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Can a citizen-science approach to collecting data assist the management of intermittent water supply in low-income and data-scarce settings?

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Abstract: *Intermittent water supplies (IWS) can be both a public health threat and an expensive challenge to address for households, requiring reliance on either costly water storage solutions or alternative water supplies. Despite the fact that IWS are present all over the world, there remains a persistent lack of data on the operation and failures of urban water supply infrastructure in low-income countries. Local government and water utilities tend to be blamed for the poor management of the water supply, and yet there is no established method for reporting or measuring the continuity, reliability, or hours of supply of pipe water delivery. This makes it difficult for water utilities to estimate real economic losses or the investment needed to improve the water supply. Lack of evidence and data on the behaviour of IWS also impedes the development of tailored water management policies, leading to inefficient decision-making from the top down. This paper therefore proposes a method to address the knowledge and data gap on IWS in low-income settings, using citizen science coupled with mobile phone technology to collect data on IWS in a bottom-up approach. The approach was trialled in Kathmandu, Nepal and has since been adopted by the local water supply company.*

Key words: citizen science, intermittent, data, water supply, low-income, mobile phone application

Introduction

Intermittent water systems (IWS) are piped water distribution networks that do not deliver water to customers continuously 24 hours per day. They are mostly supply-side-driven, as part of a reactive strategy to ration insufficient water resources (Vairavamoorthy, 2021). This means that the operator is in charge of deciding when,

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where, and how much water is delivered by the system. A predictable IWS provides water per a rotational schedule and adopts the 'some for all and not all for some' approach to water distribution. The implication is that water supply is intentionally rationed, with a well-established schedule, so that customers are able to access water at specified hours per day and plan accordingly (Lutaaya & Echelai, 2021). However, in an unreliable and/or irregular IWS, there is no adherence to a schedule – even if a schedule exists, it remains an approximation and the supply of water is often late, skipped without warning, or does not last as long as planned (IWA Specialist Group on Intermittent Water Supply, 2020). In an irregular IWS, water is delivered at unknown intervals, but consumers can rely on receiving a minimum water quantity in a unit time frame. This means that, with the help of tanks and careful planning, customers can simulate a continuous water supply for themselves (Galaitsi et al., 2016) In an unreliable IWS, customers cannot be sure to receive water by a unit time frame and need to purchase additional sources of water to sustain themselves over long periods of non-delivery (Galaitsi et al., 2016). Unfortunately, almost all IWS are unreliable (Mohan & Abhijith, 2021). Within a city, households may experience different hours of supply due to network hydraulics, elevation, water demand, valve operations, and distance from the water treatment plant (de Marchis et al., 2011; Kumpel et al., 2016; Totsuka et al., 2004).

To deal with untimely and insufficient water supply, consumers will spend time monitoring water availability and managing the collection process. In practice, this means that some people will need to wait expectantly for the water to be supplied and store as much water as they can during supply hours to overcome the unreliability of the network. Typically, consumers will not be satisfied to simply store what water they receive – they develop strategies to acquire as much water as possible from the system, sometimes not realizing that this will be to the detriment of others. Characteristically, this involves purchasing expensive pumps to draw more water from the network and investing in building water tanks to store water (Lee & Schwab, 2005). As a result, consumers collect more water than they would use with a continuously available supply (Ingeduld et al., 2008; Mohapatra et al., 2014). This approach to consumption exacerbates the problem of water scarcity in the network, as well as the problem of inequity of supply (Totsuka et al., 2004).

To make matters worse, distribution is not only unreliable but also inequitable, so that some people get less water than others (de Marchis et al., 2011), and often of inadequate quality. Indeed, all water supplied from intermittent networks is assumed to be contaminated, because of the potential for periodic intrusion of microbial contaminants (Charalambous & Laspidou, 2017; Mohan & Abhijith, 2021; Mokssit et al., 2018).

Mechanisms for dealing with untimely, inadequate, and insufficient water supply incur what the literature refers to as 'coping costs' and are borne by the consumer (Totsuka et al., 2004). Examples of this include the cost of energy used for boiling the water or installing storage tanks, rainwater collection tanks, pumps (e.g. suction pumps to draw more water from the network or lift it up to storage tanks), or water filters. In higher-income population groups, people have the option to buy water from private water vendors to refill their storage tanks or deliver barrels of spring water for drinking (Remigio et al., 2019). These types of coping costs have been estimated to reach as much as 7.6 per cent of reported income, on top of the cost of water utility bills (Vásquez et al., 2009). This reveals a profound personal concern for safe and reliable drinking water (Dauda et al., 2015).

Information available on IWS shows that they are present all over the world in varying degrees of severity, with a prevalence in developing countries. An estimated one billion people live with water intermittency (Bivins et al., 2017; Vairavamoorthy, 2021). Despite this, there is an important lack of relevant data on the operation and failures of urban water supply infrastructure in low-income countries.

The water utility company and the government are usually jointly responsible for the urban water supply, but in many developing countries the government often fails to hold water companies accountable for their managerial and financial decisions surrounding their operations (Galaitsi et al., 2016; Majuru et al., 2016). As a result of this, failures of the water supply are perceived to be induced by the utility provider and the Ministry of Water Supply, who are responsible for the planning, operation, and maintenance of supply (Mohan & Abhijith, 2021). However, there is no standard method for reporting or measuring piped water continuity or reliability (Majuru et al., 2018; WHO, 2017) and little guidance provided to utilities and local government on how to calculate their hours of supply.

This knowledge gap prevents the development of tailored water management policies (de Marchis et al., 2015) by the regulatory agencies and water utilities managers (Ameyaw et al., 2013; Gottipati & Nanduri, 2014; Ilaya-Ayza et al., 2017). Moreover, the absence of reliable and accurate data prevents the estimation of real economic losses, the calculation of the investment that would be offset by consumers' willingness to pay, and, by extension, the true budget required to make improvements to the water supply (Vásquez et al., 2009). On the consumer side, this impedes effective communication between the utility companies and their customers, especially surrounding water supply schedules and any service interruptions – which ultimately prevents consumers from making informed decisions about the way they use their water (Lutaaya & Echelai, 2021). As a result of this multi-faceted knowledge gap, the water supply system is poorly understood, making it complicated to design evidence-based water management policies with purpose.

This research offers a simple, practical, and cost-effective way to obtain essential temporal and spatial baseline data on the IWS to fill the afore-mentioned knowledge gaps. Nonetheless, it must be acknowledged that this knowledge may not directly translate into the development of economically, financially, and sometimes even politically feasible solutions, which are separate hurdles in themselves (Mohan & Abhijith, 2021).

The research was implemented in Kathmandu, Nepal, which was chosen as a test-bed due to its especially persistent and severe intermittency problems, which are exacerbated by a lack of information on service quality and a lack of resources to tackle the IWS issue. This particularly challenging environment was deemed to be representative of other countries in the Global South suffering from similar issues and presenting varying low-income and data-scarce profiles.

Indeed, although Nepal holds 2.27 per cent of the world's freshwater, there has been a large deficit in water supply in the serviced areas of Kathmandu since the 1980s, when access to water supply actually started to decline. More recently, demand reached 195 MLD (million litres of water per day) and supply only provided between 90 MLD and 150 MLD (Nepal Central Bureau of Statistics, 2019). As a result, Kathmandu residents experienced persistent intermittency issues, with most households only receiving water for an hour every fourth day (Kathmandu Upatyaka Khanepani Limited et al., 2019).

The role of citizen science in managing IWS

Citizen science is the collection and analysis of scientific data by members of the community in collaboration with scientists. This presents itself as a low-cost means to collect data in large quantities over a large area and in real time. This paper therefore seeks to demonstrate that citizen science can be coupled with personal communication technology in the form of mobile phones to bridge the information gaps on the supply of municipal water in data-scarce and resource-constrained settings, where citizen science has a particularly high value.

To the best of the authors' knowledge, the application of citizen science to monitor water supply intermittency has never previously been examined. This may be because in the developing world, there are often no reliable sources of utility-generated data to compare to, or because of a perceived lack of will to use it. Sceptics may refrain from using citizen science data, claiming that it is not possible to validate it against official sources – but it is exactly in regions where there is no official data that citizen science can be arguably the most useful, since it fills a crucial data gap.

It is likely that citizen-reported data at household level would better capture the variability of IWS than a utility company could, since the water flow is subject to so many factors between the source and the tap (Rawas et al., 2020). So far, methods to understand water intermittency collected data either through the local water board or household surveys and one-time on-site water tests (Agathokleous & Christodoulou, 2016; Guragai et al., 2017).

Importantly, citizens can also flag aspects of the intermittency that would otherwise be overlooked, voice their demand satisfaction levels, and share insights gathered from personal experience that would otherwise remain unknown (Buytaert et al., 2014). Combining citizen-collected information with formal data results in a more relevant understanding of the issue being studied (Taylor et al., 2019). Ultimately, this would lead to a more accurate representation of the intermittency, helping to make better-informed decisions in policy, management, and financial planning (Kumpel et al., 2012, 2016).

Methodology

The research employed a bottom-up approach to data collection, consisting of two workstreams conducted in parallel. The first workstream consisted of preparing and conducting semi-structured interviews with stakeholders to assess prior availability and quality of information on water supply intermittency, such as official water delivery schedules, and interviews with citizens to ensure they saw the value of the data collection. The interviews took place in person over four weeks on the ground. The second workstream consisted of designing and using a mobile phone application (app) to collect pertinent data via citizens. The app was refined multiple times over several months, based on user feedback, before it was ready for its final use.

Stakeholders were mapped and interviews sought from ten organizations in Kathmandu: the Department of Drinking Water and Sewerage Management within the Government of Nepal, the public water utility company (Kathmandu Upatyaka Khanepani Limited, locally known as KUKL), the Kathmandu Valley Water Supply Management Board (KVWSMB), international financial institutions and donors (Asian Development Bank (ADB), World Bank Group, Japan International Cooperation Agency (JICA)), and research and civil society organizations (the International Water Management Institute (IWMI), Global Water Partnership Nepal, Tribuhvan University, Water Aid Nepal, and the Valley Drinking Water Victim's Struggle Committee). The latter is an activist group created to facilitate and encourage civic engagement to combat the political inaction in the water sector in Kathmandu.

The interviews revealed that little to no information on quantity, quality, or timeliness of the water supply reaching the end-user was being systematically recorded by the water utility company (KUKL), despite residents still receiving a water bill. Moreover, it transpired that information was not shared between co-workers and departments within KUKL, nor with collaborating entities such as the ADB. Further consultations revealed that the water utility company does not have the resources in terms of finance and people to appropriately monitor and manage the water distribution. Therefore, there is little information and data on the water network, and there are not enough resources to adequately remediate this data gap.

Meanwhile, roughly 52 per cent of the total population used the internet in 2022 (International Telecommunication Union, 2022), with mobile internet users dominating the Nepali broadband market at 74.5 per cent (Nepal Telecommunications Authority, 2022). In fact, as of 2022, there were more internet mobile subscribers than people in Nepal, with just over 38 million subscriptions. Indeed, Nepal's mobile-cellular telephone subscriptions per 100 inhabitants jumped dramatically from 0.04 to 139.45 between 2000 and 2018 (International Telecommunication Union, 2020), with both men and women possessing mobile subscriptions.

Based on these initial findings, collecting data through mobile phones was both economically and technically feasible, as well as able to meet the criteria for user acceptability without introducing selection bias. Therefore, the research proceeded to design a smartphone app, custom-built for Kathmandu residents, to collect and view water service data. The app was designed for users to log information on water arrival and timeliness. It was deliberately designed for citizens to record the timings when water was supplied, rather than when there was an interruption in service,

Figure 1 The app's welcome screen, Nepali version

because the anomalous event in this context was the arrival of water, and not the interruption of supply. The app was made freely available on Android via the Google Play Store in English and Nepali (Figure 1), so it could be used by the majority of phone users in Nepal, regardless of income or education level.

The app's design featured a logo of a water valve and a simple, colour-intuitive interface featuring red and green buttons for users to click to indicate if they had received water as per the official water schedules or not.

Responses were sent to the server in real time and stored in an AWS (Amazon Web Services) database.

Enlisting members of the public to assist in this research required consideration of ethical issues, such as threats to privacy, threats to the liberty of the individual for participating in research that could reflect negatively on the local governance of the water sector in a fragile state, or unintended impacts on wellbeing. Therefore, the study design aimed to take these into consideration and sought the approval of the design from the Imperial College Research Ethics Committee before any citizens were recruited (reference 18IC4470).

Community representatives were contacted in selected sites across the water supply zones of Kathmandu. In total, 12 community representatives were contacted, leading to 12 information and recruitment sessions across different neighbourhoods, with approximately 12 people attending each session.

Extensive socio-economic data was purposefully not collected from individual participants in order to reduce the time burden of the research on them and better retain participation. However, volunteers were chosen from different neighbourhoods, which themselves were selected to present a range of socio-economic profiles. Therefore, while the individual socio-economic data is not granular, it can still be used to represent a range of socio-economic conditions.

An overview of the research and of the participation of citizens was presented to the leaders, who then facilitated community meetings. The content of the meetings covered the role of citizens in the research and how the community could benefit from participating. The aims of the community meetings were two-fold: first, to contact as many prospective participants as possible; and second, to understand the motivations of interested participants in order to incorporate these into the strategy to raise and retain participation. This approach has been shown to enhance citizen engagement by acknowledging the different dimensions of the problem, and thereby allowing the participants to find relevance in the project (Phillips et al., 2019; Shirk et al., 2012).

At the end of the session, attendees were invited to indicate whether they would like to participate in the study. Those who chose to participate were invited to stay behind if they owned a private municipal connection in their home (either indoors or outdoors). Further studies may wish to explore specific types of connection further, as this may shed further light on socio-economic biases. Information was collected from this group of interested participants on demographic characteristics, engagement with water issues, and their motivation for attending the meeting, all in order to run statistical investigations on what factors make a participant 'reliable' or not. Specifically, it was planned to compare male and female participatory responses to test whether gender affected the quality and quantity of the data collected. However, this was quickly dismissed, as community meetings were heavily gender-imbalanced. Nepalese culture is male-dominated and meetings were accordingly heavily male-dominated, resulting in women refusing to participate, even if they were present. Statistics on female participation were hence too low to be able to take the analysis on gender any further. Future work should aim to investigate differences between gender participation, as well as the potential skew towards those participants who have more resources – and perhaps therefore, by association, more free time – to participate in such research.

The interested participants were then guided through using the app on their own phone, assisted by a native Nepali-speaker if necessary.

Recognizing the challenging conditions in Nepal in which to conduct research (e.g. the language barrier between researchers and study participants), the criteria for participation were kept to a minimum. Prospective participants were simply required to be above 18 years of age, to own a smartphone with an internet connection, and to live in a residence with a private water connection to the municipal supply. There was no need to develop criteria for prospective participating communities, as water intermittency is a rampant issue in Kathmandu and all communities suffer from this affliction to some degree. With this in mind, a two-week pilot was conducted with a small group of users to test the effectiveness of data collection before the full-scale two-week study was initiated.

Results and validation

One hundred and ten individuals were successfully recruited at an uptake rate of five users per day. The users downloaded the app and used it to record data, covering approximately 82 km^2, or 14 per cent, of Kathmandu Valley's urban area. After cleaning the dataset for duplicates and inconsistencies, 816 data points were found to be usable. As the number of recordings per participant is determined by the frequency of their water supply, it was not appropriate to attempt to compare the productivity of the method or of participants in terms of data collected over time.

The success of the approach was assessed through the following criteria:

- Usefulness: did the method yield the required data?
- Validity: was the data reliable?
- Sustainability: could the data collection be sustained?
- Acceptability: was the method and data accepted by decision-makers?

Validity and reliability are concerns with citizen-generated data. A multiple internal validation mechanism was therefore applied to the data collected. Each response was validated by comparing it with the nearest geographic response from another participant in the same community within one day of the response. If two people in the same community chose a 'green' response in the app within a one-day time period, they validated each other's response. However, if one person chose 'green' and the other 'red', then the response was not validated. Equally, if there was only one response in a given day, it would count as invalid. Therefore, validation of a data point required at least two people in a community to answer during the same time period.

As there was no detailed, reliable map of the layout of the water network, it was assumed that internal zone boundaries of the water network followed the commonly understood 'community boundaries' of neighbourhoods. This assumption was supported by the fact that the official water schedules were distributed by neighbourhood. The reasoning was later deemed to be correct when participants in the same neighbourhood corroborated each other's data inputs: the total percentage of responses validated through the multiple internal validation mechanism was 87 per cent, indicating a reasonably high reliability of the data received.

The internal validation approach was compared with an external validation approach of comparing citizen-generated data against official data. However, KUKL's water delivery schedules for the study sites were incomplete. The most detailed schedules showed water arriving 'every 2 to 3 days', while others only specified part of a schedule (e.g. water may arrive any day of the week, but only between the hours of 3:00 p.m. and 4:45 p.m.) or did not have schedules at all. Based on interviews with company and government officials, there is also no robust monitoring of the water supplied in terms of quantity, timeliness, and destination.

Despite these limitations, the citizen-generated data was compared with the service schedules. As the start dates of the official schedules is not stated in public documentation, the day with the first green entry from a participant was assumed to be the start of the schedule. Subsequent actual supply dates recorded by citizens were compared with the water arrival dates specified in the schedules. The process was repeated by adopting the day for the second green entry as the benchmark for the start of the schedule. The larger percentage of agreement between the two was then used to assess the extent to which actual water arrival matched the schedules, as there was wide divergence between the two. This typically yielded between 41 per cent and 52 per cent agreement. When directly comparing the responses of any one individual with the official schedules, the highest agreement percentage found was 69 per cent. These findings clearly indicate that the official schedules are not an accurate guide to actual water supply delivery timing.

Interview findings

This section presents the findings of the interviews with key respondents, representing citizens and decision-makers in Kathmandu, around two key themes of interest: the problem of intermittency and the usefulness of the app as a tool to address intermittency in the city in the long run, should it be adopted by the utilities. The latter point is of particular importance, as unfortunately stakeholder follow-through is not guaranteed and a method is only truly valuable if it both delivers results *and* is adopted by those in charge.

Interviewees' understanding of the problem of intermittent supply in Kathmandu

The representatives of the water utilities expressed the sentiment that the water supply was not only inadequate but also inequitable. There was a strong feeling that customer trust in both the government and water utility companies was broken, as both had failed to provide adequate and safe water. Citizens expressed a strong desire for their views on water supply to be heard by the authorities, which is further demonstrated by public participation in campaigns and protests.

Moreover, the interviews with citizens exposed that a recurring concern was their conscious lack of knowledge about the quality of the water that they received. Citizens were aware of potential problems with the quality of water supplied and expressed an interest in having more information about this. This sentiment was accompanied by resentment towards the bodies governing the water supply, claiming that their concerns over quality and reliability of supply were not taken seriously or acted upon by the utility when they made complaints. In order to manage the participants' expectations of the outcomes of the study, it was explicitly stated that the research would not provide an immediate solution to the problems of the poor quality and quantity of water supplied by KUKL but rather aimed to be a stepping stone to developing a solution in the long term. It was expected that, following this statement, willingness to participate would subside – but in effect, the citizens hailed the app as a chance to record where and when they had problems with their water and what type of problem it was, giving legitimacy to their claims to the water utility companies about inadequate supply. Despite this, 3.8 per cent of initial users dropped out of the study and there was a clear decline rate in data collection of roughly –2 entries per day.

Central government explained that there is no systematic data recording, and therefore there is a lack of water knowledge and consolidated databases: data available about the situation in Nepal is typically collected by different organizations (e.g. UNICEF) and every ministry has a different administrative database, which is not shared, leading to known discrepancies in the data. This was echoed by all the other interviewees, except civilians. Hence, as one civil society organization manager expressed it, the app would make a low-cost and valuable method of filling a data gap for the operator, without flooding the system with unnecessary data.

Interviewees' perceptions of the strengths and limitations of the app to generate data on IWS
Overall, the industry interviewees expressed broad acceptance of both the methodology and the validity of the data collected. Their perceptions of the potential use of the research tool are summarized in Table 1.

Water managers perceived the data collection tool as a means to intervene at an operational level. It was seen as a versatile monitoring tool, which could evolve with the water supply system over time and yield a systematic monitoring mechanism of the water supply network. However, those directly involved in the water supply management in KUKL believed that citizens would be unwilling to engage in the research, and there was concern regarding the quantity of data able to be generated through the citizen-led approach. Ministry of Water officials saw the app as a form of service improvement, while development partners were keen to use the tool as a project monitoring mechanism.

To summarize and paraphrase the interviewee responses, the tool was seen to have multiple uses:

1. A precursor for designing operational policies
2. A bottom-up, cascading pressure mechanism to compel government to put pressure on water service providers to improve their management
3. An institutional 'dispute settlement mechanism' to be used in the event of a conflict of interest between the institution's primary interest and its financial interests. In this context, KUKL's financial interests risk influencing its decisions concerning its primary purpose of delivering water, which could be considered an institutional dispute
4. A means of influencing the water service provider into answering its customers' complaints
5. A means of promoting transparency in operations
6. A means of keeping the private market for water in check in terms of providing clean and affordable water
7. A mobilization tool, rallying people to demand their rights to water
8. An empowerment tool, giving citizens the knowledge needed to make informed decisions surrounding their water supply and use

Table 1 Key respondents' perceptions of the use of the research tool

Stakeholder	*View*
IWMI	A low-cost yet valuable tool to shape policy interventions and influence KUKL into responding in a constructive way to consumer criticism
JICA-KUKL	Remediating the absence of a feedback mechanism between customers and KUKL results in customer dissatisfaction
Ministry of Water, Government of Nepal	A kind of system improvement
University professor	A welcome way to put pressure on the government and KUKL to rectify the water situation
Journalist	Effective way to share service data with government, which may strengthen its engagement towards remediating the situation
Former member of the Ministry of Water, Government of Nepal	Effective way to mobilize public participation in water monitoring
IWMI	Opportunity to develop an information system to promote knowledge sharing and to build a database Risk-free tool for decision-makers to kick-start the process of improving the water supply without needing to invest in workers, equipment, or other resources
JICA-KUKL	Low-cost alternative to fill the data gap whilst being a constructive way of compensating for negative feelings over the lack of water supply
KUKL	Part of addressing water-supply challenges from different angles in a cost-effective way
JICA	Instrument to establish a benchmark, establish improvement targets, and eventually measure progress
Government of Nepal	Easy feedback tool with traceable data to encourage KUKL's efforts to improve the water supply
World Bank	Tool to force transparency between consumers and KUKL and the government, at the very least forcing a change in how KUKL responds to its customers
ADB	The data collection tool is appropriately simple to use, and the data that it collects is necessarily basic, concise, and easy to comprehend. Donor agencies may also use the tool separately, to monitor project deliverables
Global Water Partnership Nepal	Accountability tool by government, donor agencies, and the KVWSMB, shedding light on KUKL's successes and failures alike. This would force KUKL to deliver on its promises and ensure financial accountability towards the donors
Water Aid	Tool to easily geolocate issues in the system

All the interviewees (except one from KUKL) articulated that since there was no systematic monitoring in place, the only people capable of sharing data on the water supply quantity and quality were the customers. Therefore, the app was perceived to be 'a kind of system improvement'[1], and the majority expressed the view that users would be the most reliable source of accurate water supply data and that the mode of collection via an app was effective and rallying. For the water utility company, the data generated from the app could provide additional information on system operating performance. In the worst-case scenario where there is no possibility of further investment in the system, the data resulting from the methodology could be strategically used to optimize the operations of the current water supply system. The suggestion of internal validation methods was met with enthusiasm and interviewees even expressed the view that there should be flexibility in the margins of error of the validation. Indeed, because this is a bottom-up approach to problem-solving as opposed to a top-down approach, the data generation stream may have to be adjusted over time as the utility company focuses on particular issues and refines its data needs.

A major benefit raised was the 'value for money' of the approach – i.e. compared to installing flow meters throughout the city, this approach has the potential to provide similarly useful operational data at a much-reduced cost. Indeed, limited access to financial resources in low- and lower middle-income countries would typically not allow a utility company to install flow meters at large scale. Moreover, installing flow sensors on water distribution pipes would first require precise geo-localization of such pipes, since Kathmandu does not currently possess precise maps of the water distribution network. Even if this hurdle was overcome, employing flow sensor technology would require hiring and training technical personnel to calibrate and maintain the meters, as well as planning for potential future costs of repair and spare parts. Finally, to replicate the data collection style employed in the research methodology, one would need to choose a flow meter with remote data communication and with a daily minimum data update frequency, which is extremely costly. Such a meter could cost up to GB £225 (Bell Flow Systems, 2016). It should also be noted that, because of multiple illegal connections, it would not have been possible to place sensors higher up in the distribution network (i.e. at a water mains instead of at household level) in an attempt to capture information *en masse* for multiple households in this study.

Discussion

An objective of this research was to channel intangible customer dissatisfaction into producing tangible data that both stimulates and facilitates interventions in the piped water delivery system while empowering citizens and constituting a novel means of monitoring water supply in low-income and IWS settings. Further novelty of the research lies in the development of a new means of processing and validating the data generated by citizen science in this context.

[1] Former member of the Ministry of Water, Government of Nepal.

The research showed that the approach was feasible, being both practical to deploy and easy to reproduce. The research also demonstrated that reliable data can successfully be acquired through citizen science. However, those seeking to improve the IWS through data acquisition must be mindful that utility representatives are constrained by the physical network that they have inherited and by the resources available for system repairs – therefore, the next step to improving the IWS ultimately depends on managers being able and willing to secure the financial resources and political support for remedial actions.

The openness of decision-makers to the approach and to citizen-generated data generally was surprising. It was expected that decision-makers – across both the government and the utility company – would be reluctant to accept this citizen-science methodology as a valid modus operandi to data-gathering, in part because managers might be reluctant to admit the failures of a water supply that they have a role in shaping. It was anticipated that there would be a general dislike of using public engagement to shape decisions, which would naturally incur increased transparency and accountability from public officials. Moreover, it was assumed that public officials would be sceptical about the reliability and validity of citizen-generated data, based on claims that ordinary people do not have the skills to collect sound data or that they may manipulate it to serve themselves. However, the key information interviews demonstrated a high level of interest in, and support for, the methodology.

However, the study also pointed to possible challenges in using a citizen-centred approach to supply intermittency data collection. The two main challenges were

- ensuring consistent coverage of the service area. In this study, the researchers met with very favourable conditions, which allowed the research to attract and retain participants relatively easily. Despite this, some communities were still more readily engaged than others. In order to address this challenge, future research should seek to understand why it arises by collecting information on the socio-economic and political nature of, and resources available to, the different communities. This may also assist in a better interpretation of the results from the data generated;
- preventing attrition in long-term contribution from participants. Attrition rates in the study were low, even though the study period was relatively short, so additional incentives may be necessary to sustain participation over the medium to long term. Further research is needed to establish exactly what these incentives might be and if they are strictly necessary.

In order to strengthen this approach further, the collection and analysis of citizen-generated data should aim to become an iterative process rather than a set, one-time task. Information can also be fed back to citizens at different stages of the process, allowing the utility company to change its data collection strategy at any point along the way – whether that means going forward with more data collection or different data criteria, or even going backwards and deciding to change the application of the data – eliminating the need to recruit new citizens for each task. Ideally, once the citizen-utility feedback loop (Figure 2) is well-established, it could enable citizens to recruit more participants in their area if needed, removing the need for

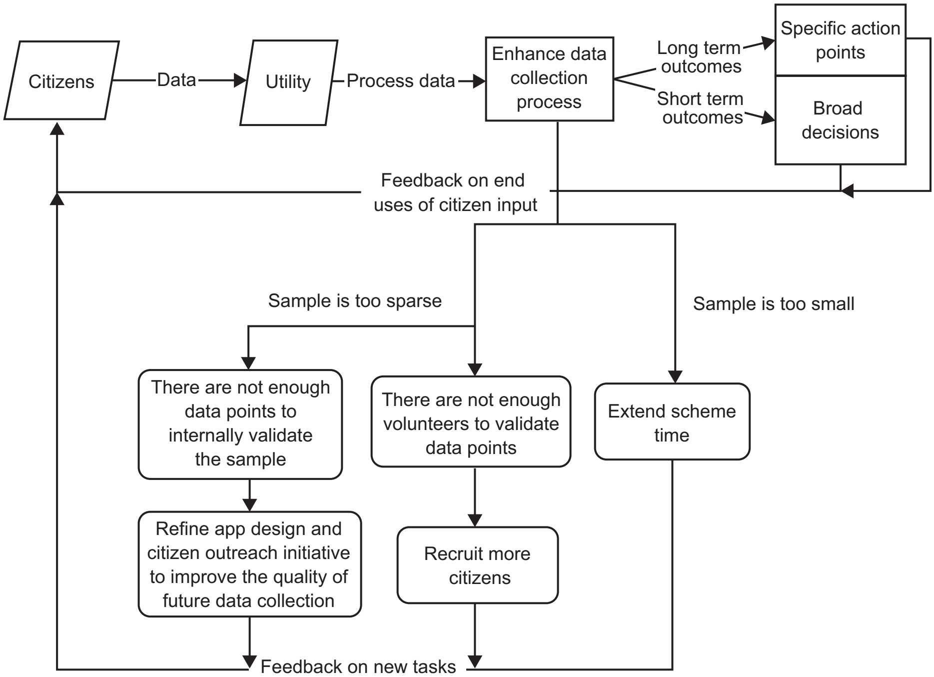

Figure 2 The citizen-utility feedback loop

the utility company to go out into the field more than once per area, which will cut down on staff time.

The advantage of having such feedback loops further lies in the fact that the utility company does not need to define the number of participants, or the spatial or temporal resolution at the start of the process. Instead, it can determine this based on the incoming data. The behaviour of the IWS will dictate the desirable spatial resolution of the location of interest. This should imperatively be decided in collaboration with the citizens being recruited in those areas, as only they will know how the water delivery varies geographically. For example, in certain areas it may be that water delivery varies per street (so each street should be visualized as a spatial unit) whereas in others it may be per block (so one block would be a spatial unit, with each block comprising innumerable streets). This, in turn, would dictate how many citizens the utility should aim to recruit. The data validation technique developed in this research requires a minimum of two participants per spatial unit in order to obtain a valid data point. The utility can then choose to build on this number or not – though this decision will of course depend almost entirely on the level of success that it encounters when recruiting citizens.

The behaviour of the IWS will similarly dictate the desirable temporal resolution of the data collected. The utility company should collaborate closely with citizens in each unit area to learn how the water delivery varies over time – daily, weekly, fortnightly, or even over longer periods. The utility company should then pick the longest time period to adhere to and decide how many cycles of data it wishes to obtain in order to satisfy its stakeholders' requirements for validation. Failure to adopt the longest time period experienced in a unit area would result in incomplete information on the area at hand and loss of citizen participants. For example, if two citizens in the same area receive water, one of them weekly and the other monthly, then the utility company should ensure that its data collection period covers at least one month; otherwise, one of the participants will not have the opportunity to record data and will lose interest. It should also ensure that each citizen has peers to validate their data point.

Hence, the feedback loop not only provides scope for flexibility in the design of the citizen-science data collection initiative, but also in the actual gathering of the data.

Aside from using the actual data collected through the app, the utility company could also benefit from using the app as a strategy tool to improve its demand-side management. Setting up a citizen-science data collection initiative sends the message that citizen needs are heard and in the process of being met. It demonstrates to the citizens that they are a part of a value chain and eliminates the 'us versus them' mentality, mending relations with the utility company while helping to promote citizen retention. The app could also be disseminated as a customer complaint tool, allowing citizens to be in direct contact with the utility company but avoiding in-person complaints when there is a failure in the water delivery. This would reduce the burden for both customers and managers, while signalling to customers that the utility company takes an active interest in their grievances and is not shying away from constructive criticism, thus restoring trust in the utility company's work ethic – even if not in its operations. In fact, this research contributed to the development and deployment of Kathmandu's water utility company's own app for this purpose in February 2020.

With prolonged application of the method, the spatio-temporal data gathered from citizens could be used to build a map of the current water supply and extrapolated to obtain information on the amount of water supplied per household per unit time. The water utility company could then verify that this meets the WHO standards on minimum water quantity for domestic and personal consumption. Those households failing to meet this standard could be identified and the utility company could then develop strategies to remediate this, such as altering its operations to distribute water more evenly through the system (for example by instructing the valve-person to leave the valves open for longer in the under-served areas) or providing rebates in billing.

That being said, in order to disseminate the app as a sustained tool for data collection, there would need to be evidence of close cooperation between government authorities and utility companies, showing that the data is contributing to decision-making at those levels. Without this, it is likely that citizens will lose their motivation to participate over time. Further research is needed to establish exactly how long citizens would continue with data collection in the absence of evidence of its use. Furthermore, the experience in Kathmandu showed that citizens are sometimes reluctant or unable to use wireless mobile data, because of the cost involved. Future applications of this research should therefore seek a solution to this impediment, for example by offering phone credits in exchange for data collection or a rebate on the water bill for the users.

Conclusion

This paper presents an innovative approach to IWS data-generation, which can complement existing data sources or replace them altogether, depending on the quantity of data generated. The approach has the potential to provide similarly useful operational data to installing flow meters at a much-reduced cost. The methodology was welcomed by key stakeholders in Kathmandu as an interim step to improve urban water supplies in low-income settings and the management of the existing IWS and its customer relations. Improvements may take many forms, starting with improved identification and characterization of the physical condition of the supply system in order to repair or replace broken system parts, more equitable distribution of water, and the dissemination of accurate information on water supply schedules. This will reduce uncertainty in delivery, allowing households to receive a more reliable supply, and restore trust in the utility (Ray et al., 2018). At the very least, acquiring this data would permit for a higher degree of control over the equity of the water delivery per household or neighbourhood by knowing how much water is delivered and where to. However, stakeholders were quick to suggest other uses of the app in assisting water management, indicating their support of the methodology and data outcomes.

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