Research Paper

# Mobile crowd participation to root small-scale piped water supply systems in India and Bangladesh

A. Mink, B. A. Hoque, S. Khanam and D. Van Halem

## ABSTRACT

In the arsenic-contaminated Ganges-Brahmaputra-Meghna Delta in India and Bangladesh, small-scale piped water supply seems a promising way to provide safe drinking water to households in the region. The use of smartphone applications can support monitoring of the system and enhance local engagement and empowerment. In this paper the scope for mobile crowd participation as a research and monitoring tool for piped water supply systems in Bihar, India and in Khulna and Chittagong, Bangladesh is investigated. In these areas, the use of smartphones and internet access are growing rapidly and smartphone applications would enable real-time water quality monitoring, payment of water bills, awareness creation, and a dialogue between the end-user and the water supplier.

To identify the relevance and acceptability of piped water supply and smartphone monitoring, four surveys with potential end-users were conducted. Based on these surveys we conclude that in the investigated areas there is a desire for piped water systems, that households already own smartphones with internet access, and that there is an interest in smartphone monitoring.

The enabling environment to deploy mobile crowd participation for piped water system monitoring stimulates further research towards an investigation of potential functionalities and the actual development of such an application.

**Key words** | end-user participation, safe water supply, smartphone application, water quality

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## INTRODUCTION

### Water safety in the Ganges-Brahmaputra-Meghna delta

In the Ganges-Brahmaputra-Meghna Delta (GBM Delta) in India and Bangladesh many people lack access to safe drinking water. Since the 1970s the focus in Bangladesh has been on installing tube-wells to protect the Bangladesh population against pathogens in their drinking water (Argos *et al.* 2010). A similar scenario applies to regions of India where the country started to use groundwater in the 1960s (Srikanth 2013; Daigle 2016). Only in the 1990s was it realized that the groundwater was severely arsenic-contaminated (Chakraborti *et al.* 2003; Argos *et al.* 2010; Bangladesh Bureau of Statistics (BBS) & UNICEF Bangladesh (UBD) 2015). Arsenic is a human carcinogen which poisons the population when they drink water with high contamination levels. Overexposure to arsenic is associated with skin lesions, oedema, gangrene, black foot disease, and malignant diseases such as skin, bladder and lung cancer (Karagas 2010; Singh *et al.* 2015; Sarkar & Biswajit 2016; WHO 2016). The limit of arsenic in drinking water by the World Health Organization is 10 μg/L (WHO 2016)



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resulting in an estimated 32 to 77 million people who suffer from overexposure to arsenic through drinking water in Bangladesh (Argos *et al.* 2010; Sarkar & Biswajit 2016) and approximately 70 million people in India (Sarkar & Biswajit 2016). Besides the arsenic contamination risk, people in Bangladesh are also overexposed to manganese, iron and salinity, and in Bihar also to fluoride and iron.

While in Bangladesh 97.9% of the Bangladeshi population uses an improved drinking water source, it emerged that 'improved water sources are much more likely to have arsenic contamination than non-improved sources' and that rural areas are more at risk than urban areas (BBS & UBD 2015, p. 72). In Bangladesh, people living in arsenic-affected areas still drink arsenic-contaminated water, despite several programmes and initiatives (Hoque *et al.* 2004). Initially, wells were tested and marked red (>50 μg/L) or green (<50 μg/L) and people were encouraged to switch to safe wells or to newly installed public deep tube-wells (DTWs), under the Bangladesh Arsenic Mitigation Water Supply Program. Due to increasing awareness of arsenic in Bangladesh since the year 2000 (Yunus *et al.* 2016), about one-fourth to two-thirds of the households switched to a safer well. However, owing to difficulties in finding alternatives, far away safe sources, lack of systematic and/or regular monitoring of water quality and arsenic content, inadequate levels of or mechanisms for sharing information about well tests, washing away of red and green paint, and fading knowledge, not all households switched to or switch away again from safe wells after some time (Pfaff *et al.* 2017; Balasubramanya & Horbulyk 2018). Since 2004, government focus has shifted to piped water supply (PWS) from a safe source (Balasubramanya & Horbulyk 2018). However, these programs are not yet able to deliver PWS at the intended scale due to organizational delays, lack of adequate capacity, and complex cost-sharing arrangements (Worldbank 2015; Balasubramanya & Horbulyk 2018). Balasubramanya & Horbulyk (2018) mention that options such as community DTWs and well testing are easier to deliver. In Bihar state, households mainly depend on privately installed, unmonitored shallow tube-wells (STWs) or government-installed DTWs. The private STWs put households at risk, and while the government DTWs are mainly free of arsenic contamination, they are dysfunctional in 24 to 31% of cases (Srikanth 2013). Also in Bihar, well testing campaigns have been organized, but due to lack of guidelines for well testing, uncontrolled and unregulated installation of hand pumps, untested areas, lack of a common repository for arsenic testing data, lack of a decision support system for arsenic mitigation, and a lack of coordination among research groups, arsenic mitigation still remains a challenge (Singh 2015).

## Piped water supply: advantages and challenges

Different arsenic mitigation strategies exist, such as well testing, use of DTWs, use of household filters, community-level treatment, rainwater harvesting, pond sand filters, and safe water points for a limited number of people. For different reasons the success of these strategies differs. Local geological and socio-economic circumstances, maintenance, logistics, convenience and costs seem to play an important role in the success of mitigation strategies (Hoque *et al.* 2006; Sarkar *et al.* 2010; Daigle 2016; Balasubramanya & Horbulyk 2018; Maertens *et al.* 2018). In the presented study the focus is on small-scale piped water supply (SPWS) (Trifunovic 2002; Kayaga & Reed 2005) systems, as it offers crucial advantages over other technological interventions. SPWS targets the safest source in the area, provides a degree of centralization (<100 households) for water quality control and treatment while keeping the system manageable within communities. It provides in-house or courtyard tap connections, which are socio-economically desirable, and it limits the number of (re-)contamination events between water collection and consumption.

However, there are several challenges to overcome for PWS systems. First of all PWS systems need acceptance by their end-users. Johnston *et al.* (2014) found PWS systems to be supported by Bangladeshi households and noted that these systems should be prioritized. However, they also noted that until now the experience with these systems is limited, that costs of the system might be an issue, and that it will take time before these systems will be fully realized in the country. This is also acknowledged by Maertens *et al.* (2018), who indicate PWS to be the most effective policy answer, but not for the foreseeable future. Ahmad *et al.* (2005, 2006) indicated that piped water systems are desired in Bangladesh, but mainly for their convenience. Therefore, the willingness of end-users to change behaviour and take up PWS might be limited, especially as PWS increases water costs. Maertens *et al.* (2018) report that the effectiveness of awareness campaigns in Bangladesh suffers from low demand, resistance to behavioural change, poverty, low literacy and other constraints. As most focus in developing regions is on the implementation of these systems and not on their operation and maintenance management, the technologies are often not sustainable (Lee & Schwab 2005; RWSN 2009; Meleg 2012; Srikanth 2013). After instalment, water quality and quantity problems are caused by intermittent water supply, leaking pipes, low water pressure, inadequate disinfectant residual, inadequate wastewater collection systems, and deterioration of infrastructure (WHO & UNICEF 2000; Lee & Schwab 2005; Johnston *et al.* 2014). Poor operation and maintenance due to political, social and economic issues thus result in substandard water supply (Lee & Schwab 2005). Well appropriation by local elites also occurs (Balasubramanya & Horbulyk 2018). Thereby, billing of water usage also causes problems, due to illegal tapping and malfunctioning meters (Lee & Schwab 2005). Problems with money collection also arise (Balasubramanya & Horbulyk 2018). This also results in lack of maintenance and wastage of water (Lee & Schwab 2005). Consequently, PWS have a slow uptake, and are merely seen as a long-term solution, while solutions are urgently required in the short term (Balasubramanya & Horbulyk 2018). SPWS systems can function as an intermediate solution, before PWS implementation on a large scale. SPWS makes operation and maintenance easier compared to bigger systems, and requires less expensive piping. According to Yunus *et al.* (2016), the installation of safe water points for no more than 50 people per point in combination with a safe source does provide long-term cost-effectiveness.

However, implementation of SPWS is not sufficient to ensure sustainable safe drinking water supply in communities. Meleg (2012) stresses the importance of considering financial, institutional and technical dynamics in relation to human factors in order to implement sustainable water supply systems. Balasubramanya & Horbulyk (2018) mention the understanding of community preferences and of the ability and willingness to pay for different options as important knowledge gaps, alongside the requirement to examine financial, regulatory and other obstacles and Abedin & Shaw (2013) strongly argue for a much greater role of local communities in developing and leading mitigation strategies, with the assistance of governmental and non-governmental organizations.

## Participation in the development of piped water supply systems

When in Northern Kenya two good-hearted Americans installed a community well to prevent women from suffering the indignity and effort of walking long distances to a watering hole, they were very much surprised that the women did not want to use the well (Fleming 2015). It emerged that the women did not accept the technology as walking to the watering hole was their form of socialization, which they did not want to miss out on (Fleming 2015). Skinner (2009) and Purvis (2016) furthermore report that when well technology is accepted in rural Africa, many of the wells fail within two to three years due to wrong drilling, failing technology, unavailable or expensive spare parts, and/or lack of ownership and local capacity leading to lack of maintenance.

Technologies shape and change our world and have the potential to support people in doing what they want to do and being who they want to be. This potential is especially valid in Design for Development (DfD) projects where products and services are developed to improve the well-being of disadvantaged and marginalized populations (Donaldson 2006, 2009). However, as shown by the example above, well-meant technologies might cause new social and environmental problems or even limit or control people in their beings and doings. Designers therefore have a high social and moral responsibility for the consequences of their innovations (Papanek 1984). Many failed products and services are unsuited to the user and/or their environment as they are either based on poorly defined needs (Donaldson 2006), or focus merely on needs instead of what people actually want (Bowman & Crews 2009). A high degree of participation enhances the possibility of designing solutions that are accessible, applicable, acceptable and adopted (Donaldson 2009; Nakata & Weidner 2012; Prahalad 2012; Robertson & Simonsen 2012; Wilkinson & De Angeli 2014; Mink 2016) and are therefore more likely to be sustained (Marshall & Kaminsky 2016). Moreover, it enhances successful implementation and community ownership (Narayan 1995; Kayaga 2013). User participation actively engages the end-user in the process, so they can design and implement new ways of being and doing themselves (Manzini 2014). The development of SPWS systems is a technological design and requires contextual learning and involvement of local stakeholders on an equal footing in order to produce systems that people can, will, and want to use, and that will continue to be used. Marshall & Kaminsky (2016) point out that the motivations of outside stakeholders (good health and well-being) might potentially misalign with the motivations of local stakeholders (e.g., status, convenience, social norms). To improve the chances of long-term success of SPWS implementation, local stakeholders should be actively involved in the process: first by consulting them and raising awareness, then by co-creation and capacity building, and finally by engaging and enabling them to monitor their own systems.

A novel approach to research and monitor SPWS systems is mobile crowd participation (MCP), which enables the local stakeholders to participate, learn and provide feedback via smartphone applications. MCP can be deployed in different ways:

1. In combination with strip tests it can be used for low-cost screening for the presence of arsenic, while making the data available to different interested stakeholders, including the end-users.
2. Improving knowledge and awareness about safe water supply and water quality (also by enabling users to test the water quality themselves).
3. When SPWS is installed, MCP enables communication between relevant stakeholders for improving service and maintenance (e.g., sharing down-time, leakage reporting, water quality information), makes payment easier, and allows for low-cost monitoring of water quality, water consumption and payments.

While external support for water service provision will remain a requirement (RWSN 2009; Kayaga 2013), MCP has the ability to engage and empower communities and supporting organizations and companies to increase the trust and uptake of piped systems and to assist in continuous capacity development. The requirements for MCP to work are smartphone ownership and internet access, and the availability of an application that is useful, usable and desirable for its users. According to GSMA (2013), access to mobile services in developing regions has outpaced the rate at which much of the population is gaining access to basic services such as electricity, sanitation and banking. In 2015, smartphone ownership in India was 24% and mobile internet penetration 49% (GSMA 2016). In 2016, smartphone ownership in Bangladesh was 28% and mobile internet penetration 53% (GSMA 2017). Based on these numbers, there seems to be scope for a smartphone application to monitor SPWS systems. It is the objective of this study to identify the relevance and scope of using MCP as a research and monitoring tool specifically for SPWS systems in arsenic-affected areas in the GBM Delta. Therefore, four surveys have been executed in Bihar, India and in Khulna and Chittagong, Bangladesh, of which the outcomes are presented in this paper.

## METHODS

Four surveys were executed among end-users to assess the demand, acceptability and affordability of small-scale piped water systems and to assess the feasibility and scope of using smartphones as a research and monitoring tool. Besides questions regarding SPWS systems and MCP, the surveys included sub-themes about socio-economic and demographic characteristics of the participants, water use practices and water quality knowledge. The surveys were developed, pre-tested in the field and revised to collect the final data. The participants were informed about the purpose of the research, data handling and security, and were asked for informed consent to use the data for research and publication prior to each survey. Representatives from households in each area were questioned by selecting the third/fourth household in the row, depending on the availability of participants. In this way, all parts of each investigated area were covered to ensure a random and representative selection of participants.

### Study 1 – Khulna district, Bangladesh

In November 2014, a semi-structured questionnaire survey was executed in Bangladesh among 601 households in the municipalities of Sathkira (SAT), Khulna (KHU) and Bagerhat (BAG). In consultation with local stakeholders, three low-income, urban and high population density settlements in an arsenic-affected area were selected. Locally recruited data collectors from the area, who followed a 2-day training in class and in the field, questioned 287 male and 314 female participants. The questionnaires lasted an average of 35 min.

### Study 2 – Khulna and Chittagong district, Bangladesh

In June 2015, a questionnaire survey among 101 households was conducted in the municipalities of Kolaroa (KOL) and Debidwar (DEB). In consultation with local stakeholders, two low-income peri-urban areas consisting of at least 100 households in an arsenic-affected area were selected for the study. Trained EPRC staff members questioned 53 female and 48 male participants. The questionnaires lasted an average of 20 min.

### Study 3 – Bhojpur district, India

In April 2017, the research team conducted a semi-structured questionnaire survey in Bhojpur district, Bihar state. In consultation with local stakeholders, seven villages in an arsenic-contaminated area consisting of at least 100 households in Bhojpur district were selected for executing the surveys: Saraiya (SAR), Sinha (SIN), Gundi (GUN), Bakhorapur (BAK), Keshopur (KES), Lauhar (LAU) and Nathmalpur (NAT). The questionnaires were conducted with representatives from 275 households, of which 15 were female and 259 male, and lasted an average of 10 min.

### Study 4 – Bhojpur district, India

In the same villages at the same time as study 3, the research team conducted an interview survey with representatives from 60 households by selecting households owning at least one smartphone, in order to gather in-depth information about the potential for SPWS and scope for MCP. The interviews lasted an average of 40 min.

## RESULTS AND DISCUSSION

Below the results are presented and discussed in three parts: first the participants' socio-economic characteristics (for all studies), then the potential for SPWS (for all studies) and finally the scope for MCP (for studies 2, 3 and 4).

### Socio-economic characteristics

The investigated areas in Bangladesh are urban and peri-urban, leaving most of the participants to work as a day labourer, small business owner or driver. The investigated areas in India are rural and most participants here are engaged in farming and small businesses or services. The average household size in India (12 people) is bigger than in Bangladesh (five people), and there is also a larger presence of children under five in Bihar (in 58% of the households compared to 43% of the Bangladeshi households). As can be seen in Figure 1, both the educational and income levels in the investigated areas in Bangladesh are lower than in India. This is also reflected in the national averages of both countries (India's human development index is 0.624, with a mean of 6.3 years of schooling and a gross national income per capita of $5.663 purchasing power parity, Bangladesh's human development index is 0.579 with a mean of 5.2 years of schooling and a gross national income per capita of $3.341 purchasing power parity (UNDP 2015)). Within each countries' settlements, the educational and income levels differ as well: the participants from Khulna district have lower levels than those in Chittagong, and in Saraiya, Sinha and Gundi these levels are lower than in Lauhar, Keshopur and Nathmalpur. In study 4 the average educational and income levels are higher than in study 3, which can be explained by the fact that the participants in study 4 were selected for owning a smartphone, which is more likely to be owned by households with a higher socio-economic status.

### Scope for piped water supply

In Table 1 the results of the current drinking water situation of all four studies are presented. Most participants use tubewells for their drinking water. In studies 2, 3 and 4 mainly privately owned STWs were situated around the house, in study 1 mainly publicly owned DTWs. In study 1, 80% of the households share a water point with more than 50 households. This results in risks regarding relationships, privacy, security, operation and maintenance, as conflicts

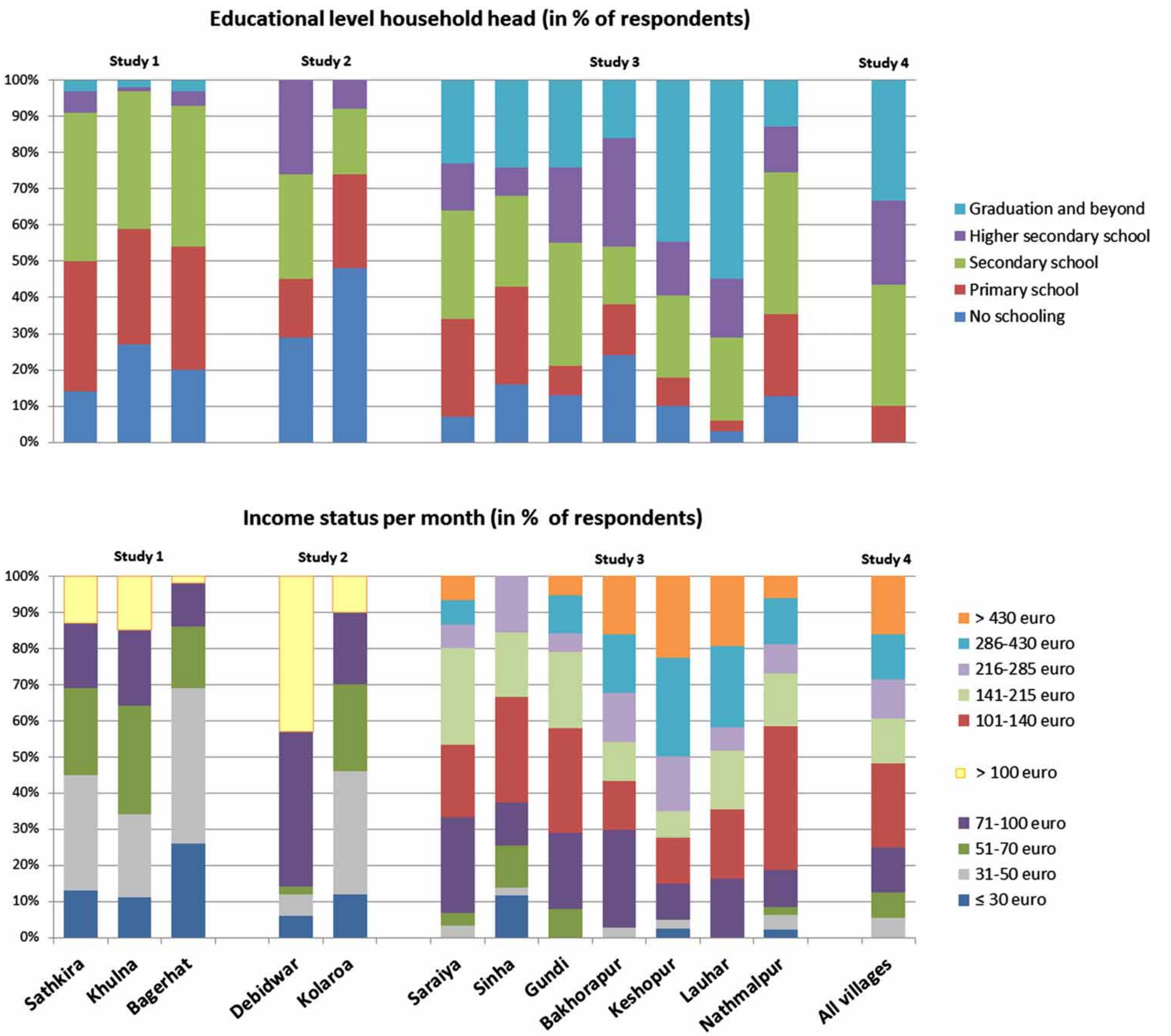


**Figure 1** | Educational level and income status per study per village.

mainly occur during peak hours. Some participants rely on publicly installed DTWs which are located only at certain points in the area. In this case, the water collectors, mainly women, have to walk long distances to fetch water.

In India (studies 3 and 4) the trust in participants' current drinking water was also investigated. Of the 335 participants in those two surveys, 61% trust their drinking water. Of these, 81% indicate that they trust their water because of its good colour, taste and/or smell, 2% because they do not suffer from water-based illnesses, and the remaining 17% indicate the water 'seems good' or that they trust the water for no specific reason. The remaining 39% of the participants indicate that they maybe trust their water (1%) or distrust their water (38%). Of the participants who distrust their water, 45% indicate they do so because the water has a bad colour, taste and/or smell, 17% because the water changes colour during storage and 9% because they suffer from water-related diseases. The remaining 29% of the distrusting participants indicate that their water 'seems contaminated' or they could not indicate a specific reason for their distrust.

**Table 1** | Existing drinking water supply characteristics of participants in Bangladesh and India

| Variables | Study 1 Bangladesh per area[a] | | | Study 2 Bangladesh per area[b] | | Study 3 India | Study 4 India |
|---|---|---|---|---|---|---|---|
| | SAT (201) | KHU (200) | BAG (200) | DEB (51) | KOL (50) | All (275) | All (60) |
| Drinking water source used (in % of participants) | | | | | | | |
| Deep tube-well (>150 m deep) | 19 | 100 | 70 | 0 | 12 | 0 | 0 |
| Shallow tube-well (<150 m deep) | 35 | 0 | 1 | 100 | 86 | 99 | 97 |
| Piped water supply | 24 | 0 | 1 | 0 | 0 | 0.5 | 3 |
| Surface water (pond/river) | 20 | 0 | 29 | 0 | 0 | 0.5 | 0 |
| Other (pond sand filter, dug well, rain water) | 1 | 0 | 0 | 0 | 2 | 0 | 0 |
| Ownership (in % of participants) | | | | | | | |
| Private | 36 | 1 | 16 | 73 | 64 | 99 | 97 |
| Shared | 17 | 4 | 10 | 27 | 18 | 0 | 2 |
| Public | 47 | 95 | 74 | 0 | 18 | 1 | 2 |
| Water availability (in % of participants) | | | | | | | |
| Throughout the year | 92 | 77 | 91 | 96 | 40 | 100 | 100 |
| Not throughout the year | 8 | 23 | 9 | 4 | 60 | 0 | 0 |
| Distance to water point (in meters) | | | | | | | |
| Minimum | 2 | 2 | 2 | 1 | 2 | - | 0 |
| Mean | 71 | 29 | 301 | 6 | 261 | - | 2 |
| Maximum | 1,600 | 305 | 1,600 | 50 | 2,250 | - | 30 |

[a]SAT, Sathkira; KHU, Khulna; BAG, Bagerhat.
[b]DEB, Debidwar; KOL, Kolaroa.

In the studied areas, the participants have little to no experience with PWS systems, except in Sathkira where 24% of the participants rely on PWS. The desire for PWS is nonetheless high, although in study 3 it is somewhat less than in the other three studies (79% compared to 98–100%). However, while in study 1, 97% of the participants indicated they wanted a PWS, 65% of them also indicated a preference for drinking hand-pumped water from a DTW. The second most preferred option is pond water supply (21%), then PWS (11%), and 3% indicated a preference for hand-pumped water from a STW. Most participants preferring DTW water indicated that hand-pumped water from this source provides an adequate volume of bacteria-free drinking water for their family throughout the day. Thereby, some indicated a distrust against PWS as a drinking water source, because of possible contamination in the water tank and pipelines. Multiple participants also indicated that groundwater tasted cooler and sweeter, and therefore they preferred to drink directly from the ground instead of from a PWS. Participants with wells containing a lot of iron mainly indicated preferring a different option than their current drinking water source, as they dislike the iron taste and colour it gives to their food and clothing. The desire for PWS is, nonetheless, high as the participants want to use piped water for cleaning, washing and cooking purposes. In all studied areas, safe water and convenience are mentioned as reasons behind the desire for PWS. In India (studies 3 and 4), the participants were specifically questioned about the reasons behind their desire for piped water supply (see Figure 2). Of the 335 participants in these studies, almost 40% indicated not trusting their current drinking water supply system, and 71% indicated they desired PWS to be able to provide their family with safe drinking water.

In most study areas, a large majority of the participants indicated prefering deep groundwater as a water source for piped water systems. However, in study 4, a significant preference for surface water (35%) was also identified. Those participants indicated that water from River Ganga is sacred

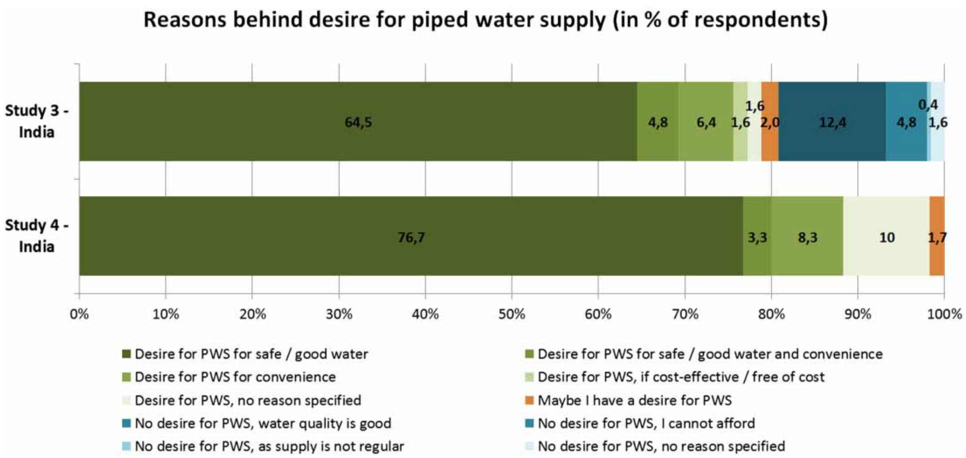


**Figure 2** | Reasons behind the desire for piped water supply in India.

and therefore considered good for health. The participants of study 4 also indicated a higher preference for using rain water (10%) than in the other studies (1% to 2%). Willingness to pay for installation, operation and maintenance of piped water supply was found to be high in studies 1 (97%), 2 (94%) and 4 (93%). In study 3, however, 50% of the participants were not willing to pay. Of these participants, 33% indicated they had no money, 14% indicated that PWS is nice but not required, and 2% indicated that the government should pay. As the participants in study 4 are of higher socio-economic status, study 3 is used to represent the willingness to pay in this area in India. The Bangladeshi participants were willing to pay an average of 52 BDT (0.50 euro) per month for operation and maintenance. In study 4, the participants shared a willingness to pay 220 INR (2.90 euro) per month. In all studies, the costs for installation, operation and maintenance were mentioned as issues of PWS systems. Thereby, in studies 1, 2 and 3 irregular water supply was noted as an issue. In study 1, where participants do have experience with PWS systems, complexities in operation and maintenance of PWS systems were also mentioned as challenges.

From these studies it seems that Bangladeshi households are more experienced with DTWs and PWS systems and more willing to pay for PWS, although a lower amount than in India. Based on the collected data, no relation could be detected between income level, educational level or profession and the desire for PWS. While there is a large desire for PWS systems for the convenience and supply of safe water, trust in the system, costs, irregular supply and challenges in operation and maintenance are factors that seem to hinder people's desire for PWS.

## Smartphone ownership and usage

Data about smartphone ownership and usage were collected in studies 2, 3 and 4. In Table 2 the results regarding smartphone and mobile phone ownership and smartphone usage are presented. Smartphone ownership in study 3 (India) is significantly higher than in study 2 (Bangladesh). However, that may be partly due to the difference in the time of investigation (2014 versus 2017) and the difference in area (urban versus rural). Other reasons might be inexpensive and overall presence of internet access in India, and the higher socioeconomic status of the Indian participants.

The smartphones owned by the participants are used for calling, messaging, taking pictures, playing games and internet usage. The participants in study 4 all have internet access and use internet on their smartphones for social networking (100%), internet searching/downloading (98%), entertainment, such as watching television/video and listening to music (42%), online payment (25%) and education/study (9%). In both Bangladesh and India, phone usage is male dominated with 53–78% of household phones only being used by males versus 4–7% only being used by females. Nevertheless, in 19–42% of the households the mobile phone is shared, leading to a considerable proportion of the female household members using smartphones, especially in the surveyed area in Bangladesh. In India, a large amount of

**Table 2** | Investigated mobile phone data of participants in Bangladesh and Bihar

| Variables | Study 2 Bangladesh Both areas (101 HH) | Study 3 India All villages (275 HH) | Study 4 India All villages (60 HH) |
|---|---|---|---|
| Mobile phone ownership | | | |
| None | 7.9 | 2.2 | – |
| One | 40.6 | 23.3 | – |
| Two | 36.6 | 23.3 | – |
| More than two | 14.9 | 51.2 | – |
| Smartphone ownership | | | |
| None | 88.1 | 50.4 | – |
| One | 11.9 | 23.2 | – |
| Two | 0.0 | 14.5 | – |
| More than two | 0.0 | 11.9 | – |
| **Phone users (in % of participants)** | **Button phone** | **Smartphone** | **Smartphone** |
| Only male | 52.7 | 77.7 | 65.0 |
| Only female | 5.4 | 3.6 | 6.7 |
| Both male and female | 41.9 | 18.7 | 28.3 |
| **Phone users (in % of participants)** | **Button phone** | **Smartphone** | **Smartphone** |
| Children (<20 years old) | 18.1 | 36.4 | 42.1 |
| Parents' generation | 74.8 | 54.1 | 47.4 |
| Grandparents' generation | 7.1 | 9.6 | 10.5 |
| **Number of households owning a smartphone** | **12 HH** | **139 HH** | **60 HH** |
| *Internet access with smartphone (in % of participants)* | | | |
| None | 0.0 | 10.9 | 0.0 |
| Always | 42.0 | 49.6 | 73.3 |
| Daily | 58.0 | 10.9 | 16.7 |
| Less than daily | 0.0 | 28.5 | 10.0 |
| *Smartphone usage (in % of participants)* | | | |
| Calling | 100.0 | – | 100.0 |
| Text messaging | 33.0 | – | 98.3 |
| Taking pictures | 67.0 | – | 98.3 |
| Playing games | – | – | 62.7 |
| Internet usage in general | 58.0 | – | 100.0 |

adolescents use the owned smartphones, mainly for social networking, entertainment or study purposes. Of the Bangladeshi participants, 46% indicated a desire to have a smartphone with internet access and are willing to spend, on average, 5% of their income on it. Most Indian participants already have internet access on their smartphones. Currently, the households in study 4 pay, on average, 503 Indian rupees (6.58 euro) per month on phone usage. Of the households in study 2, 78% pay less than 500 taka (5 euro) per month, 13% pay between 500 and 800 taka (5–8 euro) per month and 9% pay more than that.

When comparing smartphone ownership with socio-economic status for study 3, it can be concluded that there is a direct link between the average income of families owning smartphones and the number of smartphones (see also the boxplot in Figure 3). However, lower-income families do own smartphones, which can also clearly be seen in Figure 3, and for the ones who do not, the desire to own a smartphone is high, especially in households where family members do not live together or are separated throughout the day (for work or study). There is also a link with educational level (the higher the educational level, the more smartphones owned (see Figure 3)) and there seems to be a link with the profession of the household head (labourers own less smartphones, government employees own more), although this link is not that clear (see Figure 3).

From these studies, it seems that in Bihar smartphone ownership and internet usage is higher than in Bangladesh and more money is spent on phone usage. This could be because the income level and educational level of the participants in Bihar are higher than in Bangladesh and, as stated above, there seems to be a link between phone ownership and income and educational levels. However, other factors also play a role, such as differences in internet coverage and the price and availability of smartphones in the area. From study 2 it has become clear that in Bangladesh there is a desire to own a smartphone with internet access. Thereby, due to local phone manufacturers and inexpensive internet, smartphone and internet use are expected to rise rapidly in both India and Bangladesh. This enhances the scope for MCP for the purpose of water supply management.

## Scope for MCP for sustainable piped water supply

The interest in PWS systems and the current and rising availability of smartphones and internet coverage indicate the

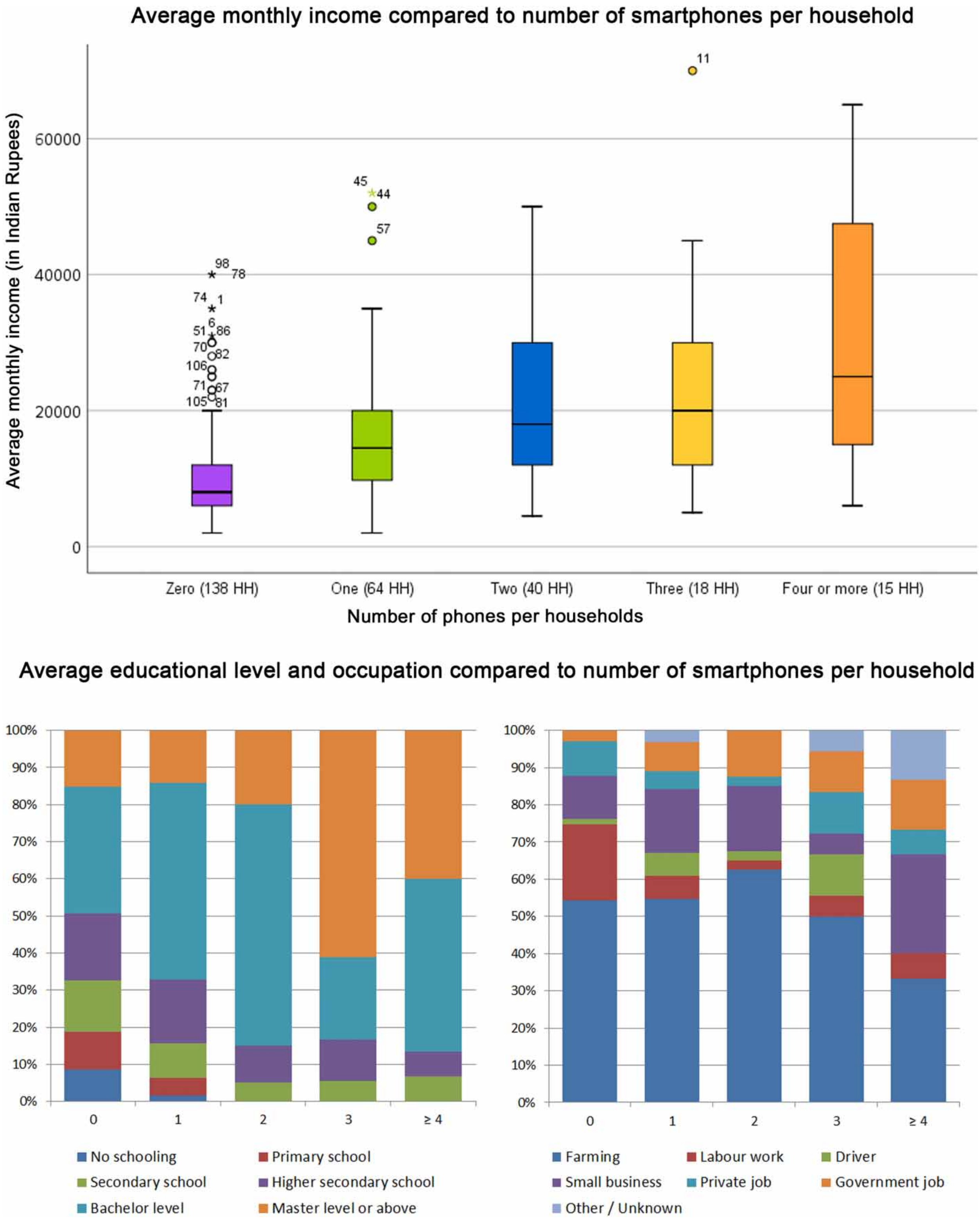


**Figure 3** | Comparison of socio-economic factors of participating households and the number of smartphones these households own, based on information from study 3 (Bihar). (Read legend from left to right and top to bottom.)

potential for the development of smartphone apps to research and monitor PWS systems, assist in operation and maintenance, and to educate end-users about water quality. Compared to the GSMA surveys, the detected smartphone ownership in Bihar is considerably higher, and in Bangladesh comparable. Thereby, the desire for smartphone ownership is high. Participants want to stay in touch with each other, and share information and photographs, especially when family members are not living together. The found internet coverage and access is much higher: 90–100% instead of the 49–53% as reported by GSMA. Smartphones are already used for online payment and when asking smartphone-owning participants about their willingness to pay their water bill by smartphone, in study 2, 85% of participants are willing to do so, and 95% of the Indian participants in study 4 like to do so. The participants find it a convenient way to pay their water bills, but are not always sure if they are able to pay through their smartphone. In addition, when asking the smartphone-owning participants in study 4 if they are interested in checking their own water quality by using a strip test in combination with their smartphone, 95% of the participants wanted to do so. When asking them about their desire to be in touch with their water supplier through their smartphone, 97% indicated wanting this. In the area of study 4, the awareness of water quality is high and that awareness combined with our presence will have influenced this interest in water quality testing, payment and smartphone interaction, but willingness is not the same as actually using smartphones in that way. However, the participants provided several arguments for their desire, which are convenience, learning and ability to take control of their own health. The rapid growth of smartphone and internet use for different purposes and the willingness of end-users to use MCP indicate good scope for using smartphones in water supply projects for various purposes. The points of attention for PWS systems (irregular supply, water safety, distrust, taste preferences, operation and maintenance issues, costs) can be used as input for developing app functionalities and water supply systems that address these issues.

## CONCLUSIONS

Based on the presented findings it can be concluded that there is an enabling environment to promote SPWS systems, as 98% of the Bangladeshi participants and 82% of the Indian participants indicate wanting this system. In addition, it may also be concluded that the majority of the participants in Bangladesh and India are willing to use smartphone applications for water supply research and monitoring. In India, most participating smartphone owners would like to use a smartphone application for water quality testing, service, communication with the water supplier and/or water payment. The existing smartphone ownership and the rapid increase of smartphone ownership and usage in both areas, the desire to own a smartphone with internet connection in Bangladesh, and the availability of cheap unlimited internet access in India indicate the scope for deploying MCP in these areas.

However, before developing new water apps, more research needs to be done in respect to participants' trust in and potential usage of SPWS systems and in the water supplier/service provider, and the context-specific conditions that influence the success of SPWS implementation, operation and maintenance. We believe that MCP has the potential to increase the trust in PWS and support its uptake, but only when properly implemented and equally accessible for everyone. The amount of access different household members have to smartphones, the possible phone and internet constraints (e.g., battery, camera quality, bandwidth) and the application's functionalities, usefulness, usability and desirability for both the end-users and service providers are points of attention: easy to understand, attractive and intuitive to use for literate as well as illiterate users, and comprising functionalities desired by both the service provider as well as the end-users. For water quality testing purposes the reliability and accuracy of the test are also important aspects that need further investigation. Another point of attention is the possible exclusion of certain groups due to using a smartphone as a platform. We expect a significant rise in smartphone ownership and usage in Bihar and Bangladesh in the coming years, leading to more inclusion in respect to people's income and educational level. However, the access to smartphones for women, who are the main water collectors and users, needs a critical look. Therefore, the exact manner of using MCP as a research and monitoring tool, the functionalities to be included, and the appearance and functioning of the app, as well as data processing, data security, and the required training and education for MCP users are the next steps to explore. For now, the relevance of using MCP seems promising, not only for the GBM Delta, but possibly also for SPWS applications in other low-resource regions.

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