PLOS WATER

RESEARCH ARTICLE

Understanding household self-supply use and management using a mixed-methods approach in urban Indonesia

Franziska Genter[1]*, Gita Lestari Putri[2], Evelyn Suleeman[3], Linda Darmajanti[3], Cindy Priadi[2], Tim Foster[1], Juliet Willetts[1]

1 Institute for Sustainable Futures, University of Technology Sydney, Ultimo, NSW, Australia, **2** Department of Civil and Environmental Engineering, Universitas Indonesia, Depok, Indonesia, **3** Department of Sociology, Universitas Indonesia, Depok, Indonesia

* franziska.g.genter@student.uts.edu.au

Citation: Genter F, Putri GL, Suleeman E, Darmajanti L, Priadi C, Foster T, et al. (2023) Understanding household self-supply use and management using a mixed-methods approach in urban Indonesia. PLOS Water 2(1): e0000070. https://doi.org/10.1371/journal.pwat.0000070

Editor: Manuel Herrera, University of Cambridge, UNITED KINGDOM

Received: July 15, 2022

Accepted: December 28, 2022

Published: January 24, 2023

Data Availability Statement: Datasets for this research are available in this paper and its supplementary information files.

Funding: This study was supported by Australia's Department for Foreign Affairs and Trade (DFAT) through the Water For Women Fund (Grant WRA 1004 to TF). FG gratefully acknowledges support from the Swiss Ausbildungs-Stiftung Kanton Schwyz, Kanton St. Gallen. The funders had no role in study design, data collection and analysis,

Abstract

In urban Indonesia, 40 million people rely on groundwater self-supply, however the role of self-supply in securing household water provision remains unexplored. This study used a mixed-methods approach to understand the use and management of household self-supply in the Indonesian cities of Bekasi and Metro, where a high proportion of households rely on private wells for water supply. Self-supply was the preferred drinking water source because of its perceived safety, taste and appearance at both study sites. The most important attributes influencing choice of domestic water source were appearance, reliability and safety in Bekasi, and safety followed by convenience and reliability in Metro. Coping strategies to overcome quality and availability problems of self-supply included water treatment, switching from dug wells to deeper boreholes and the use of multiple water sources. All households reported boiling self-supplied water, however, the labor involved was tiring for some households, leading them to resort to alternative water sources. Reasons for non-use of alternative water sources such as refill water and public piped systems included a lack of trust in water quality and perceived poor taste. Regarding self-supply management, responsibilities and decision-making varied across households, but cooperation between men and women concerning workload was common. Women were mostly responsible for household water management, and men were mostly responsible for maintenance and repairs, cleanliness of the water source and financing. To support and regulate self-supply towards a safely managed water service, strategies for improvements should be considered not only at the source, but also at point-of-use, including promotion of safe household water treatment and management. Although self-supply was the main water source at these study sites, alternative sources such as refill water and public piped systems played an important role in supplementing inadequate supplies, and hence their safety and reliability should be considered when establishing support strategies.

decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Introduction

The role of self-supply in securing household water provision in many low- and middle-income countries (LMICs) is gaining recognition in the water sector. Household self-supply refers to an on-premises water supply relying on groundwater or rainwater, that is privately owned, financed and managed by individual households [1]. Self-supply has become essential for people who are beyond the reach of utility- or community managed water supplies, and for those who need to complement an inadequate public supply [2]. Self-supply has emerged in LMICs in a range of different contexts, including densely populated urban as well as remote rural settings [3, 4]. It can be found alongside municipal piped water services as well as in areas unserved by piped systems [5–9]. Despite it being heavily relied upon by households in many LMICs, self-supply is often overlooked by policy and practice.

Self-supply provides an essential contribution to meeting household water needs in many LMICs and has implications for progress towards Sustainable Development Goal (SDG) target 6.1 [4]. At current trends, the world will fall well short of SDG target 6.1, which calls for universal and equitable access to safe and affordable drinking water for all by 2030 [10]. The criteria of a safely-managed drinking water service is met when households use an improved water source that is accessible on-premises, available in sufficient quantities when needed, and free of faecal and chemical contamination [11]. Improved water supply systems are designed to protect against outside contamination, such as boreholes, protected dug wells or rainwater harvesting [11]. Self-supply has the potential to fulfil the criteria of a safely-managed water service as it is located on the premises of a user household, however self-supply services are generally unregulated and unmonitored [1, 2].

In urban Indonesia, approximately 40 million people self-supply their drinking water from groundwater sources in the form of dug wells or boreholes [4], however, poor water quality remains a prime concern. A recent study from two cities in Indonesia detected faecal contamination in 66% (n = 337) of groundwater self-supply sources, with unprotected dug wells being more frequently contaminated than boreholes [12]. Despite widespread boiling practices, *Escherichia coli* (*E.coli)* was present in 30% (n = 52) of point-of-use samples [12]. These findings highlight the importance of understanding more about how self-supply is used and managed by households.

Self-supply can be used alone, in addition to, or alternating with various other water sources. To secure drinking water provision, households often use multiple water sources to meet daily household needs [13, 14]. Global surveys often focus on the main source of drinking water in the household, therefore the reasons for household water choices are not well understood. Water source choice is influenced by seasonality [15–17]; user perceptions of water quality such as taste, odor and color [15, 18, 19]; lack of access to, intermittency of, and insufficient quantity of a primary supply [20]; and distance to and cost of higher quality water [21, 22]. The practice of supplementing improved primary source water with unimproved source water has also been reported globally [3, 14]. It is important to recognize how households choose their water supply to inform measures to improve drinking water quality and public health in contexts where self-supply is used with or without alternative water sources.

Shortcomings in public water supply often mean the responsibility for obtaining an adequate supply falls on households, highlighting the need to consider intra-household gender dynamics and distribution of workload. As a response to inadequate water supply, strategies employed by households include water treatment, storage practices and buying water form small-scale enterprises [23]. In many LMICs, the workload related to water provision falls on women due to traditional roles with women being responsible for household chores [24, 25]. Most research to date on gender dynamics and water supply has focused on community

dynamics and in particular water supply governance [26–28]. In the context of self-supply, where water sources are privately owned and located on the premises, water-related responsibilities and decision-making between household members remain unexplored.

Understanding the reliance of households on self-supply and its associated management is crucial to developing appropriate strategies to ensure safe and reliable drinking water services for households in urban Indonesia. This study aims to address this evidence gap by using qualitative research to explain quantitative data. The study seeks to understand (i) the use and non-use of self-supply water services and alternative water choices and (ii) how self-supply is managed by individual households, including intra-household gender dynamics.

Methods

Study area

The study was undertaken in Bekasi and Metro, two densely populated cities in Indonesia (Fig 1). The cities of Bekasi and Metro were selected as study sites because of the lack of access to piped water, the widespread use of self-supply and the high population density. The metropolitan city Bekasi has approximately three million inhabitants and a population density of 13,841 people/km^2 (2017), making it one of the most populous cities in Indonesia [29, 30]. It is located in West Java on the eastern border Indonesia's capital Jakarta. Bekasi city is organized into 12 districts, three of which were covered in this study. The local water supply utility of Bekasi City only serves 26.8% of the city's total population with no service to the marginal areas [31]. In 2010, 40% of the households in Bekasi City were dependent on groundwater as their main drinking water source [32]. The minimum municipal income (Upah Minimum Kabupaten/Kota) of Kota Bekasi was 4,782,935 Rp. (approximately 310 USD) in 2021 [33]. Metro city is located in the Indonesian province of Lampung on Sumatra Island with a population of 162,976 people and a population density of 2,371 people/km^2 (2018). Metro is an urban settlement and is organized into five districts, namely Metro Barat (West), Pusat (Central), Selatan (South), Timur (East) and Utara (North). In 2018, only 1.3% of Metro's population (2,134 households) were connected to the piped municipal water system, with most customers from the district of Metro Pusat (1032 customers) and Metro Timur (920 customers). No communities used water from Indonesian's water supply company in the district of Metro Utara [34]. The minimum municipal income (Upah Minimum Kabupaten/Kota) of Kota Metro was 2,433,381 Rp. (approximately 158 USD) in 2021 [35].

Study design

An explanatory sequential mixed methods approach comprising a quantitative component followed by qualitative component [36] was used to understand the use and management of self-supply in relation to alternative water sources. The quantitative approach focused on a descriptive assessment of a cross-sectional household survey providing generalizable insights into the use and management of self-supply. The qualitative approach included in-depth interviews, providing detailed and contextualized explanatory insights.

Data collection

The data collection was carried out during wet season in Bekasi (February-March 2020) and during dry season in Metro (October-November 2020). Data for the quantitative approach were collected from 300 randomly selected households in both Bekasi and Metro. Participating households were randomly selected across three sub-districts *(Keluraham)* (Jatiluhur, Sumur Batu and Jatirangga) from three different districts (*Kecamatan*) in Bekasi (Jatiasih, Bantar

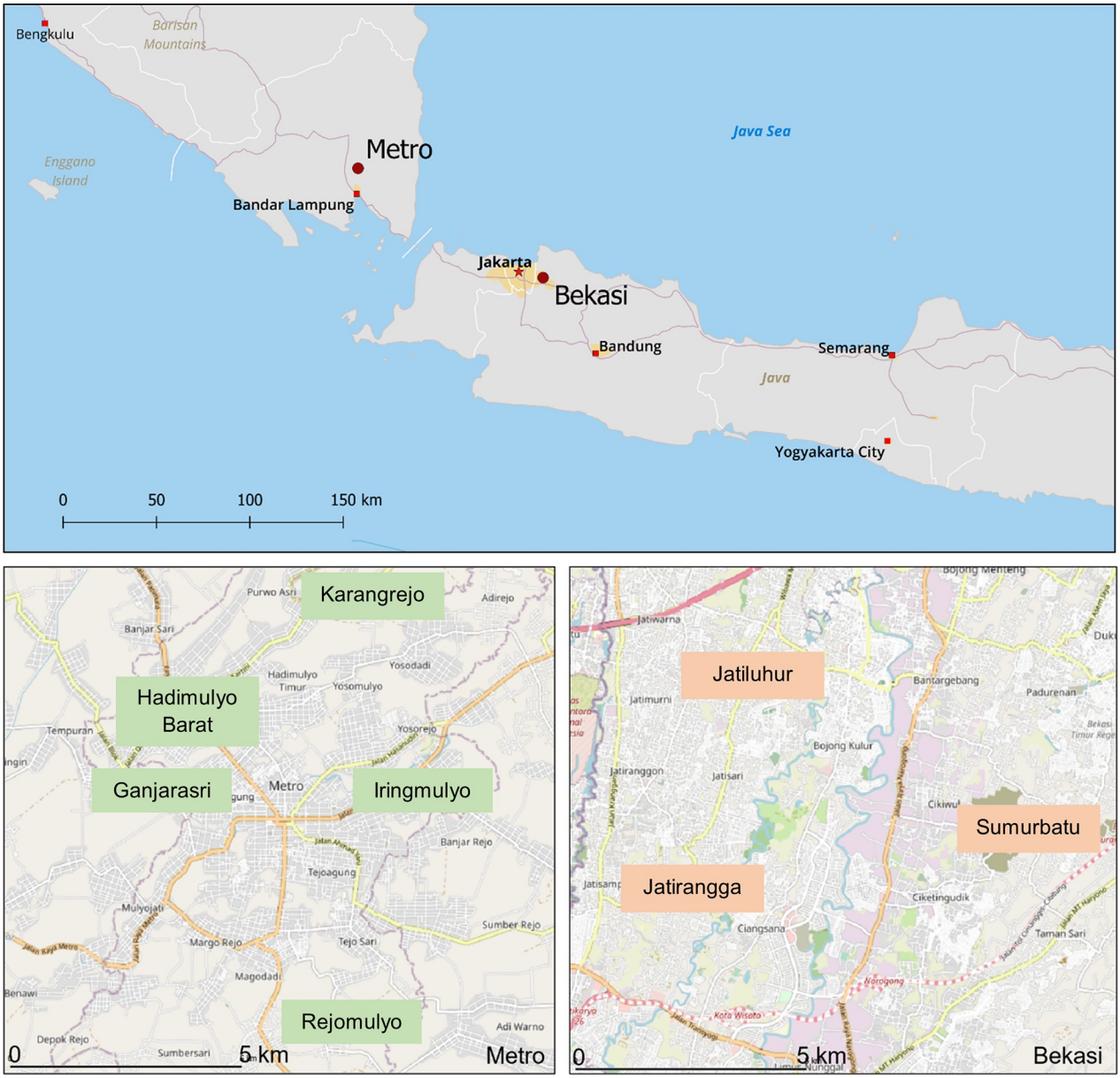

Fig 1. Study sites in Metro (Karangrejo, Hadimulyo Barat, Ganjarasri, Iringmulyo, Rejomulyo) and Bekasi (Jatiluhur, Sumur Batu, Jatirangga) (QGIS, version 3.28.1).

https://doi.org/10.1371/journal.pwat.0000070.g001

Gebang, Jatisampurna), and across five sub-districts (Karangrejo, Hadimulyo Barat, Ganjarasri, Iringmulyo and Rejomulyo) from the five different districts in Metro. Districts and sub-districts were selected purposively based on self-supply prevalence, population density, lack of access to piped water and poverty status, with information obtained from secondary data and local government. In consultation with the heads of the selected sub-districts, the selection of the hamlets (*RW Rukun Warga*) consisting of several neighbourhoods (*RT Rukun Tetangga*) was made. The neighbourhoods to be surveyed were chosen after further consultations with the respective head of the selected hamlets. Households of the selected neighbourhoods were randomly selected using Microsoft Office Excel 2016. Each neighbourhood's target number of households to be surveyed was determined in proportion to its population size.

Data collection included a household survey, sanitary inspection of self-supply sources and water quality testing. For this study, data from the household survey were used. Data on sanitary inspection and water quality are reported elsewhere [12]. Following the household survey, 24 in-depth interviews were carried out by phone (due to covid-19) from 12 purposively selected households in Bekasi (December 2020) and Metro (August 2021 and November 2021-January 2022), respectively. Prior to the data collection, informed consent was obtained in local language from heads of neighbourhoods and from all participants. Ethical approval to conduct the research was provided by the Research Ethics Committee of University of Technology Sydney as well as the Universitas Indonesia. Additional information regarding the ethical, cultural, and scientific considerations specific to inclusivity in global research is included in S2 Text. The data collection in Metro was affected by Covid-19 delays. The timing of data collection in Metro was based on the Covid-19 risk status determined by the national government. The survey was not conducted if the risk status was greater than level two of four. The decision to conduct the survey was made in consultation with all stakeholders in each district, including stakeholders from sub-districts, hamlets and neighbourhoods. During the survey, safety procedures were followed and the health of the research team and participants was paramount.

Quantitative approach. A structured household survey was conducted in local language by trained enumerators using Survey Solutions software (version 20.01, The World Bank, Washington DC, USA) in Bekasi and Qualtrics software (Qualtrics, Provo, UT, USA) in Metro (Tables K and L in S1 Text). The household survey covered a range of themes about the household, water sources used and perceptions of water service attributes. Questions about the household included themes on health and socio-economic status, water management and decision-making. Self-supply water sources were defined as groundwater sources (boreholes, protected dug wells or unprotected dug wells) that were privately owned by a household. Questions on water source usage considered alternative water sources such as public water services, neighbor's water supplies and packaged water (bottled water, refill water) and differentiated between wet and dry season. Questions on water perception included a ranking of attributes that influence households' water choices and reasons for the use and non-use of different water services. Descriptive analysis was performed in Microsoft Office Excel 2016 and statistical analysis software R (version 1.2.5001, R Foundation for Statistical Computing, Vienna, Austria). R package "DescTools" was used to calculate proportions and corresponding confidence intervals (CI). CIs for binominal proportions were calculated using the "BinomCI" function based on the Clopper-Pearson method, while CIs for multinominal proportions were calculated using the "MultinomCI" function based on the Sisonglaz method. Explanations of the various water sources used can be found in the supplementary material (Table A in S1 Text).

Qualitative approach. Following descriptive analysis of the household survey, a question guide for in-depth interviews was prepared covering themes on water choice, perception, management and decision-making. Household selection for the 24 in-depth interviews was carried out on a purposive basis to cover a range of household characteristics. The households were selected based on a sampling strategy to maximize the diversity relevant to the research question. Considered characteristics for household selection included gender of the head of household, gender of responsible person/s for water related tasks, gender of responsible person/s for decision-making processes, shared or single responsibility and decision-making, household wealth, marital status, and disability. Use of a self-supply source and ownership of a mobile phone were pre-requisites for selection. Information on household characteristics was obtained from analysis of the questions from the household survey. For the characteristics of the purposive selected households for the in-depth interviews, see the supplementary material

(Tables B and C in S1 Text). Households were listed and categorized based on the gender of the head of household (female/male) and the wealth of household (poor/middle/non-poor). The categorization of the household wealth was conducted based on the tertiles of the calculated wealth index of households. The wealth index was constructed for households in Bekasi and Metro using the same approach as the 2017 Indonesian Demographic and Health Survey (DHS) based on the relevant indicators and corresponding values [37]. Information on 23 relevant indicators such as household asset ownership, dwelling structure, type of cooking fuel and household composition were collected in the structured household survey. For each study site, a priority list including 12 households was created, taking into account shared or sole (female/male) responsibility for water related tasks and decision-making processes in a way that increases diversity. We also determined the responsibility for water related tasks was shared or assumed by a sole female or male household member from the results of the four household survey questions on water related tasks (Table K in S1 Text, questions 59–62 for Bekasi, Table L in S1 Text, questions 38–42 for Metro). Households where the respondent was the head of household were prioritized. If a mobile phone number was not available, households were exchanged with households from the backup list with similar characteristics. In-depth interviews were conducted by phone in local language and responses were recorded, transcribed and translated into English. The transcribed information was coded manually in Microsoft Office Word and Excel 2016 using a deductive approach to capture the relevant themes on self-supply water quality (risks, mitigation strategies, perceptions), water availability, water choices (reasons for non-use, perception of alternative water sources), workload (roles, responsibilities, decision-making) and conflicts.

Results

The result section draws on both quantitative and qualitative data organized in the following way. The first sub-section on water choice and perceptions includes only quantitative findings and provides an overview of the use of multiple water sources. Subsequent sub-sections are organized by water source types (private dug wells, private boreholes, public water services and packaged water) and cover information on use, water quality, water availability and reason for non-use. These sections begin with quantitative data from the household survey, if available, and are complemented by qualitative findings from the in-depth interview. The last two sub-sections in the result sections include quantitative and qualitative findings on attributes of water perception and self-supply management with regard to responsibilities, workload and decision-making.

Water choice and perceptions

Based on the household survey, households predominantly used self-supply as their main water source for drinking and domestic uses at both study sites. Regarding the main drinking water source, 48% of households (n = 144) were relying on private boreholes in Bekasi, and 47% households on private dug wells (n = 138) in Metro (Table 1). Another common drinking water source was refill water, with 21% of households reported to use refill water as their main drinking water source in Bekasi (n = 63) and Metro (n = 61). Public water service, including water from public boreholes, dug wells, piped systems and taps, was used by 12% (n = 35) and 8% (n = 22) of households as a main drinking water source in Bekasi and Metro, respectively. At the study sites, water for domestic purposes was obtained from private boreholes by 72% of households (n = 217) in Bekasi and from private dug wells by 65% of households (n = 191) in Metro mainly (Table 1). Besides self-supply, public water services, including water from public boreholes, dug wells, piped systems and taps, were used as a main source of water for domestic

Table 1. Proportion of main sources for drinking and domestic uses in Bekasi and Metro.

	Main drinking water source						Main domestic water source					
	Bekasi			Metro			Bekasi			Metro		
	n	[%]	95% CI [%]	n	[%]	95% CI [%]	n	[%]	95% CI [%]	n	[%]	95% CI [%]
Private borehole	144	48.0	42.3–53.8	39	13.3	7.8–19.4	217	72.3	67.7–77.6	61	20.7	15.6–26.4
Private dug well	18	6.0	0.3–11.8	138	46.9	41.5–53.0	17	5.7	1.0–10.9	191	65.0	59.9–70.6
Neighbor's borehole	2	0.7	0.0–6.5	8	2.7	0.0–8.8	2	0.7	0.0–5.9	8	2.7	0.0–8.4
Neighbor's dug well	0	0.0	0.0–5.8	8	2.7	0.0–8.8	0	0.0	0.0–5.2	8	2.7	0.0–8.4
Refill water	63	21.0	15.3–26.8	61	20.7	15.3–26.8	3	1.0	0.0–6.2	0	0.0	0.0–5.7
Bottled water	38	12.7	7.0–18.5	18	6.1	0.7–12.2	1	0.3	0.0–5.6	0	0.0	0.0–5.7
Public water service	35	11.7	6.0–17.5	22	7.5	2.0–13.6	60	20.0	15.3–25.2	26	8.8	3.7–14.5
Total	300	100.0		294	100.0		300	100.0		294	100.0	

https://doi.org/10.1371/journal.pwat.0000070.t001

purposes by 20% of households (n = 60) in Bekasi and 9% (n = 26) in Metro. Disaggregating the different domestic uses, self-supply was the most common source of water for all domestic uses such as cooking, making tea, washing and watering garden and animals, with private boreholes predominantly used in Bekasi and private dug wells in Metro (Figs A and B in S1 Text). Water uses were comparable in the rainy and dry seasons at both study sites (Figs C and D in S1 Text).

Private dug well. *Use*. Private dug wells were primarily used as a water source for drinking and domestic purposes in Metro, but were also used by a few households in Bekasi. Descriptive analysis from the household survey showed that water from private dug wells was used as a main source for drinking (Bekasi: 6%, n = 18, Metro: 47%, n = 138) and domestic purposes (Bekasi: 6%, n = 17, Metro: 65%, n = 191) at both study sites, but particularly in Metro (Table 1). Of the 24 in-depth interviewed households in Bekasi and Metro, 21 owned or had owned in the past a private dug well. Of those, 12 households still used the water from dug wells for drinking and/or domestic purposes. Among these 12 households, the water from the dug wells was used by ten in-depth interview informants for drinking and by ten for domestic uses such as washing clothes, showering and cooking. Ten households had subsequently replaced the dug well with a borehole (Table D in S1 Text).

Water quality. Water quality perceptions for dug wells were mixed and water treatment was common. Half of the in-depth interview informants perceived the water quality of dug wells as good, as one informant said "*The water from the dug well is safe to drink, [it is] clear and tastes good and fresh*". However, the other half reported water quality concerns such as cloudy or turbid water. One informant constructed a borehole because the water quality of his dug well had decreased "*In the past we used a dug well but now it leaks, the water cannot be used, the water is black like sewage water*." If the self-supplied water was used for drinking, informants reported boiling it before consumption to avoid health issues. "*My child said, if the water is not boiled, the stomach bloats. When the water is boiled, [it is] sweet*." One informant in Metro observed turbid water during the rainy season and let the mud settle before boiling, "*If it rains, the well water for cooking and drinking is deposited in a container overnight. In the morning, we take water with a scoop, then we boil it*".

Water availability. The perception of water availability was mixed, with poor availability reported during the dry season, resulting in dug wells being replaced or deepened. Descriptive analysis from the household survey showed that in Metro, 32% (n = 18) of the surveyed dug well owners had to deepen the dug well at least once. Also in Bekasi, where boreholes were prevalent, the well/borehole and/or pump setting was deepened by 13% (n = 33) and 10% (n = 25) of the surveyed households, respectively (Table E in S1 Text). The well/borehole had

gone dry in the past 12 months for 30.4% (n = 7) of the 23 responding households in Bekasi, and in 18.6% (n = 11) of the 59 responding households in Metro (Table J in S1 Text). Half the in-depth interview informants were not satisfied with the water availability of dug wells and explained that dug wells were often deepened or replaced with a borehole, since dug wells dry out during dry season. For example, one informant in Metro described it as follows "*In the dry season, water from the well is like a kid peeing*". Another informant in Metro had to deepen the dug well several times, as he said: *"[The] first [deepening] was 4m due to drought, [after another] deepening, the water came out [and] it was clear. Again drought [came], [so the dug well was] deepened again to 6m [depth], again drought, again deepened 2m, it [the water] was clear. Now the water is in a constant high flow, but the color has changed [no longer clear]*."

Reasons for non-use. Reasons for the non-use of dug wells were connected to the amount of work involved, the large space required, unsatisfactory water quality and availability and lack of protection for children. Dug wells were often used with a bucket and rope or hand pump, which was associated with a higher workload than using a borehole with a motorized pump. One informant explained *"The dug well was often dry. Draw water was tiring, [so we] replaced the dug well with a borehole and a Sanyo pump [Sanyo: Brand of a motorized water pump]. The Sanyo pump is more practical, [since it] doesn't need human power*." Compared to bottled or refill water, water from dug wells needed to be boiled before consumption, which was also associated with a higher workload. Eight informants elected not to use their dug wells because of the workload, as one widow explained: *"[In the past], when [I was] still strong, [I] looked for wood to boil [the water]. The wood was abundant. Now [I am] no longer strong enough to boil water, so [I] buy water in gallons*." Descriptive results from the household survey on the fuel used for boiling water showed that liquified petroleum gas (LPG) was the most common fuel for water boiling in Bekasi (96%, n = 288) and Metro (96%, n = 287), however wood was still used by 28.1% (n = 84) in Metro (Table F in S1 Text). Another informant who owned a dug well instead used refill water for drinking, since well water used for drinking needed to be boiled and it was turbid during rainy season: *"[Usually] I'm too lazy to boil the water. [But] when I boil [the water], [I] usually let it [the water] stand first to let the dirt settle to the bottom of the container."* Dug wells were also perceived by two informants as being unsafe for children: "*Dug wells can be worrying because there are many children who could fall into the well*." A further reason for the replacement included that dug wells required larger land area than boreholes: "*Dug wells are no longer used because they require more open land and are not safe for small children*."

Private borehole. *Use*. Private boreholes were mostly used as a water source for drinking and domestic purposes in Bekasi, but were also frequently used in Metro. Descriptive analysis from the household survey showed that water from private boreholes was used for drinking (Bekasi: 48%, n = 144, Metro: 13%, n = 39) and domestic purposes (Bekasi: 72%, n = 217, Metro: 21%, n = 61) at both study sites, but particularly in Bekasi (Table 1). Of the 24 households participating in the in-depth interviews in Bekasi and Metro, 12 households owned a private borehole. Of those, 11 households used it for drinking and 10 for domestic purposes. Informants also reported that borehole water was an important source of water not only for drinking, but also for daily needs: *"Borehole water is used quite a lot for washing clothes [and] watering plants. For daily needs [it is] collected in a large tub."* In the past, households often used dug wells, which have been replaced by a borehole with a motorized pump, as one respondent explained: *"It is more practical, [I] don't need to draw water, the water flows out directly from the tap."*

Water quality. The quality of water from private boreholes was mostly perceived as good though water was still commonly boiled. A deterioration of water quality was, however, perceived during rainy season. Two-thirds of the interviewed households perceived water quality

from boreholes as clear and good, as for example one respondent said "*The dug well is not closed, but the well that is being used is a borehole. The borehole is equipped with a Sanyo pump. The water from the borehole is good, the water is clear.*" One respondent mentioned the importance of using clean water for the religious purification ritual and linked this use with safety for drinking, *"The important thing is that the water has no odor. If the pure water can be used for wudhu [ritual purity for Muslim], it is drinkable."*

All interviewed households reported boiling the water from boreholes before drinking and a few respondents linked the boiling of water to potential health concerns. *"[When] the water is boiled, [it] does not make you feel sick to the stomach."* A difference between boiled and non-boiled borehole water was also perceived by another informant, as he mentioned *"the children said that the non-boiled water spoils the stomach."*

However, three interviewed households perceived an increased risk of water contamination compared to the past, as one informant noted: "*The water is good, [it is] safe to drink, but when [it is] raining there is white colored dirt. Back then, when [we were] using [a] dug well with a bucket, there was no white [colored dirt], the water remained clear.*" Another informant linked the contamination directly to a potential source: *"After the landfill exists, the water from the drilled well is getting oily."*

Some potential risks for water quality deterioration were mentioned during the interviews. If asked whether the motorized Sanyo pump is submerged in runoff during rainfall, one respondent replied: *"Yes the Sanyo is soaked. There is a roof as cover for the pump."* Further, a few respondents indirectly indicated a potential issue of bacteria growth in pipes from boreholes, as one respondent explained, *"The tube is cleaned once a week. It becomes slimy after a while. There is moss inside the tube. I saw it myself, when I saw the water from Sanyo, it was slimy on the inside of the tube, sometimes it is cleaned. [I am] afraid that the moss will get thicker the longer it goes. [I am] afraid that the tube will get clogged. Then it becomes more work."*

Water availability. Results from the household survey suggested self-supply provides a relatively reliable service, but the in-depth interviews revealed water scarcity problems during the dry season, and therefore households often shifted from shallow dug wells to deeper boreholes. In the household survey, 97.2% (n = 176) and 97.0% (n = 258) households reported to have water available the past two weeks in Bekasi and Metro, respectively (Table I in S1 Text). However, ten in-depth interviewed households had replaced the dug wells with boreholes, partly for the reason to improve the water availability. An informant from Bekasi explained, that people in Bekasi use boreholes, because the water is better and more reliable. In Metro, availability of water was noted to improve when a dug well was replaced with a deeper borehole: *"Initially, [I] used a dug well [with a rope and bucket]. But when it is dry, there is often no water. So I started using a borehole (35 m) three to four years ago. The dug well is about 10m deep, and if the well is dug again, it will collapse, so I don't dare [to deepen the dug well]."* Three in-depth informants reported that even with boreholes, water shortages were still experienced during dry season, *"[Water from the] borehole is decreasing during the dry season for at least one month. It [the location of the borehole] has been moved three times. [Previously, when it was] next to the house bedroom, it was equipped with a hand pump. Now the borehole is located at the house yard.*" or "*Last dry season, the water from the well decreased and one had to wait a while for water to come out after turning on the Sanyo pump. The Sanyo pump was lowered once*".

To counteract availability issues and to save time, some households stored the collected water from boreholes. One respondent with a 100 liter storage container explained: "*So, it won't take long. After it is used for washing, showering, there is still some left. If the lights go out [no electricity], the remaining water can still be used.*" Another household reported to store the water after boiling, as he said "*Drinking water after being boiled is collected in a bucket with a volume of 30 liters for about 5 days.*"

Reasons for non-use. Private boreholes were a preferred source of drinking water for most households in Bekasi, however boiling water can be tiring and households typically used multiple water sources for different purposes. One main reason for the switch to refill water for drinking was linked to the hassle of boiling the borehole water, as for private dug wells. "*For drinking, the process is long. [The water] must be boiled first. Sometimes turning on the stove first. So that is quite something.*" One informant even reported a deterioration in water quality due to boiling using firewood, as he said, "*Every week I boil two gallons of water and store the boiled water in the clean gallon. [I] put it first in the pan and then pour it into the gallon. The special characteristic of the boiled water is smoky, because it is boiled using firewood."* Households used multiple water sources for different purposes, as one informant said, "*For drinking, it is refill water. But when it comes to making tea, it is borehole water. And that is not much, one teapot at most.*" Even if informants used borehole water, alternative sources provided a useful back-up option, as one informant proposed: *"Maybe we can use both, the water from the artesian well and [the water] from the borehole. For backup, one could say. If the water from my borehole fails, that means the water from the artesian well is available, right."* One respondent mentioned the possibility to get access to clean borehole water from mosques, *"If they don't have a well, it will be difficult. Sometimes, they also go to the mosque. There is government aid [subsidies] for [drilling] boreholes [in mosques]. Take the water from there. If it is in the mosque, it is free. And mosques can get a discount from PLN [State Electricity Company]."*

Another reason for the non-use of private boreholes was the high cost of construction. In the household survey, 24.0% (n = 12) of respondents in Bekasi and 39.4% (n = 13) of respondents in Metro reported high construction costs as a reason for not using private boreholes (Table G in S1 Text). In the in-depth interviews, one dug well owner in Metro stated the cost of seven million rupiah (approximately 460 USD) as a reason for not using a private borehole. Another respondent in Metro, when asked why he did not use a borehole, replied, *"Yes, later. I am waiting for the [money] transfer"*.

One informant expressed his concern regarding the increasing use of boreholes: *"If everyone uses boreholes, it would be a pity for the one without. So it can be dry, left and right. I think there needs to be a regulation. Except, if the neighbor doesn't have any water, he gives it, it is okay maybe, there is a solution. Now if they are using boreholes, maybe it is just for them, right? Left and right neighbors can't get water, it is a pity thing."*

Public water services. *Use*. A few households used public piped systems as a water source to supplement self-supply for domestic purposes, but most households did not have access to public piped systems. Descriptive analysis from the household survey showed that public water services, including public boreholes, dug wells, piped systems and taps, were commonly used as a main source of water for domestic purposes (Bekasi: 20%, n = 60, Metro: 9%, n = 26). However, 75% (n = 224) and 36% (n = 101) households reported that public piped service does not supply water to this area in Bekasi and Metro, respectively (Table G in S1 Text). Of the interviewed households, 13 did not have access to public piped services fed either from surface water or groundwater from artesian aquifers. Eight households used water from public piped water supplies. The water was not used for cooking or drinking, but as an additional source of water to supplement and backup self-supply for daily needs only, such as washing or watering plants. "*Given piped water is okay for flushing, for washing motorbikes, for washing bicycles."*

One informant in Metro who was offered access to the piped network in front of his house did not use it and described the situation as follows: "*Why should I use piped water? Well water is enough, there is no shortage. If you use public piped water, you will spend more money. The water from public piped water should be boiled, which means more work. Neighbors who use the public piped service may experience shortage during the dry season. [. . .] Then the water quality is also bad. It can be black, and sometimes it smells. So people don't use it for cooking. Usually they use it for watering flowers. That is all people say. I don't use piped water anyway.*

Water quality. Water quality of public piped water supplies was perceived negatively by households that had access and households that did not have access. *"That is public piped water. The water is likely black-colored. If it is clear, it is clear, sometimes it is really black. In the rainy season, it is cloudy, it is black."* Another informant who did not have access said *"The informants are not interested in public water services from artesian wells because the quality is not good. Public water service, it is lacking, the water is bad. Lots of sand."* Therefore, the water was generally not used for drinking or cooking, as one informant said: *"Water is just for washing. For cooking or drinking, it is not quite suitable."* Also the smell of chlorine was unfavourable for consumers, as a respondent explained: *"Everyone here has public pipes installed, but the water is bad. The water is a little cloudy. Second, the smell of chlorine. So not all of us use public water services. So, in the end it stopped. In 1995–1996 there was no public water service."*

One informant who used the public supply which was connected to his sibling's house was happy with the quality, as he said *"Same taste, same clearness, but not every day [the water flow] is smooth"*. He did not have to pay and saw the connection as beneficial. *"There are many benefits, saving a lot of electricity. Sometimes [I] wash [e.g. laundry, not showering] using water from public water services."*, he said.

Water availability. Problems were identified with public piped water supply in terms of access, reliability and availability of water. Many households still did not have access to a piped water service, and some were not even aware of this as a water supply option, with an informant replying: "*There isn't one. It is in the village, not in the city*." Public piped water did not reach all households equally; therefore, not all households could get access to pipe connections, as for example one informant said *"My house is far from the road, so I can't get a pipe from the government or urban village. My house is inside, so the connections are far away"*. Another respondent from the same district mentioned the same issue "*The pipe network is unevenly distributed. Here too. There is no pipe. The artesian pipes are mainly located only next to the main road. It is said that it will be installed gradually, per community association (RT–rukun tetangga). It is said that the pipe network installation for my community association will be done later. But after some time, it is not installed yet. But it is alright."*

A decrease in the water availability was also perceived from public piped services based on groundwater, "*In the dry season, water from artesian wells also decreases, so the distribution must be in shifts."* Public water service is also not always reliable, as one informant said "*Water from public water services does not always flow, the benefit is saving electricity usage*." Another informant mentioned that the public piped supply was broken since a long time. *"Previously there was piped water from the landfill artesian well [artesian well was constructed as the compensation of the new landfill], but it had been damaged for a long time by a neighbor's children. Water from the artesian well was used only for washing, not for drinking."*

Reasons for non-use. Most households did not have the possibility to connect to public piped services because they were not available in these regions (Table G in S1 Text). However, if available, public piped services were generally not used due to several reasons such as lack of trust, lack of reliability, perceived bad smell of chlorine, costs, and the preference for self-supply water. Descriptive results from the household survey showed that most households would not connect if public services were to expand infrastructure to their area (Bekasi: Definitely not n = 108, 38%; Metro: Unlikely n = 132, 52%) (Table H in S1 Text).

A major reason for not using piped water was the general preference of groundwater self-supply. Three respondents associated the preference for private supply over public supply with the taste of chlorine, *"Well water is better because if water is from public piped service, there is a taste of chlorine, maybe we are not used to chlorine. The well water has no [chlorine taste]. It is pure."* Respondents connect the taste of chlorine with medicine, *"It tastes different, smells like medicine. What smell, I don't know. It does not smell good."* One respondent mentioned a

preference for groundwater supplied from public boreholes owned by mosques compared to the chlorinated public piped water because of the chlorine taste *"Once, I opened it [public piped service], the water was not good. Maybe too much chlorine. Medicine [refers to chlorine] is added to the public piped water, right? This morning, I took the water at the mosque because I avoided the chlorine. We are not used to the smell of chlorine. Water from the mosque is good, [it is] from boreholes, a support from the mosque. The borehole is a government aid. I only take two gallons to boil drinking water. However for washing clothes and showering, we use water from the dug well."*

Public services were also not perceived as reliable sources of water for some households, as one informant said *"People who get artesian piped water also have [private] wells, because artesian water doesn't always flow every day, it just flows at midnight. What is the point if the water only flows at night."*

Respondents did not want to pay for bad public services, if they already had access from self-supply. *"If I had to pay, I would change my mind. Roughly speaking, only for daily needs we made the effort [and] dug [the well]. For Sanyo water [from private borehole], we do not need to pay for as much as we use."* However, if water from public supply were reliable, people would also be willing to connect, as one informant said "*I also want to pay as long as the water is good and abundant, proportional to the usage. It is natural if we use it [public piped water]. The [use of the] public piped water is the recommendation of the government."*

Packaged water. *Use*. Packaged water was frequently used as a drinking water supplement for self-supply. Refill water and branded bottled water were commonly used as a main drinking water source by households in Bekasi (21%, n = 63) and Metro (21%, n = 61). Of the 24 interviewed households, six households mentioned drinking refill water and seven bottled branded water. Many households used refill water as a backup for self-supply, as one informant explained *"[I] buy gallon water—refill water—when there is no more water."*

Packaged water was considered as practical and hassle-free, since it did not need to be boiled. *"The refill water [is practical] if you want to have an event, any gathering, just buy refilled water. Let it be easy, let it be practical, that's it. The drinking water for families is still boiled water."* Thus, informants also drank bottled water if they got invited *"when I go to a wedding invitation, I drink bottled water. Therefore, I know that bottled water is tasteless."* It was also consumed if household members did not wish to go to the effort of boiling water. *"[I am] already not strong enough to boil water, so [I] buy gallon water, [it costs] 5000 rupiah."*

Water quality. Water quality of bottled branded water was perceived as good, while some respondents believed refill water led to health issues. Water quality of bottled branded water was perceived as good by seven of eight in-depth informants. However, 11 of 14 informants perceived the water quality of refill water as poor. Refill water consumers needed to get used to the taste, as one informant elaborated *"According to my tongue, the taste is different. I'm more confident with boiled water, out of habit, maybe. Habit from childhood."* However, other respondents might already be used to the taste. *"The taste of gallon water and well water is the same."* Many refill water consumers reported health issues and feeling bloated after drinking it, as one informant said: *"Before, I wasn't used to it, I had a bloated stomach. Now I'm used to it [and my stomach is] no longer bloated."*

Reasons for non-use. Generally, the self-supply water source was preferred, which was often because of the taste. *"I have never bought it. . . it tastes better when I boil it myself. . ."* or *"My water source is already good and clear. I don't want to use refill water. I tried refill water, it is the same. But I and my children feel that refill water is tasteless. It is better to use my own source."*

Other informants had no trust in refill water and experience health issues, as one informant elaborated, *"[There are] many fake branded bottled water, [I] had a stomachache. [I] experienced it myself when I went to Cirebon by bus [and] bought [a water bottle] from a street vendor,*

many were fake. The water was a bit cloudy and the taste was different. The branded bottled water has a hint of sweetness". Also in the household survey, 29% (n = 57) and 38% (n = 81) of households reported as a main reason for the non-use that refill water is unsafe to drink.

Reasons for non-use were also the costs, with packaged branded water having higher costs than refill water. "*Refill water is 7 thousand rupiah. Branded bottled water is more expensive, 17 thousand rupiah. People say branded bottled water is good. My child also likes boiled water."* Even if refill water was seen as more practical, it could not always be used because of the cost, as one informant explained, *"Refill water is more practical. After eating, [I] don't have to bother boiling water or looking for a water container. There is refill water available, then it is okay. But if there is no money at all, then [I] have to boil water, just one teapot"*.

Attributes of water perception

Descriptive analysis from the household survey indicated that safety was the most important attribute for drinking water choice, followed by taste and appearance at both study sites (Table 2). The most important attribute for domestic water choice was appearance, followed by reliability and safety in Bekasi, and safety followed by convenience and reliability in Metro (Table 2).

Descriptive results from the household survey were in agreement with the qualitative results from the in-depth interviews. Households perceived water as safe, if the consumption was not related to disease or pain, as one informant said, *"The currently used water is safe, in the sense that it does not cause pain."* Another informant mentioned taste and appearance as important attributes of safe water, *"Safe water is like gallon water, clear, tasty, cool, fresh."* That taste is considered more important than appearance when choosing drinking water was also noted by a statement of a dug well owner in Metro, who said "*I'm just afraid, the color isn't very clear, that is how it is. But [the water from the dug well is] still used for drinking because it doesn't smell*."

Self-supply management

Responsibility, workload and decision-making. Water management tasks of self-supply services were usually distributed between female and male household members. Based on the descriptive results of the household survey, female household members were mostly responsible for managing water in home, while male household members were mostly responsible for maintenance and repairs, cleanliness of source and finance at both study sites (Fig 2). Approximately two-thirds of the surveyed households shared the responsibility of self-supply tasks

Table 2. Most important attributes for drinking and domestic water choice in Bekasi and Metro.

	Most important attribute for drinking water choice						Most important attribute for domestic water choice					
	Bekasi			Metro			Bekasi			Metro		
	n	[%]	95% CI [%]	n	[%]	95% CI [%]	n	[%]	95% CI [%]	n	[%]	95% CI [%]
Safety	125	41.7	36.0–47.6	116	38.8	33.1–44.8	61	20.4	14.7–26.4	84	28.2	19.0–29.4
Taste	68	22.7	17.0–28.6	85	28.4	22.7–34.4	11	3.7	0.0–9.7	85	28.5	19.3–29.7
Appearance	48	16.0	10.3–21.9	31	10.4	4.7–16.3	89	29.8	24.1–35.8	32	10.7	4.0–14.5
Reliability	24	8.0	2.3–13.9	16	5.4	0.0–11.3	84	28.1	22.4–34.1	46	15.4	8.0–18.5
Affordability	9	3.0	0.0–8.9	12	4.0	0.0–10.0	9	3.0	0.0–9.0	16	5.4	0.0–9.9
Convenience	15	5.0	0.0–10.9	15	5.0	0.0–11.0	30	10.0	4.3–16.0	65	21.8	13.5–24.0
Smell	11	3.7	0.0–9.6	24	8.0	2.3–14.0	15	5.0	0.0–11.0	20	6.7	0.6–11.0
Total	300	100.0		299	100.0		299	100.0		298	100.0	

https://doi.org/10.1371/journal.pwat.0000070.t002

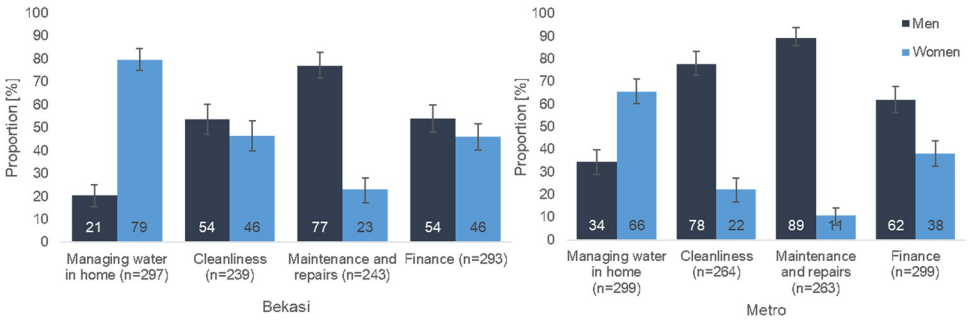

Fig 2. Responsibilities of self-supply tasks based on gender in Bekasi and Metro.

https://doi.org/10.1371/journal.pwat.0000070.g002

between household members at both study sites (Fig 3). In one-third of the surveyed households in Bekasi, either only one male household member or one female household member was responsible for all the tasks. In Metro, it was more common for male household members to be solely responsible for all the tasks than female household members. Decisions related to self-supply were usually made jointly or were solely the responsibility of a man. In nearly half of the surveyed households in Bekasi, solely a man decided to invest in the construction of a dug well or borehole (Fig 3). In approximately 12% of the surveyed households, a woman solely decided to invest and in 24%, the decision was shared between different household members. In Metro, the decision-making was mostly joint by 67% of the households surveyed. In 25% of households, a man was the sole decision-maker, while in 8% of households a woman was the sole decision-maker.

Household members usually cooperated on responsibilities and workload of self-supply services. One male informant explained, *"I handle all the tools [tools to repair the well]. I'm the one who bought the Sanyo, installed it and turned it on. The boiling is the part of the wife. If there is any damage [of the well], it is my part [to repair it]. Yes, [it is] team work."* Responsibilities were typically distributed such that the wife was responsible for managing the water in the home, while the husband took the lead in maintenance and repairs, cleanliness of the source, and

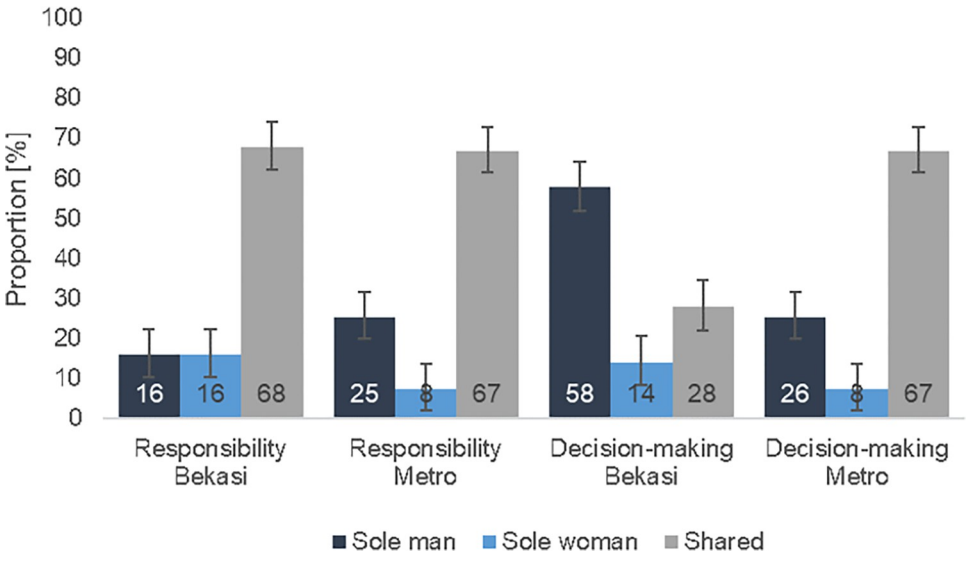

Fig 3. Distribution of self-supply responsibilities and decision-making by gender.

https://doi.org/10.1371/journal.pwat.0000070.g003

finance. One woman in Metro reported that when her husband was still alive, he never boiled water to drink and that mostly women take care of the housework. "*It is all me. My husband was just making money. My husband only helped sweeping the floor and not cooking. Cooking is women's thing. Housework is women's thing. The husband only helped cleaning the house, when he was not working. If there were no activities, [the husband] helped in the house, cleaning up. However, I think a lot of women take care of the house."* Also specific tasks were shared amongst household members, as for example one wife told that she and her husband shared the responsibility to clean the bathtub. "*If I see a dirty bathtub then I clean it. We always take turns to do it."* Broken pumps were usually repaired by external mechanics, as one woman told, "*Since I have lived [here], the pump has broken once. [I] called someone to fix it* ". Also a male informant from Metro told: "*Boiling water is done together with the wife, washing is also done together. This morning, my wife was washing dishes, I was washing clothes."*

However, some respondents had specific gender norms and expectations regarding the roles of women and men. One woman said, "*Water is my responsibility, wife's job is at the kitchen then husband just eat."* When a women in Metro was asked why the man would not boil water, she replied: *"Seriously, the man who boils water? Have you ever imagined a man boiling water?"* The informant laughed and said, "*No need. It is simple. Just turn the stove button, that is all. Take water, it is not difficult*."

Widows, people who were living alone and families with members with special needs faced increased challenges regarding workload. One widow said, "*[if] there is no male, it is difficult, there is no head of the family."* Children were often helping with household chores, even with special needs. "*My last child has special needs. She is just helping what she can. She can turn off the stove. Sweeping floor after waking up and after eating [she] does the dishes by herself. That is all she can do. She has only been able to walk for three months, previously she used a wheelchair."*

Decision-making related to self-supply was typically the responsibility of the head of the household. However, a few households reported a joint decision between household members related to self-supply. One woman explained that her husband determined the location of the well, but she made decisions related to household matters. She further explained, "*That is my husband's responsibility when the gas runs out. He is the one who is making money. I said we were running out of gas, so he told me to just buy it, then I bought it."*

Households usually share the water with the neighbors if they ask for it, when their well is dry or has bad quality. One informant in Metro elaborated "*In fact, sometimes the neighbor's well is dry. So they asked [for water] here."* When the dug well is dry, an informant in Metro explained "*Usually I take water from my neighbors for two or three days, only for drinking. For showering or other things, I usually go to Ayuk [older sister's] place."* Another informant in Metro answered when asking what if a neighbor asks for water and how many have asked for: "*It is okay. Poor them. The water is turbid. A lot [have asked for water]. Ten houses. They draw it [the water] up themselves and use a jerry can to bring it home by motorbike."* However, one informant who relied on polluted water from a dug well decided to drill a borehole since he no longer felt comfortable to ask neighbors for water.

Discussion

Self-supply provides a valuable informal on-premises water service for households in Bekasi and Metro. The question then arises, to what extent self-supply could support achieving and sustaining the SDG 6.1 target of safely managed drinking water for all. The study identified the overall preference for self-supply over alternative water sources, as well as a common perception that water from private boreholes is of good quality. The water quality perception partially

aligns with the water quality results, which indicated on the one hand that boreholes provided higher quality water than unprotected dug wells, but on the other hand showed *E. coli* contamination in 55% of boreholes [12]. This study showed that households used coping strategies for water quality and availability problems, such as treatment and storage practices, as well as the replacement of shallow dug wells with deeper boreholes. Boiling water before drinking was shown to be widespread in Bekasi and Metro and was found to improve the water quality between source and point-of-use [12]. The water treatment step, including costs and resource use must be considered in the discussion of whether self-supply provides a safely managed water service. In terms of water availability, household survey results showed that water from dug wells were available the past two weeks during wet season in Bekasi, and dry season in Metro. However, qualitative results of this study showed that half the interview respondents were not satisfied with the water availability of dug wells and explained that dug wells were often deepened or replaced with a borehole, since dug wells dry out during dry season. Supporting households to invest in reliable as well as safe forms of self-supply such as boreholes, could reduce availability and quality issues and contribute towards reaching SDG 6.1.

Water treatment is essential for self-supply to be considered a safely managed drinking water service. The study showed that boiling of self-supplied water before consumption was widely practiced. Boiling is the most prevalent household water treatment and effectively removes waterborne pathogens, but also has limitations such as the associated workload, fuel costs and household air pollution caused by the fuels to boil water [38]. In Bekasi and Metro, LPG was the most frequently used fuel for water boiling, however wood was still used by 28% (n = 84) of households in Metro. Among the primary global health risks, household air pollution is ranked eighth, ahead of unsafe water, which ranks 14th [39]. This highlights the need to promote the use of safer fuels or electricity for water boiling, or better still, promote other household water treatment technologies such as filters. Results from the household survey of this study indicated that all households use boiling for self-supply water treatment. However, a study in peri-urban Cambodia suggested that actual use of boiling for drinking water treatment may be lower than self-reported use [40]. Qualitative results of this study showed that the labor involved in boiling water could not always be managed, so households must resort to alternative water sources. The study showed that refill water from refill water depots was frequently used as an alternative water source, since many households believe it does not require boiling and is therefore more convenient. However, some respondents perceived health issues from drinking refill water. Convenience has also been suggested as a reason for using unsafe bottled water by a study of Cohen et al. 2017 in China, which examined the predictors of drinking water boiling and bottled water consumption. To safely manage self-supply, low-cost, efficient and convenient treatment strategies are necessary. The promotion to switch from boiling with pots towards electric kettles could have a positive impact [38]. However, one-time investment cost and associated electricity costs could be barriers to adaption. To support self-supply for better health impact there is also an opportunity to enhance the adoption of other household water treatment technologies, such as chemical, filtration or ultraviolet, taking into account user preferences [41].

Household management of self-supply showed high levels of cooperation between women and men, which is an important consideration in enhancing and sustaining safely managed drinking water services. Although traditional gender roles were still prevalent, the results from the in-depth interviews showed that the division of labor in managing self-supply was mostly shared between different household members of different genders. However, socially constructed norms mean women and girls disproportionately shoulder the burden of unpaid care and domestic work associated with sub-standard water services [42]. A meta-analysis across 45 developing countries found that in 72% of households, collecting drinking water was the task

of women and girls [43]. Since women are often the main users and beneficiaries of water service delivery in the household and generally bear the burden of labour [24, 44–46], it is often assumed that they have a vested interest in its success and their involvement in decision-making will lead to better performance [47]. Several studies in different countries confirm the positive correlation between the participation of women in water committees and improved functionality of community-based water systems [47–49]. However, these studies on women's participation and water service functionality have tended to focus on the community sphere, while self-supply management takes place within the household sphere. In this study, in the household sphere, certain gendered norms and roles were also visible, with women generally responsible for household water treatment, and men more often responsible for maintenance and financial matters. Household decision-making was predominantly shared in one study site, and predominantly by men in the other study site. Nevertheless, the cooperation between household members in terms of management and the shared strong interest in its success was such that operational sustainability was high.

To sustain self-supply services in the long-term, regulations are needed to protect groundwater availability and quality. It is challenging to retrospectively regulate already existing private self-supply infrastructure with individualized responsibility for risk management. Households participating in the in-depth interviews expressed concerns about declining water quality and availability. The depletion of groundwater and its increasingly negative impact on quality and availability, as well as worsening inequalities in access to safe water, are already known in greater Jakarta region [50–52]. The qualitative in-depth interviews of this study revealed that households that could afford to replace dug wells with deeper boreholes with a motorized pump as a response to groundwater problems. The shift towards higher-quality and more convenient services has also been observed in rural Bangladesh [53]. Fischer et al. (2020) viewed the shift towards on-premises piped systems and electric pumps as an opportunity to align user demand and payments with regulated services, since it is more politically palatable to provide new infrastructure over regulating the use of existing infrastructure. Licensing and standardization of drillers as well as education and demonstration on drilling and well installation could provide other approaches for regulation [54].

The feasibility of supporting and regulating self-supply towards a safely managed service should be weighed against other strategies, such as the investment in public piped services. Alternative water sources still provide an important source of water for households relying on self-supply, which should be considered in establishing sustainable supporting strategies for households [13]. This study showed that households often preferred water from self-supply over alternative water sources. Therefore, investment in public piped services comes with the risk of non-use. Households often viewed taste as the most important attribute for drinking water. This raises the prospect of households rejecting chlorinated water in favor of the unsafe option, as the chlorine taste from public water services was generally perceived as unpleasant. Other studies have also shown that taste plays a crucial role in drinking water choice and should therefore be considered in chlorination dosing guidelines for piped services [55]. Further, reliability was identified in the household survey as an important attribute for using water to meet daily needs, and in-depth interviews indicated that reliability was a reason for not using public piped systems. Safety was also rated as an important attribute for water choice, but compared to other attributes such as taste, reliability or appearance, the safety of a water supply is more difficult for households to judge. Accordingly, for households to connect to public water systems, trust must be created through provision of reliable and functioning services. The willingness of households to pay for connection fees and on-going tariffs will ultimately be determined by whether or not piped services meet the expectations of households, particularly in relation to the service attributes that they value most.

This study's explanatory mixed-methods approach provided a deeper insight into the overlooked aspects of purely quantitative or purely qualitative research on understanding of the use and non-use of self-supply. For example, qualitative findings provided further understanding on water availability problems and corresponding coping strategies of households. Half of the participants in the in-depth interviews expressed dissatisfaction with the availability of water from dug wells, particularly in the dry season, and explained that dug wells often had to be deepened or replaced with a borehole. Also, quantitative and qualitative results revealed contradictory findings, as quantitative results suggested that all households boil their self-supply water, while qualitative results indicated that the workload involved in boiling could not always been managed. This highlights the value of using mixed-methods to address limitations of solely quantitative and qualitative methods. Due to some study limitations, further investigations would be beneficial to inform strategies to support and regulate self-supply and weigh them up against other strategies to improve safety and reliability of public water services in urban Indonesia. While data on water quality of self-supply sources was collected [12], data on water quality of alternative water sources would be beneficial for determining the potential health implications of multiple source use. Furthermore, generalizations should be made with caution, as the use and choice of water sources may vary greatly by region and the study sites were selected based on the high prevalence of self-supply.

Conclusion

This study provides important insights into the use and management of self-supply in urban Indonesia. An improved understanding of how and why urban households self-supply their water is crucial for accelerating progress towards SDG target 6.1 in Indonesia. A mixed-methods approach was used, which allowed for more comprehensive findings and provided both broader and deeper insights into the use and management of self-supply than a purely quantitative or qualitative approach. This study found that households in Bekasi and Metro generally preferred groundwater self-supply water, but still used alternative water sources to supplement inadequate supply. Some considerations to support and regulate self-supply towards a safely managed water service can be concluded from this study: (i) self-supply use was connected with water boiling, which increased water quality at the point-of-use but came with an additional workload for household members and the potential use of fuel which is harmful to health; (ii) in response to groundwater availability issues, households that could afford it often switched from shallow dug wells to deeper wells with a motorized pump; (iii) there was little trust in quality of alternative water sources such as refill water and public piped systems; (iv) gendered intra-household dynamics varied across households, but showed cooperation between women and men and certain clearly defined roles in terms of responsibilities and decision-making. Strategies to improve the safety and reliability of self-supply should not only include the improvement of self-supply source infrastructure, but also consider the point-of-use including safe household water treatment and its management. Furthermore, the safety and reliability of alternative water supplies such as refill water and public piped system should be considered, as these supplies serve as a supplement to address groundwater quality and availability issues that will increase in the future.

Supporting information

S1 Text. Supplemental tables and figs.
(DOCX)

S2 Text. Inclusivity in global research.
(DOCX)

Acknowledgments

We thank the enumerators of Universitas Indonesia and Universitas Muhammadiyah Metro, Faculty members of Universitas Muhammadiyah Metro, Mitsunori Odagiri from UNICEF Indonesia, Angela Harris from NCSU, Bekasi and Metro local government, Indonesian Ministry of National Development Planning (Bappenas) and all participating households in Bekasi and Metro.

Author Contributions

Conceptualization: Franziska Genter, Juliet Willetts.

Data curation: Franziska Genter.

Formal analysis: Franziska Genter.

Funding acquisition: Cindy Priadi, Tim Foster, Juliet Willetts.

Investigation: Franziska Genter, Gita Lestari Putri, Evelyn Suleeman, Linda Darmajanti.

Methodology: Franziska Genter.

Project administration: Franziska Genter, Gita Lestari Putri, Cindy Priadi, Tim Foster, Juliet Willetts.

Resources: Cindy Priadi, Tim Foster, Juliet Willetts.

Supervision: Cindy Priadi, Tim Foster, Juliet Willetts.

Validation: Gita Lestari Putri, Evelyn Suleeman, Linda Darmajanti, Cindy Priadi, Tim Foster, Juliet Willetts.

Visualization: Franziska Genter.

Writing – original draft: Franziska Genter.

Writing – review & editing: Franziska Genter.

References

1. Grönwall J, Danert K. Regarding Groundwater and Drinking Water Access through A Human Rights Lens: Self-Supply as A Norm. Water. 2020; 12(419):21. https://doi.org/10.3390/w12020419
2. Grönwall JT, Mulenga M, Mcgranahan G. Groundwater, self-supply and poor urban dwellers—A review with case studies of Bangalore and Lusaka. Hum Settlements Work Pap Ser—Water Sanit. 2010; 26:87.
3. Genter F, Willetts J, Foster T. Faecal contamination of groundwater self-supply in low- and middle income countries: Systematic review and meta-analysis. Water Research. 2021. https://doi.org/10.1016/j.watres.2021.117350 PMID: 34198198
4. Foster T, Priadi C, Kotra KK, Odagiri M, Rand EC, Willetts J. Self-supplied drinking water in low- and middle-income countries in the Asia-Pacific. npj Clean Water. 2021; 4(1):1–10. https://doi.org/10.1038/s41545-021-00121-6
5. Foster T, Shantz A, Lala S, Willetts J. Factors associated with operational sustainability of rural water supplies in Cambodia. Environ Sci Water Res Technol. 2018; 4(10):1577–88. https://doi.org/10.1039/C8EW00087E
6. Healy A, Upton K, Capstick S, Bristow G, Tijani M, Macdonald A, et al. Domestic groundwater abstraction in Lagos, Nigeria: A disjuncture in the science-policy-practice interface? Environ Res Lett. 2020; 15 (4). https://doi.org/10.1088/1748-9326/ab7463

7. Butterworth J, Sutton S, Mekonta L. Self-supply as a complementary water services delivery model in Ethiopia. Water Altern. 2013; 6(3):405–23.
8. Sutton S, Butterworth J. Self-Supply: Filling the gaps in public water supply provision. Rugby: Practical Action Publishing; 2021. 356 p. https://doi.org/10.1088/1748-9326/ab7463
9. Foster S, Bousquet A, Furey S. Urban groundwater use in Tropical Africa—A key factor in enhancing water security? Water Policy. 2018; 20(5):982–94. https://doi.org/10.2166/wp.2018.056
10. WHO, UNICEF. Five years into the SDGs—Progress on household drinking water, sanitation and hygiene [Internet]. Geneva; 2021. Available from: https://www.oecd.org/dac/
11. WHO, UNICEF. Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Vol. 53. 2017. 1689–1699 p.
12. Genter F, Putri G, Pratama M, Priadi C, Willetts J, Foster T. Microbial Contamination of Groundwater Self-supply in urban Indonesia: Assessment of Sanitary and Socio-economic Risk factors. Water Resour Res. 2022; 58. https://doi.org/10.1029/2021WR031843
13. Elliott M, MacDonald MC, Chan T, Kearton A, Shields KF, Bartram JK, et al. Multiple household water sources and their use in remote communities with evidence from Pacific Island Countries. Water Resour Res. 2017; 54:9106–17. https://doi.org/10.1002/2017WR021047
14. Daly SW, Lowe J, Hornsby GM, Harris AR. Multiple water source use in low- and middle-income countries: A systematic review. J Water Health. 2021; 19(3):370–92. https://doi.org/10.2166/wh.2021.205 PMID: 34152293
15. Kumpel E, Cock-Esteb A, Duret M, Waal O De, Khush R. Seasonal variation in drinking and domestic water sources and quality in port harcourt, Nigeria. Am J Trop Med Hyg. 2017; 96(2):437–45. https://doi.org/10.4269/ajtmh.16-0175 PMID: 27821689
16. Benneyworth L, Gilligan J, Ayers JC, Goodbred S, George G, Carrico A, et al. Drinking water insecurity: water quality and access in coastal south-western Bangladesh. Int J Environ Health Res. 2016; https://doi.org/10.1080/09603123.2016.1194383 PMID: 27277537
17. Kelly E, Shields KF, Cronk R, Lee K, Behnke N, Klug T, et al. Seasonality, water use and community management of water systems in rural settings: Qualitative evidence from Ghana, Kenya, and Zambia. Sci Total Environ. 2018; https://doi.org/10.1016/j.scitotenv.2018.02.045 PMID: 29454211
18. Özdemir S, Elliott M, Brown J, Nam PK, Hien VT, Sobsey MD. Rainwater harvesting practices and attitudes in the mekong delta of Vietnam. J Water Sanit Hyg Dev. 2011; 1(3):171–7. https://doi.org/10.2166/washdev.2011.024
19. Shaheed A, Orgill J, Ratana C, Montgomery MA, Jeuland MA, Brown J. Water quality risks of "improved" water sources: Evidence from Cambodia. Trop Med Int Heal. 2014; 19(2):186–94. https://doi.org/10.1111/tmi.12229 PMID: 24252094
20. Hoko Z. An assessment of the water quality of drinking water in rural districts in Zimbabwe. The case of Gokwe South, Nkayi, Lupane, and Mwenezi districts. Phys Chem Earth. 2005; https://doi.org/10.1016/j.pce.2005.08.031
21. Adeniji-Oloukoi G, Urmilla B, Vadi M. Households' coping strategies for climate variability related water shortages in Oke-Ogun region, Nigeria. Environ Dev. 2013; 5(1):23–38. https://doi.org/10.1016/j.envdev.2012.11.005
22. Kosinski KC, Kulinkina A V., Abrah AFA, Adjei MN, Breen KM, Chaudhry HM, et al. A mixed-methods approach to understanding water use and water infrastructure in a schistosomiasis-endemic community: Case study of Asamama, Ghana. BMC Public Health. 2016; https://doi.org/10.1186/s12889-016-2976-2
23. Nastiti A, Muntalif BS, Roosmini D, Sudradjat A, Meijerink S V., Smits AJM. Coping with poor water supply in peri-urban Bandung, Indonesia: towards a framework for understanding risks and aversion behaviours. Environ Urban. 2017; 29(1):69–88. https://doi.org/10.1177/0956247816686485
24. Acey C. Gender and community mobilisation for urban water infrastructure investment in southern Gender and community mobilisation for urban water infrastructure investment in southern Nigeria. Gend Dev. 2010; 18(1).
25. Carrard N, Crawford J, Halcrow G, Rowland C. A framework for exploring gender equality outcomes from WASH programmes. Waterlines. 2013; 32(4).
26. Caruso BA, Conrad A, Patrick M, Owens A, Kviten K, Zarella O, et al. Water, sanitation, and women's empowerment: A systematic review and qualitative metasynthesis. Vol. 1, PLOS Water. 2022. e0000026 p. https://doi.org/10.1371/journal.pwat.0000026
27. Cleaver F, Hamada K. "Good" water governance and gender equity: A troubled relationship. Gend Dev. 2010;
28. Mandara CG, Niehof A, van der Horst H. Women and rural water management: Token representatives or paving the way to power? Water Altern. 2017;

29. BPS. Statistics of Bekasi Regency [Internet]. 2021 [cited 2021 Sep 1]. Available from: https://bekasikab.bps.go.id/statictable/2021/07/17/2801/distribusi-dan-kepadatan-penduduk-menurut-kabupaten-kota-di-provinsi-jawa-barat-2017.html

30. BPS Kota Bekasi. Bekasi Municipality in Figures 2021. BPS Kota Bekasi. 2021;(1907.3763).

31. Bappeda Kota Bekasi. Rencana Pembangunan Jangka Menengah Daerah Kota Bekasi 2018–2023. 2018;

32. BPS Kota Bekasi. Bekasi Municipality in Figures 2019. BPS-STatistics of Bekasi Municipality; 2019. 352 p.

33. WageIndicator. UMP/UMK Jawa Barat [Internet]. 2022. Available from: https://gajimu.com/garmen/gaji-pekerja-garmen/gaji-minimum/ump-umk-jawa-barat

34. BPS Kota Metro. Metro Municipality in Figures 2019. 2019;(1907–4751):262.

35. WageIndicator. UMP/UMK Lampung [Internet]. 2022. Available from: https://gajimu.com/garmen/gaji-pekerja-garmen/gaji-minimum/ump-umk-lampung

36. Creswell JW, Chu P, Chang Y. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. J Soc Adm Sci. 2017;

37. National Population and Family Planning Board (BKKBN), Statistics Indonesia (BPS), Ministry of Health (Kemenkes), ICF. Indonesia Demographic and Health Survey 2017 [Internet]. Jakarta; 2018. Available from: https://dhsprogram.com/pubs/pdf/FR342/FR342.pdf

38. Cohen A, Zhang Q, Luo Q, Tao Y, Colford JM, Ray I. Predictors of Drinking Water Boiling and Bottled Water Consumption in Rural China: A Hierarchical Modeling Approach. Environ Sci Technol. 2017; 51 (12):6945–56. https://doi.org/10.1021/acs.est.7b01006 PMID: 28528546

39. Lim SS, Allen K, Dandona L, Forouzanfar MH, Fullman N, Goldberg EM, et al. Measuring the health-related Sustainable Development Goals in 188 countries: a baseline analysis from the Global Burden of Disease Study 2015. Lancet. 2016; https://doi.org/10.1016/S0140-6736(16)31467-2 PMID: 27665228

40. Brown J, Sobsey MD. Boiling as household water treatment in Cambodia: A longitudinal study of boiling practice and microbiological effectiveness. Am J Trop Med Hyg. 2012; https://doi.org/10.4269/ajtmh.2012.11-0715 PMID: 22826487

41. WHO. Results of Round II of the WHO International Scheme to Evaluate Household Water Treatment Technologies. World Heal Organ. 2019;

42. Grant M, Huggett C, Willetts J, Wilbur J. Gender Equality & Goal 6: The Critical Connection. Australian Water Partnership; 2017.

43. WHO, UNICEF. Progress on sanitation and drinking water—2010 update. 2010; Available from: http://whqlibdoc.who.int/publications/2010/9789241563956_eng_full_text.pdf

44. Brocklehurst C, Bartram J. Swimming upstream: Why sanitation, hygiene and water are so important to mothers and their daughters. Bull World Health Organ. 2010; 88(7):482. https://doi.org/10.2471/BLT.10.080077 PMID: 20616962

45. Fisher J. For Her It's The Big Issue: Putting women at the centre of water supply, sanitation and hygiene. Water Sanit Hyg Evid Rep. 2006; 36.

46. Fisher J. Women in water supply, sanitation and hygiene programmes. Munic Eng. 2008; 161 (ME4):223–9.

47. Mommen B, Humphries-Waa K, Gwavuya S. Does women's participation in water committees affect management and water system performance in rural Vanuatu? Waterlines. 2017; 36(3):216–32.

48. Van Wijk-Sijbesma C. The Best of Two Worlds? Methodology for Participatory Assessment of Community Water Services. IRC International Water and Sanitation Centre; 2001.

49. Foster T. Predictors of sustainability for community-managed handpumps in sub-saharan Africa: Evidence from Liberia, Sierra Leone, and Uganda. Environ Sci Technol. 2013; 47(21):12037–46. https://doi.org/10.1021/es402086n PMID: 24111486

50. Delinom RM. Groundwater management issues in the Greater Jakarta area, Indonesia. Groundw Subsurf Environ Hum Impacts Asian Coast Cities. 2008;(8). https://doi.org/10.15068/00147302

51. Kooy M, Walter CT, Prabaharyaka I. Inclusive development of urban water services in Jakarta: The role of groundwater. Habitat Int. 2018; 73:109–18. https://doi.org/10.1016/j.habitatint.2016.10.006

52. Furlong K, Kooy M. Worlding Water Supply: Thinking Beyond the Network in Jakarta. Int J Urban Reg Res. 2017; 41(6):888–903. https://doi.org/10.1111/1468-2427.12582

53. Fischer A, Hope R, Manandhar A, Hoque S, Foster T, Hakim A, et al. Risky responsibilities for rural drinking water institutions: The case of unregulated self-supply in Bangladesh. Glob Environ Chang]. 2020; 65:102152. https://doi.org/10.1016/j.gloenvcha.2020.102152

54. Jamil NB, Feng H, Ahmed KM, Choudhury I, Barnwal P, Van Geen A. Effectiveness of Different Approaches to Arsenic Mitigation over 18 Years in Araihazar, Bangladesh: Implications for National Policy. Environ Sci Technol. 2019; 53(10):5596–604. https://doi.org/10.1021/acs.est.9b01375 PMID: 31033281

55. Smith DW, Islam M, Furst KE, Mustaree S, Crider YS, Akter N, et al. Chlorine taste can increase simulated exposure to both fecal contamination and disinfection byproducts in water supplies. Water Res. 2021; https://doi.org/10.1016/j.watres.2021.117806 PMID: 34768105