly all households (95%) said they regularly boiled their water before drinking (Table 3). Relatively fewer protected springs users practiced boiling as compared users of other source types (X^2 (1, $N = 500$) = 7.90, $P < 0.01$).

Enumerators collected 95 samples from drinking water sources and 107 samples from household water storage containers. Among samples originating from a piped source, the mean free residual chlorine (FRC) concentration was 0.1 mg/L (SD = 0.1), below the recommended target range of 0.2–0.5 mg/L per Ugandan water quality standards (US EAS 12: 2014). Among households with an improved water supply located on premises, 64% of source samples and 46% of household stored water samples met the JMP's criteria for microbial safety (<1 CFU E. coli/ 100 mL). Bivariate comparisons across source types show that both source and household stored water samples from improved water sources were significantly less contaminated than those from unimproved sources (Table 4). Samples taken from yard or in-house piped water taps were also less contaminated than samples from other source types. However, stored water samples from households with piped water on premises were no cleaner than stored water originating from other sources, indicating recontamination of piped water supplies when storage was necessary (e.g., when services were intermittent or unreliable). Figure 1 shows the spatial distribution of contamination risk categories among improved and unimproved sources, corroborating the results of the statistical analysis. Figure 2 shows how water quality generally deteriorates from source collection to household storage containers.

Sanitation facility type and accessibility
All surveyed households used non-sewered facilities providing either a basic (i.e., private improved facility that separates excreta from human contact) or limited (an improved facility shared with other households) level of service to users. Most respondents (96%) indicated that their main sanitation facility was an unlined pit latrine, most of whom (74%) said their latrine was not intended for emptying and reuse (i.e., the pit would be buried when full). A small share of households (4%) had a flush toilet with a septic tank that drained directly into the surrounding environment or an adjacent soak pit. Some households might also have flush toilets that drain directly to cesspools, since the local municipality does

Table 4. Bivariate comparisons of faecal contamination concentrations in source and household stored water containers across different source types.

		All sources	Improved sources	Other sources	Improved source on-premises	Other sources	Piped on-premises	Other sources
Source water samples	Median CFU *E. coli*/100 mL	0	0	25	0	0	0	2
	Independent samples Mann–Whitney *U* test	–	$N = 89$ $U = 273$ $P < 0.001$		$N = 89$ $U = 595$ $P = 0.140$		$N = 89$ $U = 507$ $P = 0.029$	
Household stored water samples	Median CFU *E. coli*/100 mL	2	1	10	3	2	2	2
	Independent samples Mann–Whitney *U* test	–	$N = 97$ $U = 477$ $P = 0.012$		$N = 97$ $U = 810$ $P = 0.892$		$N = 97$ $U = 805$ $P = 0.949$	

not have records of constructed septic tanks and respondents were often unaware of underground infrastructure[19]. Four out of five survey respondents had a private on-plot sanitation facility, 19% had a shared on-plot facility, and 1% relied on a public facility (Supplementary Fig. 1).

One out of 10 respondents said their household regularly switched to a different sanitation option, most often from a private on-plot to a shared on-plot facility. One reason given for the switch was the water shortages experienced during the dry season or daytime[19,20]. This mainly affected households with flush toilets who also retained an on-plot pit latrines for use during emergencies or large social gatherings[20]. Households in high density cells were more likely to make use of a shared sanitation facility for some part of the year as compared to those in low density cells (X^2 (4, $N = 500$) $= 12.24$, $P = 0.016$).

Only 3% of sanitation facilities had reportedly been non-functional in the 3 months prior to the survey, the main reasons being the latrine's pit had filled up, a new latrine was under construction or the pit had collapsed due to poor construction. Nyakutsikwa (2018) further noted that some households struggled with pit destruction during the rainy season. Eight percent of households reported investing a median of UGX 199,389 (US $54.22) in the past 12 months for sanitation-related upgrades. A household's upgrade to a private on-plot flush toilet was linked to the introduction of a private yard tap by the local municipality[20].

Safe faecal sludge management

Enumerator observations of the latrines and toilets showed that 8% had visible contamination with faeces and urine and 7% had a purpose-built access point for emptying. Most households did not empty their sanitation facilities: they either covered (50%) or abandoned (22%) their pits or tanks when full. Reasons given for not emptying or re-using sanitation infrastructure were that it was cheaper to build a new facility, the superstructure was too old or poorly designed, or being unaware of emptying services.

Households in high density (as compared to low density) cells of Bushenyi-Ishaka Municipality were more likely to use professional emptying services (X^2 (2, $N = 498$) $= 10.72$, $P = 0.005$). Nyajutsikwa (2018) and Kafwembe (2019) reported that pits or tanks were emptied either by vacuum trucks or manually by 'night labourers' and ostensibly transported and treated at a treatment facility 60 km east of Bushenyi town in the Mbarara District. Despite municipal by-laws that discourage manual emptying due to concerns about environmental and public health risks, households tended to prefer this option to motorized emptying because more sludge was removed, it was less expensive, and wait times were shorter. Costs for manual emptying ranged from UGX 80,000–350,000 (US$ 21.69–94.88). The frequency of emptying ranged from monthly to annually for pits and every 10 years for septic tanks[19].

While manual emptiers reported having adequate profits and return on investment, this perspective likely does not account for occupational health and safety considerations. Nyakutsikwa (2018) observed manual labourers entering pits without appropriate personal protective clothing. These labourers further reported struggling with chest pain and infectious diseases, which they claimed were caused by exposure to chemicals and fumes from emptying. Moreover, they shared concerns about pits collapsing due to poor construction. Lastly, Nyakutsikwa notes that the limited monitoring and corollary expenses associated with safely transporting and disposing sludge in Mbarara likely results in most collected sludge being illegally dumped in nearby swamps[19].

Hygiene facilities and practices

A quarter of the respondents said a handwashing facility was always available at their toilet or latrine, 15% said it was sometimes available, and 58% said it was never available. Among those with a handwashing facility, most (75%) said both soap and water were available and used. Enumerator observations of the handwashing facility showed that 65% were in clean and good condition, and the rest were either in poor condition (22%) or not observable (13%). There was no statistically significant relationship between cell level housing density and the observed condition of the handwashing facility, nor the observed presence of soap. Households reported problems with children playing with or damaging the handwashing station. Users of shared sanitation facilities were often unsure who was responsible for maintaining facilities, including the handwashing station, and said it was easier to wash their hands within the home or carry their own jerrycan to the toilet for personal use.

Diarrhoeal disease

Among the 500 households interviewed, a total of 25 (5%) reported that someone in the family had experienced an episode of diarrhoeal disease in the past week. Eleven of these episodes were experienced by children age 0–2 years and 7 episodes were experienced by children age 3–5 years (corresponding to an incidence rate of 7% and 3% among these age group, respectively). Most households had sought some sort of treatment, with 12 going to a local hospital, 9 visiting a pharmacy, and 2 using traditional medicine. The median cost of treatment per episode among these households was UGX 9000 (US$2.44).

Insights for policy and practice

This study examined the case of Bushenyi-Ishaka, a municipality in southwestern Uganda that is typical of other rural–urban transition zones in sub-Saharan Africa. We aimed to describe the distinguishing features of water supply and sanitation services operating across the municipality, with the central hypothesis being that access rates and service modalities vary when moving
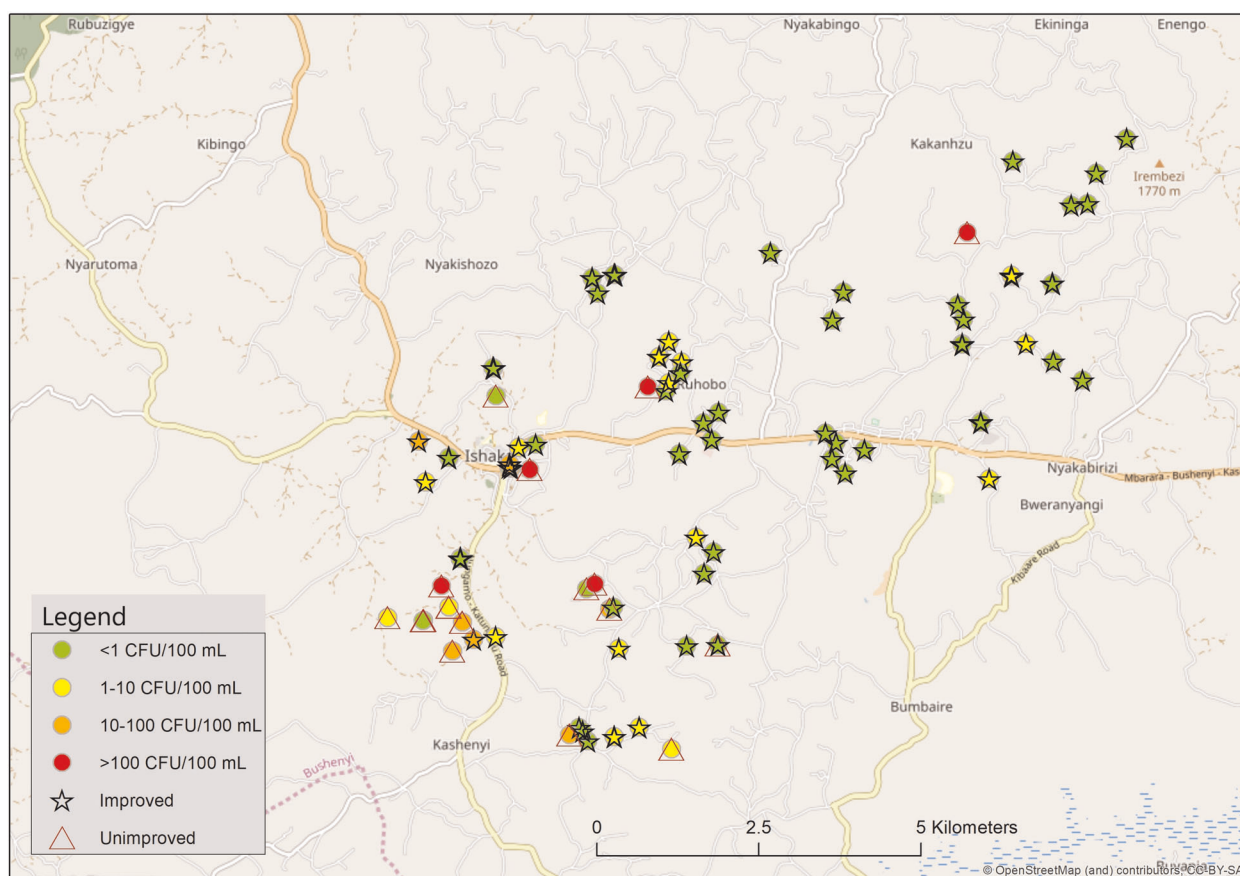
Fig. 1 Map of water source type and quality. Spatial distribution of improved and unimproved water sources with contamination risk categories shown. Scale bar indicates 5 km.

from more urban to more rural areas. We used a randomized sampling approach to maximize the external validity of the survey results, such that conclusions lend insight to similar rural–urban transition zones across sub-Saharan Africa. The analysis focused specifically on the JMP's standard indicators of water and sanitation accessibility, availability, affordability and service quality that inform global monitoring of progress toward SDG 6.1 and 6.2.

Over three-quarters of the households surveyed in Bushenyi-Ishaka Municipality enjoyed access to an improved water source. Such improved sources were less likely to be impacted by faecal contamination as compared to unimproved sources, resulting in improved water quality at the point of consumption. In particular, samples collected from piped water on premises were also less impacted by faecal pollution as compared to other source types, likely due to the chlorination of NWSC's distribution network. These findings are aligned with a meta-analysis that reported piped water supplies globally were less likely to be contaminated with faecal pollution as compared to other source types[22]. However, in contrast to the aforementioned study, we did not find that households with piped water on premises had superior stored water quality. This finding suggests that service models aiming for universal access to safely managed water at the rural–urban divide must prioritize not only piped water services on-premises, but also sufficient reliability such that the need for household level storage of drinking water is minimized.

A main driver of households' reliance on off-plot improved sources was cost concerns. Across all density strata nearly half of survey respondents reported using a protected spring without paying, many of whom said they bypassed a closer source that charged a fee for use. Other water service characteristics, such as location on plot, a NWSC managed tap, and regular payments for

water, were more likely to be found in more (as compared to less) densely populated cells, suggesting that these measures are defining features of urban neighbourhoods in Bushenyi-Ishaka Municipality.

In terms of sanitation and hygiene, most households did not meet the JMP's criteria for safely managed sanitation services and hygiene facilities. While use of shared sanitation facilities was relatively rare, the vast majority of residents (96%) reported having latrines with unlined pits that potentially pollute the environment. The survey results indicated that households utilized non-sewered sanitation facilities regardless of financial ability. Complementary qualitative research suggests that poorly built infrastructure and unsafe faecal sludge management are likely to be contaminating the environment and thereby endangering public health. Continued use of unimproved pit latrines due to seasonal factors and after upgrading sanitation infrastructure also sheds light on the need to account for seasonality and affordability to minimize households climbing up and down the service ladder.

Illegal and unregulated manual emptying services introduced further environmental and public health risks from faecal contamination, especially to manual labourers. These health concerns suggest a need for NWSC to increase its support for non-sewered sanitation options, and especially for safe and financially viable excreta management across the sanitation value chain. Rao et al. (2016) recommended installing transfer stations as intermediate emptying points for small towns like Bushenyi, where infrastructure tends to be manually emptied and illegal disposal is common due to financial disincentives[23]. Given the prevalence of manual emptying and households' limited economies, local regulations should also be amended to support hygienic and physically safe faecal sludge emptying. Provisions for
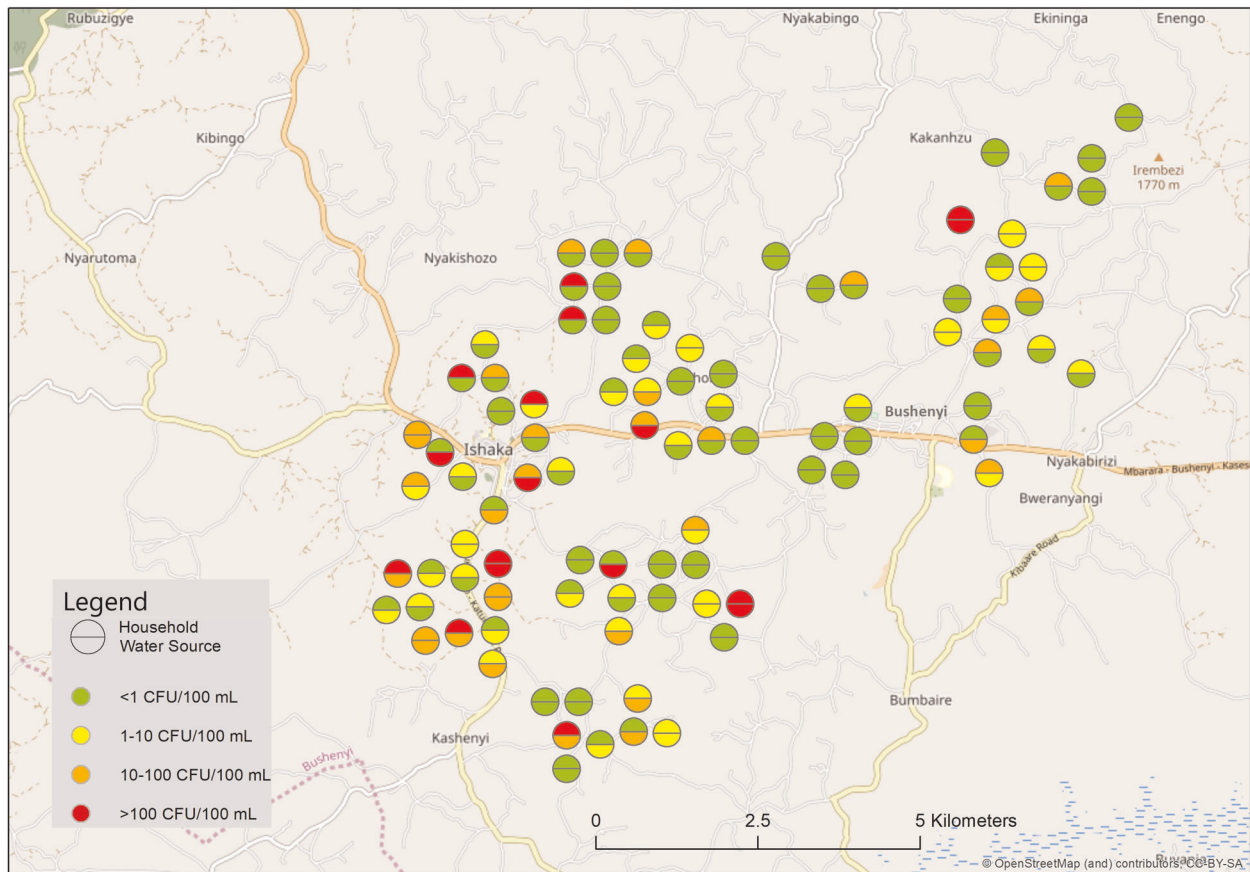
Fig. 2 Map of water sample location and quality. Spatial distribution of household water storage containers (top half of circle) and their corresponding water sources (bottom half of circle) with contamination risk categories shown. Circles have been shifted to improve visibility and do not correspond to the exact location for all households. Scale bar indicates 5 km.

manual labourers can be informed by ongoing research from South Africa and Bangladesh[24,25].

Most households lacked handwashing facilities adjacent to toilet infrastructure. Households that had handwashing basins reported inconsistent handwashing behaviour following toilet use, as not all had dedicated hand basins with soap and water. Some respondents further indicated a preference to wash their hands within their domicile following use of toilets located outside their dwelling, due to uncertainties regarding who was responsible for maintaining the facility. Limited infrastructure and inconsistent handwashing behaviour highlights the need for a two-fold approach to increase hygiene practices.

Study limitations
The results of this study are subject to a few limitations. First, about one quarter of survey respondents were the male head of household, who may have been less aware of domestic water supply and sanitation issues as compared to women in the home. Second, plot-level observations reported in the survey might have been subject to different interpretations by the enumeration team. Third, the survey's cross-sectional design does not allow for conclusions regarding causal relations, for instance the observed association between more urbanized zones and greater access to improved water sources.

Summary
This study indicates that small towns are not only heterogeneous among themselves, but are also diverse within the administrative boundaries delimiting these towns, since they can embody

characteristics of urban centres and remote rural areas. All surveyed households used non-sewered sanitation facilities, and most of these facilities did not achieve safe containment or disposal of excreta. Households in the urban areas of Bushenyi-Ishaka Municipality were distinguished from rural areas by a greater likelihood to have an improved on-plot water supply, pay regularly for water services, rely on a shared sanitation facility, and make use of pit emptying services. This spectrum of characteristics across the rural–urban transition zone has implications for planning and resource allocation, as well as indicates a need for more integrated service models suitable to the diverse and dynamic environment of small towns.

METHODS

Study area
Uganda is a landlocked country in East Africa that lies across the equator with a total area of 241,551 km^2. As of the last census in 2014, the population is estimated at 34.6 million, with 79% of the population residing in rural areas and an average annual population growth rate of 3%[26]. The percentage of the population with access to an improved drinking water source, defined as one protected from outside contamination and located within a 30 min journey from one's home, was 33% in rural areas and 73% in urban areas[1]. When focusing on piped supplies, 12% of the population is served in rural areas and 53% in urban areas. However, when applying the JMP's criteria of a safely managed water source that is free from faecal bacteria and chemical contaminants of concern, the percentage with access drops to 4% and 18% in rural and urban areas, respectively. The JMP also estimates that access in 2015 to at least a basic sanitation service was 17% and 28% in rural and urban areas, respectively. Coverage with basic handwashing facilities was 15% in rural

areas and 31% in urban areas, but with significant inequalities between rich and poor urban residents[1].

The objective of Uganda's principal water sector law—the Water Act (CAP 152, 2000)—is to promote the provision of a clean, safe and sufficient supply of water for domestic purposes to all persons. Under the Water Act, the Ugandan Potable Water Standards (US EAS 12:2014) sets minimum requirements for physical, chemical and microbiological domestic drinking water quality[27]. Roles of different government actors and governance levels are defined in the Local Government Act (Cap 243, 1997), as well as the National Water and Sewerage Corporation (NWSC) Act (CAP 317, 2000).

The NWSC was established in 1972 and works in tandem with town administrations and local municipalities that are responsible for public health services such as sanitation and solid waste management. The 100% Ugandan owned public utility's mandate is to provide sound and commercially viable water supply and sewerage services in urban centres throughout Uganda. From 2013, NWSC began expanding its geographic coverage area from the cities of Kampala, Entebbe and Jinja to include towns and rural municipalities throughout the country. From 2013 to 2016, the number of towns serviced ballooned from 23 to 165, and at present NWSC services 253 designated urban areas. Through this process NWSC has primarily replicated its servicing framework and mechanisms from its Kampala water and sanitation operations. Several years of implementation has indicated, however, that servicing models based on the conditions of Uganda's largest cities are incompatible with the contexts of towns at the rural–urban transition zone[8]. Smaller urban centres and rural municipalities have small sewer networks and low levels of household connections, making the unit operation costs high for piped water and sewerage. NWSC has recognized the need to transform its business and service models to meet the needs of smaller towns and rural municipalities, in order to achieve its broader goals of increasing by 2021 water service coverage from 76% to 100%, sewerage from 6% to 30%, and ensuring a 24/7 water supply reliability[21].

Project SMALL is a longitudinal study of water supply and sanitation service provision in towns of Uganda situated at the rural–urban transition zone, in partnership with NWSC and Makerere University (called Project SMALL; see Tutusaus, 2019 and Kanyesigye et al., 2019). The present household survey was carried out as a part of Project SMALL from June to July 2018 in Bushenyi-Ishaka Municipality of Bushenyi District, located in the south-western region of Uganda. Bushenyi-Ishaka Municipality has a land area of 81.2 km² at an average altitude of 1432 m above sea level. The region has two distinct rainy seasons from April to May and August to December. The municipality's population in 2014 was 41,063[26]. The research team chose this study site since the municipality is characteristic of rural-to-urban transition zones in Uganda in terms of population, water source types (conventionally treated surface water, gravity flow schemes, protected springs and boreholes) and availability of historical data on water quality and other basic services.

Sampling frame

The sample frame was developed based on the standard administrative units found throughout Uganda. Bushenyi-Ishaka Municipality consists of three divisions (Ishaka, Nyakabirizi, and Central) divided into 15 wards and 74 cells. A cell is the lowest form of administrative boundary in Uganda, usually spread over an area of 1–2 km² with 100–200 households[28]. One-third of the 74 cells (24) were randomly selected for sampling using the RAND function in Microsoft Excel. The population in the sampled cells varied from 168 to 3536 (Supplementary Table 2).

Household enrolment

Within each cell, seven enumerators selected 21 households at random for participation in the study following a systematic transect walk approach. Due to difficulties in obtaining official cell maps and a reliable list of head of household names, the enumerators worked with local leadership to draw community maps with key landmarks and identified potential routes for enrolling households following a randomized non-stratified selection procedure. In brief, after arriving in the cell, the field team met with the cell chairman, Village Heath Team (VHT), and/or other local residents to sketch community maps with roads, rivers, water points, schools, health clinics and household clusters. From this map, the seven enumerators were transported to different boundaries of the cell. While they were walking within their respective areas of the cell (usually towards a pre-defined central location), each enumerator visited three households approximately equally dispersed along their pathway. If a household was skipped for any reason (e.g. residents were not at home or not willing to be interviewed), enumerators offered enrolment to the next household along the path.

Data sources and analysis

Data collection took place over 13 days in June and July 2018. Across the 24 cells, a total of 500 household surveys were conducted. The research team spent about half a day in each cell to complete all data collection activities, with every enumerator interviewing an average of six households per day. The median length of an interview was 33 min.

The questionnaire consisted of sections pertaining to socio-demographic characteristics of the households; health history (diarrhoeal disease in the past week); seasonal uses of water sources; water storage and treatment practices; and sanitation options. The questionnaire was pre-tested in one community that ultimately was not included in the study area, in order for enumerators to familiarise themselves with the questions, seek clarifications and make content revisions. The questions were written in English and translated orally into Runyankore, the most common local language spoken in south-western Uganda. Interviews were conducted in the preferred language (English or Runyankore) of the respondent. Each survey was conducted with a self-identified adult head of household (female or male) or other adult member of the household if the head was unavailable. Interview data were collected on smartphones installed with the ODK Collect app (Open Data Kit, Department of Computer Science & Engineering, University of Washington) to allow for real-time data entry and management. Data were uploaded daily to a secured server, compiled in Excel, and then anonymized.

In each of the 24 cells, drinking water samples were taken at 4–7 of the 21 households interviewed. Samples were taken by collecting 100 mL from the household's stored drinking water container and its self-reported main drinking water source during the survey period (June–July 2018). All households reporting having experienced diarrhoeal disease in the past one week before the interview were automatically included in the water sample study; the other water samples were randomly selected from the remaining households at the time of the survey. In total, 107 household container and 95 source water samples were collected for microbial analysis.

At the taps or outlet of pipes, water was run for 10 s before sampling to wash out any deposited residue and ensure a representative sample from the piped system. The household water samples were collected from the storage container, either directly from the container or via a drinking water glass (i.e., 100 mL in the same way a glass of water for drinking would be provided). The water samples were collected in sterile 100 mL Whirl-Pak sampling bags (Nasco, Fort Atkinson, USA). For piped water, Whirl-Pak Thio-bags containing sodium thiosulfate were used to neutralize any residual chlorine, since microbiological water samples held without dechlorination may have a high false negative rate[29]. The samples were stored at 4 °C in cooler boxes containing plastic ice packs and transported 10–15 km to NWSC's laboratory at Nyaruzinga Water Treatment Plant in Bushenyi for testing. All samples were processed within 12 h of collection. A negative (distilled water) control was processed on each sampling day.

The samples were processed by membrane filtration using reference medium m-ColiBlue24® (Hach, Duesseldorf, Germany). In brief, 50 or 100 mL water samples were filtered through 0.45 µm membrane filters. The m-ColiBlue24 Petri dishes were incubated at $35 \pm 2\,°C$ for 22–24 h. Total coliforms and E. coli colony forming units (CFU) were quantified and reported as CFU per 100 mL. The lower and upper limit of detection for the enumeration of E. coli were <1 and 200 CFU/100 mL, respectively. The countable range (1–200 CFU) was expanded beyond the recommended range of 20–80 CFU to reduce the resources (both material and time) needed. Furthermore, Nissui Compact Dry EC plates (Nissui Pharmaceuticals, Tokyo, Japan) were also punctually used to control and complement the results obtained with m-ColiBlue24®.

At the time of microbial sampling, additional water was collected for analysis of pH and FRC using 300 mL glass bottles. Bottles were rinsed with distilled water and flushed one time with the sampled water, and analysis of the sample was conducted within a maximum of 3 h. Measurement of pH was carried out on site with a HQ40D portable multimeter (Hach, Duesseldorf, Germany) that was calibrated every day with Hach buffer sets (pH 4.01, 7.00 and 10.01). Measurement of FRC was carried out with a Pocket Colorimeter™ II (Hach, Duesseldorf, Germany) and DPD reagent powder pillows. In total, pH measurements were carried out at every source ($n = 109$) and storage container ($n = 110$). FRC measurements were only carried out at the source ($n = 23$) and container ($n = 19$) if the household reported piped water to be its main drinking water source.

Finally, empirical data on sanitation services drawn from qualitative field research[11,12,19,20,28,30] is referenced to complement and offer further details about Bushenyi-Ishaka Municipality's non-sewered sanitation services and faecal sludge management practices. The qualitative research was undertaken from December 2017 to February 2018 and January–February 2019. Methods included in-depth key informant interviews ($n = 104$) and

focus group discussions ($n = 12$) with government officials from Bushenyi-Ishaka Municipality and from the Ministries of Health (MoH), Water and Environment (MoWE) and Education and Sports (MoES); public utility officials from NWSC, including from the Mbarara District treatment facility; water and sanitation customers in households and institutional settings (Red Cross facilities and schools); and mechanical and manual emptying service providers. Sanitation researchers additionally used transect walk and service delivery assessment checklists to collect structured observational data[31,32]. Qualitative research on the implications of the rural to urban transformation on the access to water services for various groups of residents is described and discussed in more detail elsewhere[12].

Survey and water quality data were cross-checked and exported into SPSS for analysis (IBM SPSS Statistics, Version 25, Chicago, IL, USA). Central tendencies of survey and water quality data were reported as mean (standard deviation) and median values. Chi-square tests of independence were used to draw statistical comparisons of categorical data across housing density strata. Independent samples Mann–Whitney U tests were used to test for differences in faecal contamination levels across sample and source types.

ETHICS STATEMENT

The study is based on the ethical principles of the Helsinki Declaration[33]. Written informed consent from households was obtained before starting the interview. Respondents were informed that their participation in the study was voluntary, their identities would remain confidential and they were free to discontinue participation at any time. The research protocol was approved by the Eawag Ethics Committee (policy directive 16-09) and received clearance from Makerere University Research Ethics Committee and Uganda National Council of Science and Technology (registration number SS 4672).

DATA AVAILABILITY

The authors declare that the data supporting the findings of this study are available within the paper and its supplementary information file.

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AUTHOR CONTRIBUTIONS

Conceived and designed the research: L.T., D.W.B., G.C.-C., G.F., F.K., J.S.K.-S., C.K., S.J.M. Conducted the field research: G.C.-C., J.T.B., C.K., N.E.R. Analysed the results: L.T., G.C.-C., S.J.M. Wrote the first draft of the manuscript: G.C.-C., G.F., S.J.M. Contributing to the writing of the article: L.T., D.W.B., G.C.-C., G.F., F.K., N.E.R., J.S.K.-S., C.K., J.T.B., S.J.M.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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