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Waterborne exposure during non-consumptive domestic use of surface water: a population study across WASH service levels in rural India

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ABSTRACT

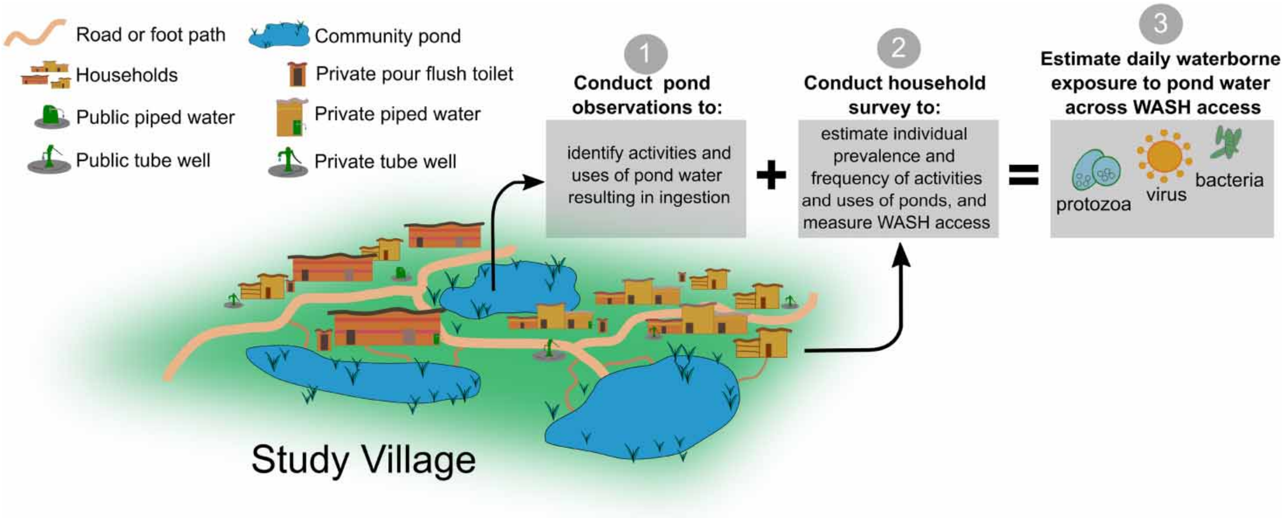
Exposure to pathogens from domestic use of surface water is understudied. In many low- and middle-income countries, surface water is used for hygiene, sanitation, amenity, and recreational purposes. In this study, self-reported use of and structured observations at community ponds were collected to measure waterborne exposure across water and sanitation service levels in a rural population of Khorda District, India. Overall, 86% of households ($n = 200$) reported using ponds on a regular basis. Among observed people ($n = 765$), 82% put water into their mouth at least once, with a median frequency of five occurrences per visit. Reported and observation data were combined to estimate the proportion (p) of the population that put water in their mouth at least once per day, and their mean daily rate of oral exposure (OE). These were highest for individuals with neither safely managed water nor basic sanitation access ($p = 93\%$, OE $= 14$ day^{-1}), but still high among those with both ($p = 67\%$, OE $= 6$ day^{-1}). The results suggest widespread exposure to waterborne pathogens in settings where non-potable surface water bodies continue to be used for domestic purposes, even among households with access to safely managed drinking water.

Key words: domestic use, exposure, pathogens, rural, surface water, WASH

HIGHLIGHTS

- Structured observations and household survey data were combined to examine domestic use of surface water bodies in rural India.
- Results suggest domestic use of surface water may be widespread in rural areas of low- and middle-income countries despite improved access to water.
- Exposure to pathogens in surface water from domestic use represents an understudied health risk.

GRAPHICAL ABSTRACT



INTRODUCTION

Domestic water use includes consumption (drinking and cooking), personal and domestic hygiene including food hygiene, sanitation, amenity and productive uses, and sometimes recreation (Howard *et al.* 2020; Russo *et al.* 2020). The Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) defines four levels of household water access. Only the highest level of safely managed access defined as an 'improved source located on premises, available when needed, and free from fecal and priority chemical contamination' is thought to provide an adequate quantity of water at home for domestic activities considered essential for health (UNICEF 2017; Howard *et al.* 2020). While reasonable, there is limited supporting empirical evidence for this assumption, and some speculation that health improvements may require consumption of greater quantities of water afforded only by 'optimal' access, defined by the WHO as water supplied continuously at home through multiple taps (Howard *et al.* 2020). At JMP basic and lower levels of water access, households are likely to conduct some to many of their domestic daily water use activities at water sources away from home (Howard *et al.* 2020). In many settings across the globe households use multiple water sources to meet their daily water needs, including drinking, irrespective of access level (Daly *et al.* 2021). In particular, Daly *et al.* (2021) found high rates of supplemental use of unimproved sources, including surface water bodies, for households with basic or higher JMP access in studies from South Asian and Sub-Saharan African countries.

Thus, although used only by 2% of the global population as a primary drinking source (WHO 2019), surface water bodies, such as rivers, canals, lakes, tanks, and ponds, continue to be extensively used as secondary or supplemental sources of drinking and domestic water in low- and middle-income countries where households use multiple water sources or lack safely managed access. The most recent JMP global estimate of those lacking safely managed water stands at 29% overall and 60% for rural populations, representing approximately 2 billion people (UNICEF 2017). The prevalence of and potential for waterborne exposures during domestic use of surface water bodies among populations with less-than-optimal access to water (as defined by WHO) are currently unknown due to a lack of studies.

To better understand the risks associated with non-consumptive domestic use of surface water bodies in low- and middle-income countries and how these vary with water and sanitation access, we conducted an exploratory study in Khorda District of Odisha, India where safely managed water and basic sanitation access varies across the rural population, though all have at least basic water service, and community ponds are widely available. First, we used structured observations at ponds to characterize the purposes and quantify practices and exposures occurring during domestic water use of ponds by age group and gender. Next, we used a household survey to measure water and sanitation (WASH) access and reported frequency of pond use by purpose among household members. Lastly, we merged the household survey and pond observation data to assess how pond waterborne exposure varies across the study population.

METHODS

Study region

Khorda District is a mixed urban–rural coastal region of Odisha, one of the eastern states in India. Rural water infrastructure consists of government installed, regulated and operated piped water schemes delivering treated water to private household tap connections (i.e., on-plot safely managed water) and to public taps (i.e., basic access) under the Government of India's Rural Water Supply and Sanitation (RWSS) project, as well as community tube wells (i.e., basic access) and private household tubewells (i.e., on-plot protected groundwater). Under the RWSS piped water schemes, households have the option to apply and pay for a private connection at the time of construction. Those who choose not to have a private connection get free access to the schemes piped water at community taps. Households also have the option to install a private tubewell on their property that provides the convenience of at-home access, as these are relatively inexpensive in this coastal area. Community ponds are also a common feature of the landscape. While no one drinks pond water and all households have at least basic water access, community ponds continue to be used for non-consumptive domestic purposes including bathing, dish washing, swimming for heat relief, and livestock watering among other purposes. Sanitation infrastructure and practices consist of private household pour flush latrines (basic sanitation) and open defecation. For those practicing open defecation, ponds are commonly used afterwards for anal cleansing and bathing (Routray *et al.* 2015).

Sampling approach

In one block of Khorda District, we purposively selected eight rural villages with these characteristics: having at least one community pond, located at least 5 km from the river, diversity in size and access to safely managed water, and ease of access from the nearest large city, Bhubaneshwar, where field researchers were based. The most heavily used 1–2 community ponds were selected for observation. Twenty-five households per village were randomly selected for the survey using a random route walk that included hamlets of different castes. Free and informed consent of the participants was obtained and the study protocol was approved by the Ethical Review Committee at the Asian Institute of Public Health, Odisha, India.

Structured observations at community ponds

To identify and document the types of domestic activities conducted at ponds, those that result in oral exposure to pond water, and the duration of these activities, structured observations were conducted of users at 10 community ponds across the study villages. Two trained observers, one male and one female, used a data sheet (Supplementary Appendix 1) to record the purpose and behavior of one pond visitor at a time. The data sheet was developed and piloted to include any activity that might result in pond water exposure. For each observed visitor, the number of times (n) water entered the mouth and the duration (seconds) water was in the mouth was recorded. This might occur, for example, by water accidentally splashing into one's mouth while bathing or intentionally when rinsing the mouth with water after brushing teeth. Gender and age group of each observed visitor was also recorded. Age was approximated as: Child = 0–5 years, Juvenile = 6–17 years, Adult = 18–60 years, and Elder = >60 years. The female observer was posted at the female area and the male observer at the male area of the pond. Each observed as many people as possible for two 6-h periods spread over two consecutive days at each pond, with one observation period occurring in the morning hours (6 am–12 pm) and one in the afternoon hours (12 pm–6 pm). A visitor was observed and recorded from the time they first entered the pond until they exited. A pond visit often lasted longer than time in the pond and individuals frequently conducted multiple activities in a single visit. For this analysis, only time in the water was recorded.

Self-reported frequency of pond use

To measure the frequency of using ponds for purposes identified during pond observations, we surveyed a sample of 200 households across the 8 study villages. At each household where the head or spouse was present, a questionnaire (Supplementary Appendix 2) was administered by trained enumerators that asked about the frequency of using community ponds for each purpose. Frequency for this study was categorized as: (1) never, (2) multiple times per day, (3) daily, (4) several times per week, (5) about once a week, or (6) about once a month. Questions were also asked to ascertain access to WASH. According to the JMP definition, an improved drinking water source on premises, available when needed and free from contamination, is considered safely managed access. Households in this study with on-plot water from the government's RWSS piped scheme and/or from a private tubewell were categorized as having safely managed water access. These facilities meet the first three of the four conditions for safely managed access. Given a lack of rural water quality data and monitoring challenges, we make a common presumption that the fourth condition holds, and water from these two sources is free of fecal contamination. While reasonable in the context of this study where the first three conditions of safely managed water are most salient, there is evidence from elsewhere that protected tubewell groundwater in coastal Odisha may not always be 100% free of fecal contamination (Clasen *et al.* 2014). Access to a household pour flush latrine on premises was considered basic sanitation. The questionnaire was structured to collect pond usage at the individual level, along with gender and age, as reported by the head or spouse for themselves and their household members.

Simulated frequency of pond water exposure

We used a stochastic computational approach to estimate the daily frequency of pond water oral exposure in the study population and assess how this varied with age, gender, and WASH group. We started by generating a simulated population of 400,000 individuals and uniformly distributed this population into one of four groups based on access to basic sanitation (yes/no) and to safely managed water (yes/no). We then assigned the gender and age of each individual such that each WASH group had the same demographic profile as the overall surveyed population (Supplementary Appendix 3, Table 1). Then, for each simulated individual, we combined reported pond use with the structured pond observation data to compute the estimated number of times the individual put pond water into their mouth daily using the following steps.

First, we used the household survey data to estimate a frequency of pond visits per month (*fopv)* contingent on age group, gender, and basic sanitation and safely managed water access for each purpose. Pond visit data were quantified as follows: (1) never = 0 times per month, (2) multiple times per day = 62 times per month, (3) daily = 31 times per month, (4) several times per week = 8 times per month, (5) about once a week = 4 times per month, or (6) about once a month = 1 time per month. To estimate *fopv* for each individual in the simulated population, we sampled the relevant distribution of reported monthly rates. Supplementary Appendix 3, Tables 2.1–2.9 provide lists of the self-reported frequencies for each purpose and WASH access group.

Next, we assigned a probability of putting water into one's mouth (*pwim*) when visiting a pond for each purpose. This was equal to the fraction of observed individuals in the relevant age, gender, and purpose strata who did so at least once during their pond visit. Supplementary Appendix 3, Table 3 provides a list of the observed fractions. For a simulated individual with oral exposure (i.e., pond water entering one's mouth) for a given purpose, we estimated a non-zero value of the number of times this occurred (*nwim*) by sampling the relevant distribution of observed occurrences at ponds. Supplementary Appendix 3, Table 4 shows the minimum and maximum *nwim* for each age-gender-purpose. We applied random resampling with replacement of the empirical data, which ensures empirical values have equal probability of being selected, including multiple times, to assign *fopv* and *nwim*.

Last, we combined *fopv*, *pwim*, and *nwim* to estimate the total number of times per day a simulated individual put pond water into their mouth for each purpose using the following formula:

$$N_{(pur)} = \frac{\Sigma\, binom(1,\ pwim_{pur},\ 1,\ fopv_{pur}) \times nwim_{pur}}{30}$$

where $N_{(pur)}$ is the total number of times an individual put water into their mouth (n day^{-1}) for a given purpose (*pur*), *pwim* is the probability of putting any water into one's mouth when visiting a pond, *fopv* is the frequency of visiting a pond in number per month, and *nwim* is the number of times during a visit water is put in one's mouth. Note that when *pwim* is zero for a purpose, irrespective of the frequency of pond visits, $N_{(pur)}$ is zero.

Following the simulation, for each of the four WASH groups, we calculated the proportion (p) in each group that had a simulated oral exposure (OE) to pond water per day greater $OE \geq 1$. For the simulated individuals where $OE > 1$, we then calculated the mean count in the WASH group across all purposes and compared how OE differed between groups. We also stratified these estimates for each age and gender category within a group to see how oral exposure to pond water varied demographically.

RESULTS

Domestic uses of ponds

Pond observations identified nine common domestic activities occurring at ponds (Table 1). While the majority of observed domestic pond water use activities, such as bathing, washing clothes, washing utensils, washing vehicles/equipment/cattle,

Table 1 | Activities (visit purpose) observed at ponds

Activity
Anal cleansing
Bathing (whole or parts of the body)
Swimming
Brushing teeth
Rubbing gudakhu
Washing cattle
Scour utensils (or vegetables)
Washing vehicles (car/bike) or equipment (agricultural)
Washing clothes (or shoes)

and swimming, are likely to occur in other low- and middle-income countries where communities rely on surface water, anal cleansing in ponds following open defecation and rubbing gudakhu, a local tobacco product applied to gums and teeth involving mouth rinsing, may be culturally particular to rural India.

Prevalence and frequency of pond use

The household survey generated data on reported pond use for 1,021 individuals. Of these, 69% were categorized as having safely managed water access (SMWa, i.e., private piped connection and/or tubewell on premises) while the rest had basic access (BWa, i.e., public tap and/or tubewell nearby). 45% had basic sanitation access (BSan, i.e., household pour flush latrine) with the balance open defecating (ODef). Figure 1 shows the proportion of surveyed individuals using ponds for domestic purposes in Table 1. Results are stratified by age group, gender, and WASH access. Very few strata of individuals reported rarely if ever using ponds for any purpose, while 100% of individuals in other strata used ponds for multiple

Figure 1 | Proportion of the surveyed sample of individuals using ponds for each domestic purpose stratified by safely managed water access (i.e., private piped connection and/or tubewell on premises) and basic sanitation (i.e., household improved latrine) access, gender, and age group. Sample sizes of each strata are shown below the strata label. Values are color coded (■ = 0–24%; ■ = 25–75%; ■ = 76–100%). Strata with no individuals are denoted with no data (ND). Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/wh.2023.309.

purposes. Across age groups, elders ($\geq$ 60 years) generally had the highest rates of pond use. Children ($\leq$5 years) tended to use ponds the least or not at all. Exceptions among children where for anal cleansing and bathing among households without basic sanitation, and additionally for teeth brushing, scouring utensils, and washing clothes, particularly female children, in households that also lacked safely managed water. In this latter group (BWa + ODef), ponds were used for anal cleansing and bathing by 31–46% of children and for brushing teeth by 15–31% of children. Males generally reported using ponds at higher rates than females. Overall, a large proportion of the population, irrespective of WASH group, used ponds for anal cleansing and bathing.

The prevalence and frequency of individuals who reported using ponds for each of the nine purposes, grouped by WASH access, is shown in Figure 2. It shows that for four out of nine purposes, most of those that used ponds did so on a daily or more frequent basis. For example, greater than 75% of individuals using ponds for anal cleansing, bathing, brushing teeth, and scouring utensils did so at least daily. Lacking access to basic sanitation and safely managed water, compared to having both, tended to double the prevalence of using ponds for nearly every purpose. For example, 86 and 78% of people lacking access to a latrine and private water supply on premises used ponds for anal cleansing and bathing respectively, compared to 41 and 40% of those with access to both. Among those with safely managed water access, the prevalence of using ponds for every purpose was higher for individuals without a toilet.

Observed pond behavior

A total of 764 individuals were observed entering the water to conduct domestic activities at 10 ponds in the study area. The duration individuals spent in the pond varied from a few minutes to a maximum of approximately 33 min (Figure 3). During this time, individuals were observed to put water into their mouth from zero to 27 times. The relationship between duration of time spent in a pond and frequency of putting water into one's mouth was nearly constant at approximately one event per minute, with a slight downward trend (Supplementary Appendix 3, Figure 1). Overall, 90% of observed visitors spent between 0 and 12 min in a pond and therefore put water into their mouths about 0–12 times.

The prevalence of putting water into the mouth during an activity in the pond, stratified by gender and age, is shown in the pie charts at the bottom of Figure 4. It shows the majority (82%) of those visiting and entering a pond put water into their

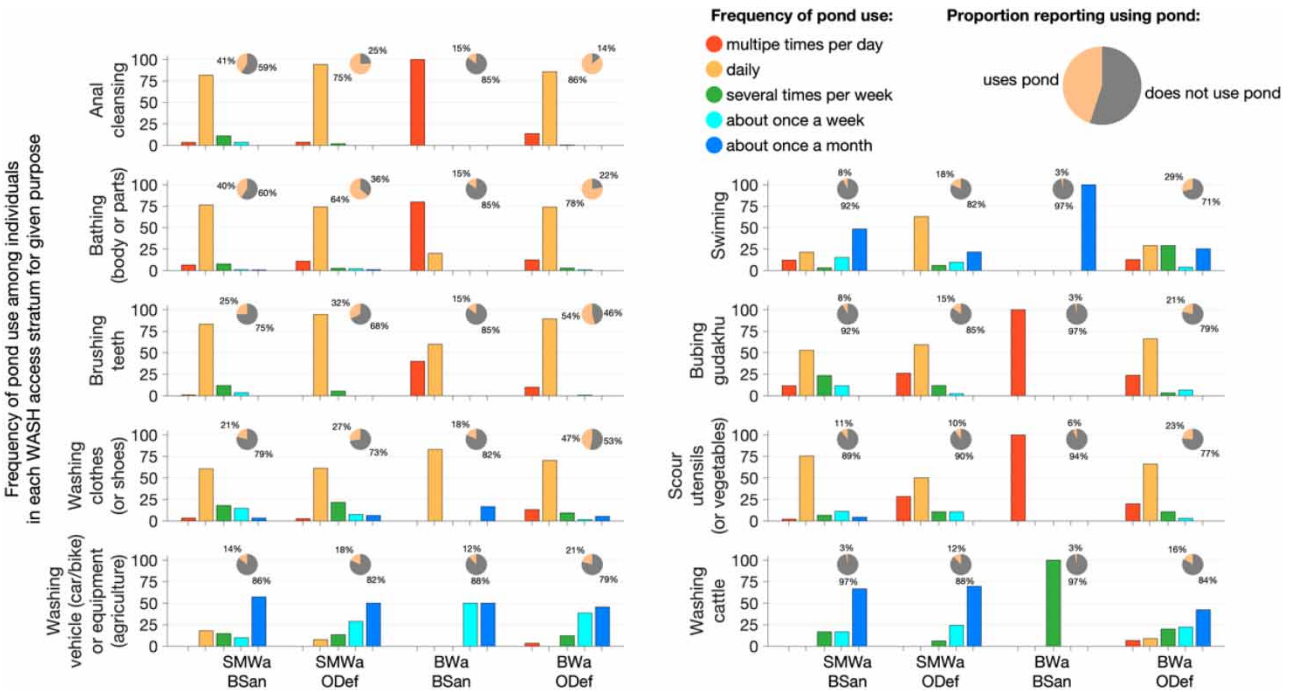


Figure 2 | Frequency of pond use reported by individuals using ponds for each indicated purpose stratified WASH group. Pie charts show the proportion of the sample population in each WASH group that reported using ponds for a given purpose. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/wh.2023.309.

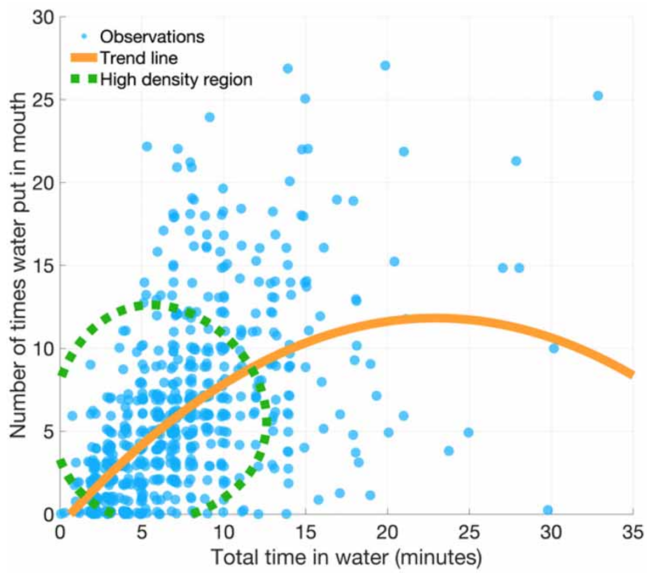


Figure 3 | Relationship between the duration an observed individual spent in the pond and the number of times they put water into their mouth, with a polynomial trend line and 90th percentile density region plotted. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/wh.2023.309.

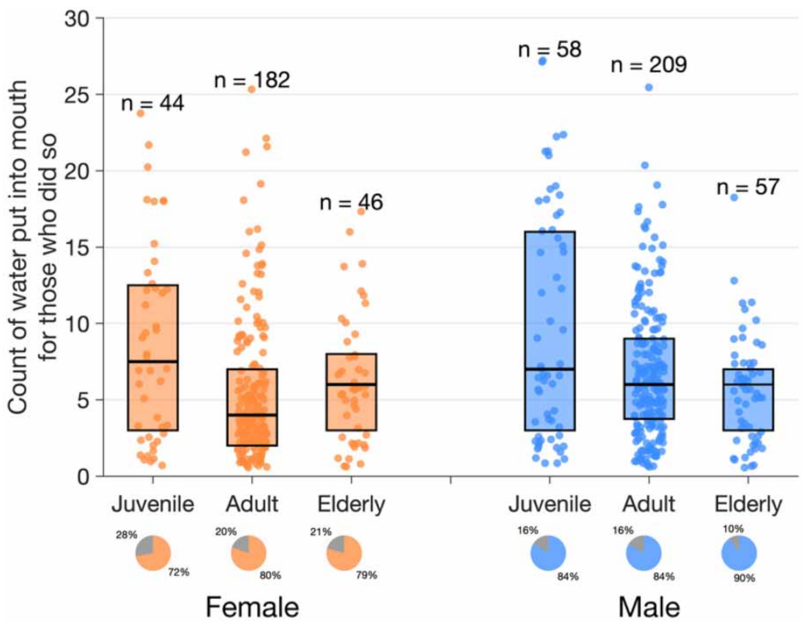


Figure 4 | Number of times observed individuals put water into their mouth while in the pond stratified by age group and gender, for those that put water into their mouth at least once. Points are observed individuals (*n*), while box plots report the 25th, 50th, and 75th percentiles for each group. Pie charts below each age-gender group show the proportion (color shaded region; orange = Female and blue = Male) of that group observed to put water into one's mouth. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/wh.2023.309.

mouth, that in each age group, males were more likely to do so than females, and the prevalence of this behavior was highest among male elders. However, the median frequency of putting water into one's mouth among those who did so during their visit (box plots, Figure 4) was similar for females and males (5 and 6 times, respectively). Variability in the number of times water entered the mouth was greater for juveniles (25th and 75th percentiles between 3 and 15 events) than for adults and the elderly (25th and 75th percentiles between 3 and 8 events). Note that children are excluded from Figure 4 due to low observation numbers; only 15 children were observed at ponds of which only 3 put water into their mouths.

Simulated frequency of pond water exposure

Results from the simulation model to estimate frequency of pond waterborne exposure are shown in Figure 5. For each strata, the proportion of the population estimated to put water into one's mouth at least once (p) and the mean daily rate of oral exposure (OE) for those who did, is reported and the simulated distribution is shown. Across WASH access group (top row, Figure 5), those with neither safely managed water nor basic sanitation access (BWa and ODef) had the largest proportion and highest mean rate of putting water into one's mouth ($p = 93\%$, OE = 14). Gender did not play a clear role in exposure across WASH access groups, with females sometimes having lower, similar, or higher exposure than males. Elders and adults tended to have similar exposure levels that were greater than juveniles and children, expect for those that lacked access to both safely managed water and a latrine. In that case exposure estimates were similarly very high for elders, adults, and juveniles ($p = 91$–100%, OE = 12–22 times/day). Male children ($\leq$5 years) had almost no daily exposure, while the prevalence of daily oral exposure for female children varied from 5 to 37% across WASH groups. Estimates in Figure 5 for the BWa and BSan group may be unreliable, in particular for females in the elderly, juvenile, and child age groups. The surveyed individuals in this WASH group were few ($n = 34$) and there were few or no surveyed individuals in some demographic strata (see Figure 1).

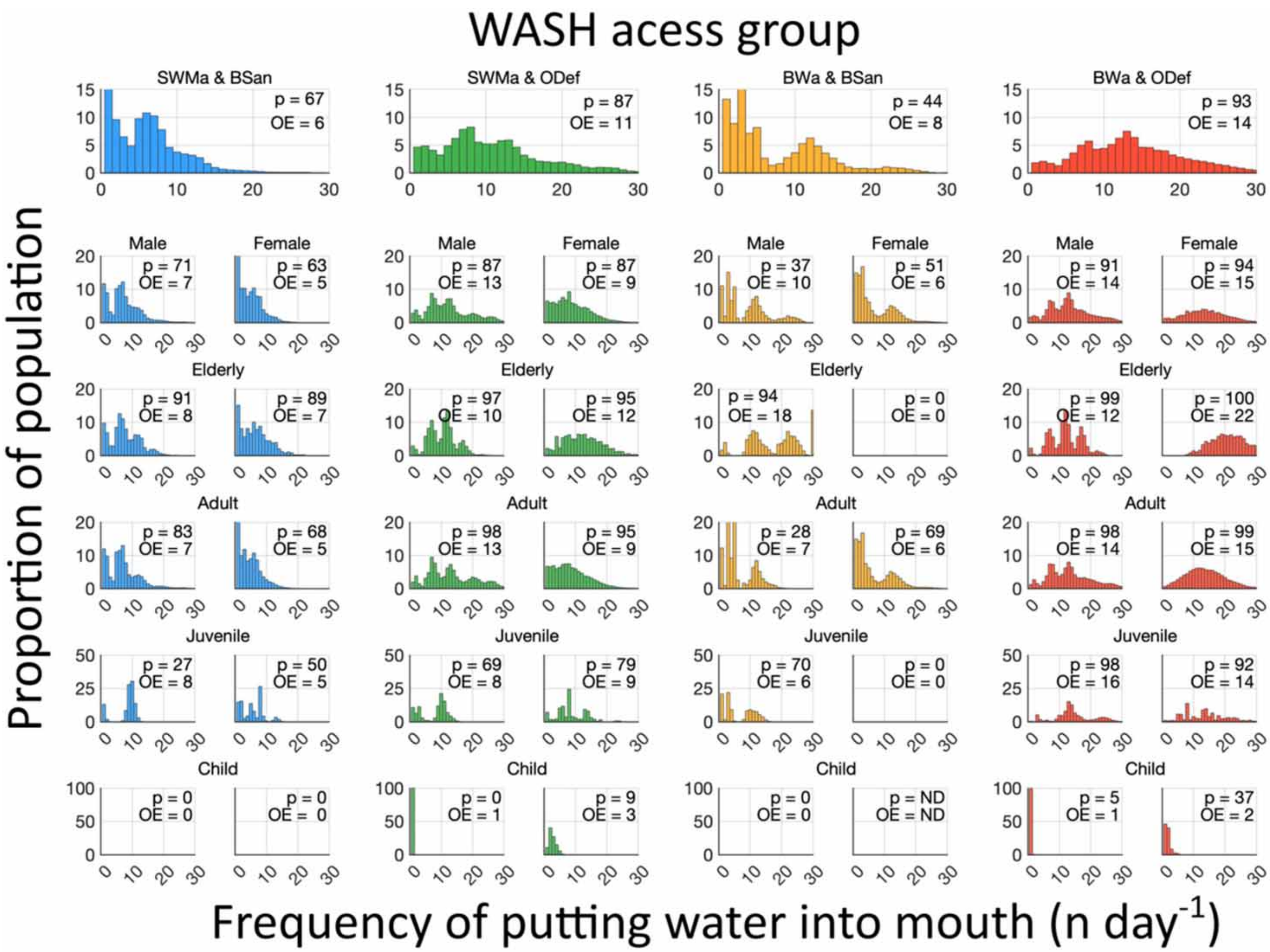


Figure 5 | Estimated frequency of putting water into one's mouth stratified by access to safely managed water (i.e. private piped connection and/or tubewell on premises) and/or basic sanitation (i.e. household improved latrine), gender, and age group. Each subplot shows the distribution in the relevant strata of a simulated population of 400,000 individuals, with the proportion (p) of the sub-group putting water into their mouth at least daily, and the mean daily frequency (OE) reported. Strata with no individuals are denoted with no data (ND). Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/wh.2023.309.

DISCUSSION

We identified surprisingly high rates of daily oral exposure to surface water in a population with relatively high access, at 69%, to safely managed water and the balance with basic access to nearby government tubewells and taps. An estimated 44–93% of people had daily oral exposure to pond water with ingestion likely occurring 6–14 times on average per day. Despite good drinking water quality access at or near homes in this setting, individuals used ponds to meet many daily water needs for personal and domestic hygiene, sanitation, recreation, and amenity uses. Use of surface water bodies for such things as bathing, laundry, brushing teeth, food hygiene (scouring utensils and vegetables), and swimming exposes individuals to waterborne pathogens in fecally contaminated surface water as well as water-based and vector-borne diseases when present (White *et al.* 1972).

Studies show ponds in this region have high levels of fecal pathogen contamination, including with pathogenic *E. coli*, rotavirus, pathogenic protozoa, and *Vibrio cholera* (Mukherjee *et al.* 2011; Biswas *et al.* 2014; Daniels *et al.* 2015; Odagiri *et al.* 2016). *Vibrio cholera* outbreaks in the neighboring state of West Bengal have been repeatedly linked to the use of community ponds for scouring utensils, bathing, and mouth washing, with initial contamination attributed to cholera-infected individuals washing soiled clothes in ponds and defecating near or in ponds (Mukherjee *et al.* 2011; Biswas *et al.* 2014). Elsewhere enteric diseases including cholera have similarly been traced to using surface water for such things as bathing, doing laundry, washing utensils, and brushing teeth (Birmingham *et al.* 1997; Acosta *et al.* 2001; Hamner *et al.* 2006). Even in developed countries where surface water quality is more likely to be monitored and regulated, ingestion of fecally contaminated water during swimming is a frequent cause of disease outbreaks linked to fresh water recreation (Schets *et al.* 2011; Graciaa *et al.* 2018).

Whether these findings are unique to India or broadly relevant is important to consider. Anal cleansing and rubbing gudakhu with pond water may be particular to the Indian context. However, the other domestic and personal hygiene activities occurring at ponds in this study are commonly reported uses of unprotected water sources in many low- and middle-income settings where multiple water sources are widely used to meet domestic water needs (see for example, studies reviewed in Elliott *et al.* (2017) and Daly *et al.* (2021)). The high rate of oral exposure, approaching 1 per minute (Supplementary Appendix 3, Figure 1), during the execution of these activities at ponds is also remarkable and may be unique to India. Oral exposure occurred during both accidental and intentional ingestion. Specific behaviors observed at ponds that involved intentional oral exposures included rinsing the mouth, sipping water and submerging the body including the lower portion of the head with the mouth open. Nonetheless, the high prevalence of contaminated pond water use for so many domestic activities, even in households with safely managed water, raises the question 'why?' Are traditions or habits, religious beliefs, cultural preferences, mistaken risk perceptions, or the structure, characteristics or quality of the water service driving these practices? We have no evidence that cost, time, availability, or reliability of piped water or tubewells in study villages posed a significant barrier to the quantities used. On the other hand, reported daily and often more frequent use of ponds for these routine activities by so much of the population might suggest a combination of habit, preference, and lack of awareness of risks as important contributors. Further study to understand why these activities continue to occur at ponds despite good water access is needed to develop appropriate policies and interventions to reduce exposures.

Water access at the JMP basic level is thought to allow for the use of adequate quantities of safe water at home for drinking, cooking, food hygiene, handwashing, and face washing, but not necessarily for bathing and laundry which may be conducted at water sources away from home (Howard *et al.* 2020). Access provided at the higher JMP safely managed level is expected to provide sufficient quantities of water at home to allow all essential health needs to be met, although empirical evidence to support this assumption is weak (Howard *et al.* 2020; Daly *et al.* 2021). This exploratory study lends support to the assumption that basic access is often inadequate for bathing and laundry needs, but suggests it may also be inadequate for other important personal and food hygiene needs. At the same time, findings for those with safely managed water access, even when they also had basic sanitation, would undermine the notion that this service provides adequate water quantities at home for all daily personal and domestic hygiene activities needed to protect health. Instead, this study offers potential support for the idea that health protection requires 'optimal' access, or the consumption of greater quantities of water afforded by water supplied continuously at home through multiple taps (Howard *et al.* 2020).

Sanitation water needs are not addressed in the WHO assessment of the adequacy of quantities provided at different water service levels, but emerge here as important for anal cleansing after defecation and would also be critical for toilet flushing in a setting such as this where pour flush toilets are the main sanitation technology. Lack of access to basic sanitation increased the likelihood of using ponds for anal cleansing and bathing, irrespective of water access level, however, reported rates of pond use for these activities were still notably high among those with basic sanitation (Figure 2). Individuals who had both basic sanitation and safely managed water access had the lowest rates of using ponds for anal cleansing and bathing, at 41 and 40%, respectively. The extent to which basic sanitation access reduced pond exposure for households without safely managed water is unclear, given the very small sample of just 34 out of 1,021 individuals surveyed in the WASH group with basic water and basic sanitation access (see Figure 1). However, qualitative and quantitative studies of latrine use behavior in Odisha show that until households with basic sanitation access also have on-plot water access for anal cleansing and bathing at home, they continue to defecate in the open near surface water bodies where they can conveniently cleanse and bath following defecation (Jenkins *et al.* 2014; Routray *et al.* 2015).

This was an exploratory study, with a relatively small survey sample size, just 200 HHs, resulting in limited or no data for some age-gender-WASH strata. For example, the survey population had no female children and just one female juvenile and elder in the WASH group with basic water and basic sanitation. The WASH group of individuals observed and recorded at ponds was unknown, and behavior during activities conducted at ponds may have differed by the WASH group. However, survey communities were ethnically, economically, and religiously very similar, individuals observed at ponds came from the surveyed villages, and activities (Table 1) were commonly reported as practiced at ponds by individuals in each demographic (except children) in each of the three main WASH groups. Nonetheless, this limitation could have resulted in the over- or under-prediction of exposures for a given sanitation/water group in the simulation modeling.

We found that at least one person in most households (86%) in our study reported using ponds on a daily or more frequent basis for a variety of non-consumptive domestic needs, with anal cleansing the most often reported use (71% of households using ponds). Observations at ponds showed that 82% of ponds users, irrespective of purpose, accidentally or intentionally put water into their mouth a median of 5 times per visit. These findings highlight the potential for surface water exposures outside the home to confound health outcomes from WASH interventions focused solely on exposure routes in the home environment, wherever households use multiple water sources to meet non-consumptive daily water needs. Others have also highlighted the need to consider additional sources of exposure outside the home when designing and evaluating WASH interventions to maximize their health impacts (Elliott *et al.* 2017; Pickering *et al.* 2019). In this particular case, to gain a better understanding of the disease burden implications of the high rate of daily oral exposure to pond water identified in this study population, methods such as Quantitative Microbial Risk Assessment (QMRA) that combine exposure and pathogen concentration data to estimate infection risk and illness, as done elsewhere (Purnell *et al.* 2020; Uprety *et al.* 2020), may be useful.

CONCLUSIONS

This study demonstrates how structured observations can be combined with household survey data to examine water use activities and practices occurring at surface water bodies away from home. These activities, as shown in this study, may present an important overlooked pathway of exposure to fecal pathogens in surface water usually assumed to be absent where people have good access to safe drinking and cooking water. Greater attention to and study of non-consumptive domestic uses of unsafe water sources, in particular surface water bodies, are needed to establish the extent of the problem and potential overlooked health risks that may be occurring in populations with basic or safely managed water access. Studies should also investigate the reasons why these practices occur to inform policy as to whether higher levels of optimal access, health education, behavior change, and/or other kinds of infrastructural investments, for example home bathing rooms, improved household water storage, or public laundry facilities at safe sources, may be required to achieve the health improvements expected from investments in basic and safely managed water access. Such studies would also help to determine whether findings in this study are unique to India or more broadly relevant in low- and middle-income settings where communities use multiple water sources.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Acosta, C. J., Galindo, C. M., Kimario, J., Senkoro, K., Urassa, H., Casals, C., Corachán, M., Eseko, N., Tanner, M. & Mshinda, H. 2001 Cholera outbreak in southern Tanzania: risk factors and patterns of transmission. *Emerging Infectious Diseases* **7** (3 Suppl), 583.

Birmingham, M. E., Lee, L. A., Ndayimirije, N., Nkurikiye, S., Hersh, B. S., Wells, J. G. & Deming, M. S. 1997 Epidemic cholera in Burundi: patterns of transmission in the Great Rift Valley Lake region. *The Lancet* **349** (9057), 981–985.

Biswas, D. K., Bhunia, R., Maji, D. & Das, P. 2014 Contaminated pond water favors cholera outbreak at Haibatpur village, Purba Medinipur district, West Bengal, India. *Journal of Tropical Medicine* **2014**, 1–5.

Clasen, T., Boisson, S., Routray, P., Torondel, B., Bell, M., Cumming, O., Ensink, J., Freeman, M., Jenkins, M., Odagiri, M., Ray, S., Sinha, A., Suar, M. & Schmidt, W.-P. 2014 Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial. *The Lancet Global Health* **2** (11), e645–e653.

Daly, S. W., Lowe, J., Hornsby, G. M. & Harris, A. R. 2021 Multiple water source use in low-and middle-income countries: a systematic review. *Journal of Water and Health* **19** (3), 370–392.

Daniels, M. E., Shrivastava, A., Smith, W. A., Sahu, P., Odagiri, M., Misra, P. R., Panigrahi, P., Suar, M., Clasen, T. & Jenkins, M. W. 2015 Cryptosporidium and Giardia in humans, domestic animals, and village water sources in rural India. *The American Journal of Tropical Medicine and Hygiene* **93** (3), 596.

Elliott, M., MacDonald, M. C., Chan, T., Kearton, A., Shields, K. F., Bartram, J. K. & Hadwen, W. L. 2017 Multiple household water sources and their use in remote communities with evidence from Pacific Island countries. *Water Resources Research* **53** (11), 9106–9117.

Graciaa, D. S., Cope, J. R., Roberts, V. A., Cikesh, B. L., Kahler, A. M., Vigar, M., Hilborn, E. D., Wade, T. J., Backer, L. C. & Montgomery, S. P. 2018 Outbreaks associated with untreated recreational water – United States, 2000–2014. *Wiley Online Library* **18**, 2083–2087.

Hamner, S., Tripathi, A., Mishra, R. K., Bouskill, N., Broadaway, S. C., Pyle, B. H. & Ford, T. E. 2006 The role of water use patterns and sewage pollution in incidence of water-borne/enteric diseases along the Ganges River in Varanasi, India. *International Journal of Environmental Health Research* **16** (2), 113–132.

Howard, G., Bartram, J., Williams, A., Overbo, A., Fuente, D. & Geere, J.-A. 2020 *Domestic Water Quantity, Service Level and Health*, 2nd edn. World Health Organization, Geneva, Geneva.

Jenkins, M. W., Freeman, M. C. & Routray, P. 2014 Measuring the safety of excreta disposal behavior in India with the new safe san index: reliability, validity and utility. *International Journal of Environmental Research and Public Health* **11** (8), 8319–8346.

Mukherjee, R., Halder, D., Saha, S., Shyamali, R., Subhranshu, C., Ramakrishnan, R., Murhekar, M. V. & Hutin, Y. J. 2011 Five pond-centred outbreaks of cholera in villages of West Bengal, India: evidence for focused interventions. *Journal of Health, Population, and Nutrition* **29** (5), 421.

Odagiri, M., Schriewer, A., Daniels, M. E., Wuertz, S., Smith, W. A., Clasen, T., Schmidt, W.-P., Jin, Y., Torondel, B., Misra, P. R., Panigrahi, P. & Jenkins, M. W. 2016 Human fecal and pathogen exposure pathways in rural Indian villages and the effect of increased latrine coverage. *Water Research* **100**, 232–244.

Pickering, A. J., Null, C., Winch, P. J., Mangwadu, G., Arnold, B. F., Prendergast, A. J., Njenga, S. M., Rahman, M., Ntozini, R. & Benjamin-Chung, J. 2019 The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health* **7** (8), e1139–e1146.

Purnell, S., Halliday, A., Newman, F., Sinclair, C. & Ebdon, J. 2020 Pathogen infection risk to recreational water users, associated with surface waters impacted by de facto and indirect potable reuse activities. *Science of The Total Environment* **722**, 137799.

Routray, P., Schmidt, W. P., Boisson, S., Clasen, T. & Jenkins, M. W. 2015 Socio-cultural and behavioural factors constraining latrine adoption in rural coastal Odisha: an exploratory qualitative study. *BMC Public Health* **15** (1), 1–19.

Russo, G. S., Eftim, S. E., Goldstone, A. E., Dufour, A. P., Nappier, S. P. & Wade, T. J. 2020 Evaluating health risks associated with exposure to ambient surface waters during recreational activities: a systematic review and meta-analysis. *Water Research* **176**, 115729.

Schets, F., Husman, A. D. R. & Havelaar, A. 2011 Disease outbreaks associated with untreated recreational water use. *Epidemiology & Infection* **139** (7), 1114–1125.

UNICEF, WHO 2017 *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), Geneva.

Uprety, S., Dangol, B., Nakarmi, P., Dhakal, I., Sherchan, S. P., Shisler, J. L., Jutla, A., Amarasiri, M., Sano, D. & Nguyen, T. H. 2020 Assessment of microbial risks by characterization of *Escherichia coli* presence to analyze the public health risks from poor water quality in Nepal. *International Journal of Hygiene and Environmental Health* **226**, 113484.

White, G., Bradley, D. & White, A. U. 1972 *Drawers of Water: Domestic Water Use in Fast Africa*. University of Chicago Press, Chicago, London.

WHO, UNICEF 2019 *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017. Special Focus on Inequalities*. United Nations Children's Fund (UNICEF) and World Health Organization, New York.

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