Combining sensor monitoring and ethnography to evaluate household latrine usage in rural India

Kathleen O'Reilly, Elizabeth Louis, Evan Thomas and Antara Sinha

ABSTRACT

This paper advances research on methods used to evaluate sanitation usage and behavior. The research used quantitative and qualitative methods to contribute to new understanding of sanitation practices and meanings in rural India. We estimated latrine usage behavior through ethnographic interviews and sensor monitoring, specifically the latest generation of infrared toilet sensors, Portland State University Passive Latrine Use Monitors (PLUMs). Two hundred and fifty-eight rural households in West Bengal (WB) and Himachal Pradesh, India, participated in the study by allowing PLUMs to be installed in their houses for a minimum of 6 days. Six hundred interviews were taken in these households, and in others, where sensors had not been installed. Ethnographic and observational methods were used to capture the different defecation habits and their meanings in the two study sites. Those data framed the analysis of the PLUM raw data for each location. PLUMs provided reliable, quantitative verification. Interviews elicited unique information and proved essential to understanding and maximizing the PLUM data set. The combined methodological approach produced key findings that latrines in rural WB were used only for defecation, and that low cost, pit latrines were being used sustainably in both study areas.

Key words | behavior change, ethnography, India, policy, sanitation, sensor monitoring

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INTRODUCTION

While Indian sanitation policy is increasing coverage in rural areas through state-funded, social marketing, and behavior change approaches, toilets are not necessarily being used. Individual household latrines (IHLs) are converted to storage units, animal housing, or are neglected entirely (O'Reilly 2010). Toilets are only sporadically/seasonally used, or are used by some family members and not others (Coffey *et al.* 2014). Toilets are used in ways that are unsanitary and fail to reduce in disease (Montgomery *et al.* 2010; Jenkins *et al.* 2014). The process of becoming a toilet user remains little understood, in part because of the myriad factors and processes that play a role in toilet adoption (Waterkeyn & Cairncross 2005; Joshi *et al.* 2011; Barnard *et al.* 2013; O'Reilly & Louis 2014). Furthermore, sanitation studies have yet to resolve the question of how to measure toilet usage with accuracy and sensitivity, leaving open the question of whether current policy is effective (Cousens *et al.* 1996; Rodgers *et al.* 2007). As Thomas *et al.* (2013) recommended, more rigorous, innovative evaluations are needed to guide best practices and improve future programs. Without clarity on why sanitation is adopted in some places and not others, programing and policy development is made more difficult.

This paper intends to fill a gap in studies of rural sanitation by demonstrating the combined strengths of quantitative and qualitative methods. We used Passive Latrine Use Monitors (PLUMs; instrumented monitoring) to quantify toilet usage. We used ethnography to learn about users, their beliefs about sanitation, and how beliefs influenced practices (Rheinländer *et al.* 2010). Ethnography is judged methodologically by different criteria than quantitative methods (Small 2009), leading to some tensions in research design. However, combining the two methods enabled insights into everyday sanitation

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behavior, including key findings that: (1) toilets across the WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation spectrum were sustainably used in both study areas; and (2) beliefs of impurity limited toilet use to defecation in West Bengal (WB). We discuss these findings below, after a brief review of the literature.

UNDERSTANDING AND MONITORING SANITATION ADOPTION

Studies deploying ethnographic methods, especially in-depth interviews, have uncovered a number of non-health-related reasons motivating toilet building, e.g., social prestige, protection of women family members, desire to be modern, desire to take advantage of something given with little opportunity cost to the family, and rising household incomes (Srinivas 2002; Jenkins 2004; Jenkins & Curtis 2005; O'Reilly & Louis 2014). Interviews and focused group discussions have illuminated geographic variations in meanings of waste and hygiene; local norms for gendered, age-relevant defecation practices; and socio-religious rules about waste disposal matter for sanitation uptake (Mcfarlane 2008; O'Reilly 2010; Drangert & Nawab 2011). As Rheinländer *et al.* (2010) argued, knowledge of communities' beliefs about defecation is critical, as practices derive from beliefs. Insights into beliefs, values, and meanings may be learned by asking people about them, and by observing their practices as a reflection of their beliefs. We used ethnography to illuminate geographically specific toilet use behaviors and the beliefs behind them.

Researchers have tackled the problem of assessing toilet usage (e.g., Olsen *et al.* 2001; Montgomery *et al.* 2010), but as yet, no single observational solution manages to be accurate, sensitive, and non-intrusive. Structured observation at peak times of toilet usage is intrusive and may alter users' behavior (Ram *et al.* 2010; Clasen *et al.* 2012). It is also time-consuming, costly, and therefore difficult to scale up, while only providing a limited snapshot of potentially biased behavior. Observational methods such as looking for fresh feces in the pit or in open defecation areas, presence of materials for anal cleansing, and/or a wet toilet floor are subjective, lack sensitivity and specificity, and may be impossible given the toilet technology (Clasen *et al.* 2012). Self-reporting is also problematic as individuals may over-report in an effort to please the data collector, and gender of the evaluator has been shown to cause under-reporting (Manun'Ebo *et al.* 1997).

Cellular phone network-based monitoring technology has been field-tested to record usage and behavior change in WASH and other public health interventions, e.g., the provision of household water filters, hand washing stations, and cookstoves (Thomas *et al.* 2013). Effective use of remote monitoring is made possible by improved cellular networks, low cost of electronic components, and improved battery technology (Thomson *et al.* 2012; Thomas *et al.* 2013). The main argument for using electronically instrumented monitoring technologies is that they provide cost-effective, objective, accurate, regular, and continuous data thereby filling a critical gap in the ability to monitor health interventions effectively (Clasen *et al.* 2012; Thomas *et al.* 2013).

Below we discuss the study site and population selection rationale before moving into the specific methods guiding the quantitative and qualitative portions of the research. An analytical section follows, including a description of our iterative process, and discussion of findings. We conclude that, despite the challenges of integrating disparate methodological tools, combined methods offer new understandings of sanitation behavior in rural India.

SITE SELECTION AND STUDY POPULATION

Our goal was to contribute new insights into effective sanitation by studying unique places where sanitation was adopted at rates of almost 100% in parts of rural India. Therefore, the research was conducted in rural village areas of WB and Himachal Pradesh (HP) – two geographically and economically different states that have made some of the greatest improvements in sanitation coverage in the past 20 years (Table 1).

Table 1 | Percentage of households without toilets in WB and HP – 1992/93 to 2011

State	1992/93[1]	2001[2]	2011[2]
WB	59.6	56.3	41.2
HP	87.4	66.6	30.9
All India	69.7	63.6	53.1

Source: [1]NFHS-1 and NFHS-2 (National Family Health Survey), India. www.nfhsindia.org.
[2]Census of India, 2011.

We chose Gram Panchayats (GPs; i.e., political subdivisions comprising multiple small villages) that won the Clean Village Award (NGP; a cash award for open defecation free status) in the past 3–5 years and that were well-known locally and extra-locally as areas of high toilet usage. Selected GPs were of mixed caste and class composition to enable a broad, socio-demographic cross-section of participants. Several IHL types were observed at each site; most were improved sanitation (Table 2). Toilet cabins ranged from plastic sheeting to brick and mortar walls with slab roofs. Almost all toilets were built at a distance from the main dwelling. In HP, some households had attached (to the house) toilets in a room large enough for bathing (hereafter, toilet/bathroom).

The field team in WB comprised the second author and two local research assistants who worked from September to December 2012. The field team in HP comprised the second author, one of the WB research assistants, and two local assistants working from January to March 2013. The first author was on site for the first month of the field period in each state. All teams were fluent in Hindi; local assistants spoke the local language(s). The villages and informants were given pseudonyms. Interviews took place after participants were informed of the research goals, work plan, and consent documents. The research was approved by the Texas A&M Office of Research Compliance Institutional Review Board.

Table 2 | Socio-demographics of households interviewed

	All	WB1	WB2	HP1	HP2
Number of households	607	150	156	151	150
Age of interviewees					
18–24	44	15	13	3	13
25–30	59	18	15	8	18
31–35	74	20	19	17	18
36–40	76	23	18	17	18
41–45	60	21	15	14	10
46–50	75	19	19	19	18
51–55	54	13	13	18	10
>55	165	21	44	55	45
Gender of interviewees					
Female	286	70	70	74	72
Male	327	80	84	78	85
Marital status					
Married	547	141	147	133	126
Single	25	1	5	5	14
Widowed	35	8	4	13	10
Divorced/separated	0	0	0	0	0
Education					
Illiterate	100	34	32	14	20
Did not complete primary school	66	28	26	6	6
Completed primary school	43	14	8	7	14
Some secondary school	240	57	69	76	38
Completed high school	83	5	9	24	45
In or completed college	75	12	12	24	27
Sanitation facility					
No facility	2	0	0	0	2
Pit latrine without slab	2	2	0	0	0
Pour flush to pit latrine (cement pan or *kaccha toilet*)	172	70	98	1	3
Pour flush to pit latrine (porcelain pan or *pucca toilet*)	428	77	58	150	143
Shared toilet	3	1	0	0	2
Water scarcity					
2–4 months	35	0	0	30	5
None	572	150	156	121	145

QUANTITATIVE METHODS

Sensor monitoring

The technology employed in this study, Portland State University PLUMs, is described in technical detail in other publications, including Thomas *et al.* (2013). A simple infrared motion detector was used, identical to the commercial sensor selected in the Clasen *et al.* (2012) study. A comparator circuit was linked with the motion detector, and recorded each detected motion. One or more times per day, the comparator board relayed logged data events to the internet via GSM cellular technology. A handheld cell phone was used to determine if a signal could be located at the household, indicating the PLUM could communicate with the cell phone tower. If a strong signal was unavailable, it was switched into local logging mode on a micro-SD card and data were manually uploaded after removal from the toilet. PLUMs were fastened with zip ties (also known as cable ties) within 5 feet of the toilet pan.

Forty PLUMs were utilized and were rotated between 291 households. In related studies, PLUMs suggested low behavioral reactivity after the first several days, so PLUMs were installed for 7–10 days to capture behavior for at least 6 days of data. PLUM installations occurred based on willingness to accept, and the presence of the household head. The PLUM installation sample illustrates one of the tensions arising from combining qualitative and quantitative methods: we do not claim a representative, random, or unbiased sample of households with PLUMs installed. Ethical obligations prevented the installation of PLUMs in households that refused them, which may have biased the data if refusal was due to toilet non-use. However, respondents were forthcoming in interviews about household members who went for open defecation whether they accepted PLUMs or not, nor was there a noticeable difference in PLUM acceptance across the study sites once we routinized our installation strategy. Informants' honesty also enabled us to better calculate the number of toilet users per household, refining PLUM data analysis. It is possible that interviewing before installation and the initial presence of the PLUM may have influenced household behavior. This potential reactivity has not been rigorously characterized to date.

The PLUM online software system contains several data correction, reduction, and analysis routines. Subsequently, an R code is run to interpret the raw data and generate estimates of 'usage events'. The algorithm employed is largely based on Clasen *et al.* (2012), with some adjustments to account for technological differences between the sensors. To validate the adjusted interpretation algorithm, the current technology (SweetSense PLUM; third generation) was deployed alongside the earlier, validated technology (2G PLUMs; second generation) in 11 household latrines conducted outside the research study environment, in rural communities in Orissa, India in the fall of 2013 (Sinha in preparation). A Bland Altman comparison, a method commonly used to analyze agreement between two different measurement methods (2G PLUMs v. SweetSense (SS) PLUMs) of the same parameter, is shown in Figure 1. The mean difference between usage events detected by both 2G and SS PLUMs of 2.3 events per household per day is represented by the horizontal solid line with the differences from the mean shown in a scatter plot. The comparison indicated agreement, on average, between the two technologies, but with a large standard deviation. The large standard deviation of approximately eight usage events per household per day suggested that an additional comparative method was required to have confidence in the comparability of these two technologies.

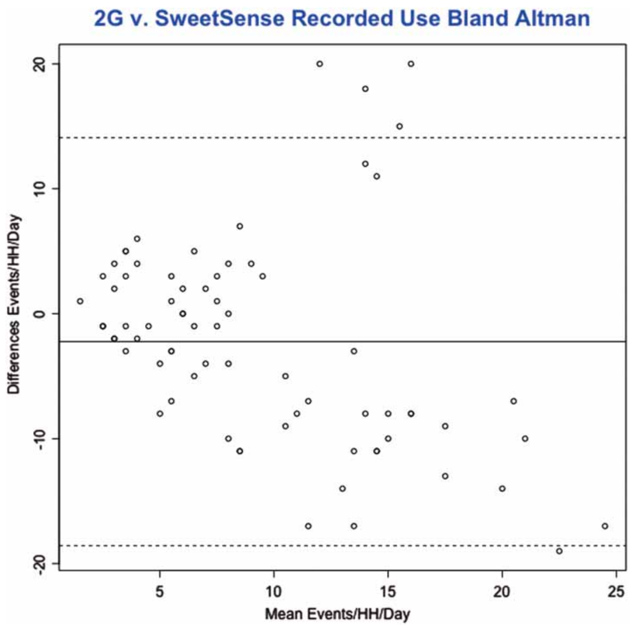

Figure 1 | Bland Altman Test: 2G PLUMs versus SweetSense PLUMs recorded use.

Therefore, a secondary data source was used consisting of structured observations, also in Orissa, India. The structured observations included deploying both versions of the PLUMs and having an observer manually record use of each latrine (Figure 2). First, each sensor-detected event was compared against the temporally nearest manually observed event, allowing for an evaluation of error associated with over-reporting events, or false positives ('o' scatter plot and associated line fit). The converse was then applied, comparing each manually observed event against the temporally nearest sensor-detected event, indicating error associated with under-reporting, or false negatives ('x' scatter plot and associated line fit). The axes are shown in Unix seconds (seconds since 1 January 1970) for ease of computational analysis. The analysis shows near perfect agreement between the observed and sensor-detected events, with only three outliers. Two 'o's (overlaying each other) show observed events that were not closely aligned with sensor events. One 'x' is the converse. The sample size of the observed versus recorded events

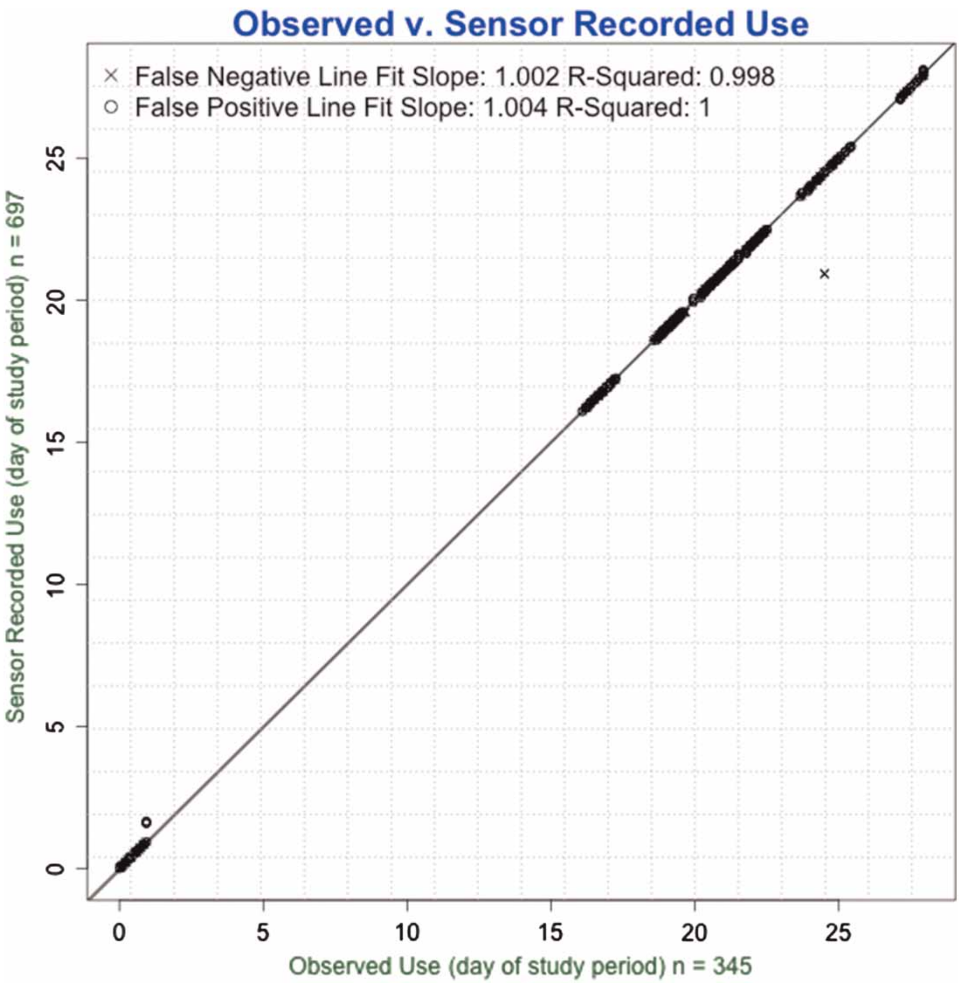

Figure 2 | Structured observed use versus sensor recorded toilet use.

are different because the sensors were in place considerably longer than the observers, leading to a greater number of sensor events available for the correlation analysis. These results suggest that the latest generation of PLUM sensors interpret usage events in a method substantially similar to the earlier, validated, technology.

QUALITATIVE METHODS

Ethnography

We conducted over 600 in-depth semi-structured interviews with household members and key informants. The rationale for 600 interviews was to ensure saturation (i.e., interviews produced no new data) and to interview across socio-economic characteristics and toilet type in each of the four GPs (see Table 2). We only interviewed in households where toilets were present and householders reported that they were being used. Respondents were adults, but not necessarily the household head. Household interviews covered: family composition, general usage, household toilet building history, and their understandings of human waste, sanitation, and hygiene. We did not ask respondents about their usage habits because we found early in the field period that respondents grew suspicious that we were 'checking' (i.e., official record keeping that may have negative repercussions for households) on toilet usage. Households were reassured that we were not checking, but seeking to confirm our information that these were GPs where most households used their toilets.

This strategy of reassuring interviewees highlights again the tensions between qualitative and quantitative methods – in order to allay subjects' fears, the research team informed subjects of the research goals in ways that may have biased their answers. The size of the interview sample may have compensated for bias, but ethnography also depends on the research team's ability to sense if informants lie or prevaricate. We omitted such interviews from our analysis. Once PLUMs were installed, the time and date of installation was logged in a field notebook. At the final study site, on the day the PLUM was removed, interviewees were questioned about their toilet use habits of the day before. It was only after extensive fieldwork that we felt confident that (1) we could install PLUMs even if we asked about individual usage and (2) that asking would not bias PLUM data beyond expected reactivity.

The research team lived in the GPs while the research was conducted. This facilitated unstructured participant observation events in the form of multiple, informal visits to households to observe household sanitation practices and to triangulate interviews and PLUM data. We also assembled participant households' photographic data sets of toilet type, cabin construction, PLUM installation, and path to toilet from house. Fieldnotes on unstructured participant observation and interview transcripts were coded by recurring themes and analyzed for significant patterns. Household socio-economic data were entered into a spreadsheet. The photographic record was organized by household and referred back to during the iterative analytical process described in the Discussion section. Key informant interviews were used to create a history of sanitation interventions for each study site. After the first round of PLUM data analysis, the research team returned to the field during September 2013 for results' dissemination with stakeholders. We now turn to results and a discussion of findings from each method and as part of an iterative process.

RESULTS

Qualitative results

The detailed ethnographic results have been published elsewhere (O'Reilly & Louis 2014). In brief, successful sanitation depended on three factors: political will, political ecology, and proximate social pressure. Each forms one leg of the 'toilet tripod,' united by political economy – the 'seat' of the toilet tripod. Political will encompassed long-term, multi-scalar government and NGO (Non-Governmental Organization) efforts to facilitate toilet building and usage. Political ecology included the complex human–environment relationships that changed over time to support toilet adoption. Proximate social pressure comprised the informal encounters that influenced neighbors and family members to build and use toilets. All four study sites had different economies, types of government intervention, NGO involvement, and environmental resources. Nevertheless, the framework of the toilet tripod comprehended the success of sanitation in each location. Below we address specific behavior, values, and patterns that emerged through combining ethnography and sensor monitoring.

Quantitative results

Of the 291 household data sets, a total of 258 households' data were included in the analysis. These households had PLUM readings for at least 6 days. Thirty-three households were excluded for having less than 6 days of data, usually due to PLUM failure, and occasionally because households covered or removed PLUMs. A specialized R code for this study parsed interpreted sensor data for each household deployment across the four sites. For each sensor, outliers were removed based on 1.5 times the interquartile range for that data set, a standard outlier removal approach (Weinberg & Abramowitz 2002). For per person usage calculations, the algorithm relied on recorded household toilet user data. Children too young to use a toilet were not counted, as their feces were not generally disposed of in IHLs (O'Reilly & Louis 2014).

The data sets at each site were not normally distributed, likely due to clustered low-end recorded behavior. The total aggregate recorded per person use is shown in a histogram (Figure 3). Therefore, groups were compared using the Wilcox ranked sum test that is less sensitive to non-normal data than the *t*-test. The Wilcox ranked sum difference may be interpreted as a comparable mean difference value as often presented in a *t*-test. Figure 4 and Table 3 show the mean per capita usage events at each of the four sites.

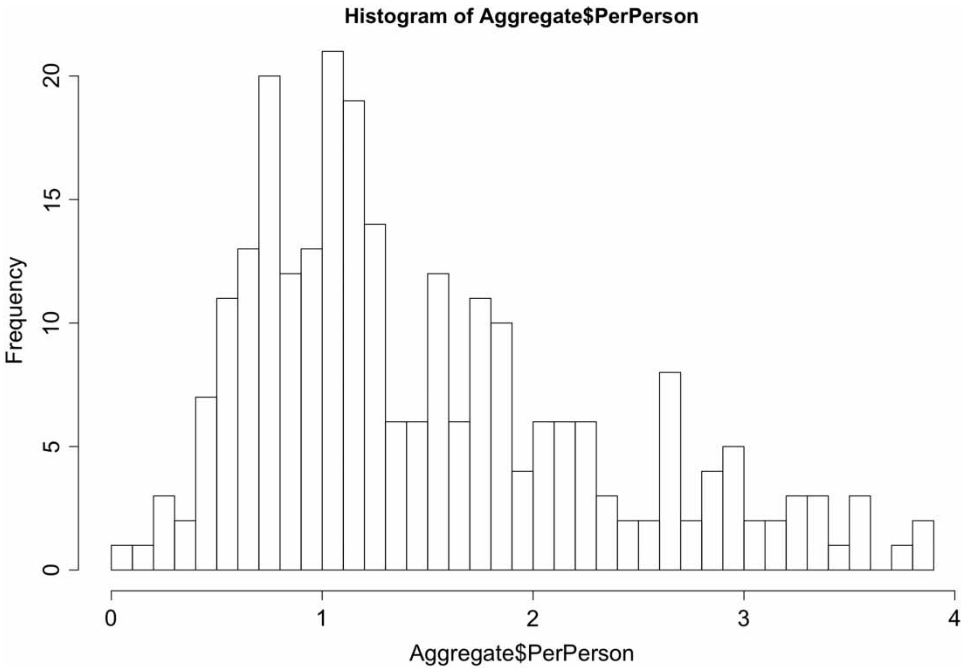

Figure 3 | Histogram of aggregate per person per day latrine use.

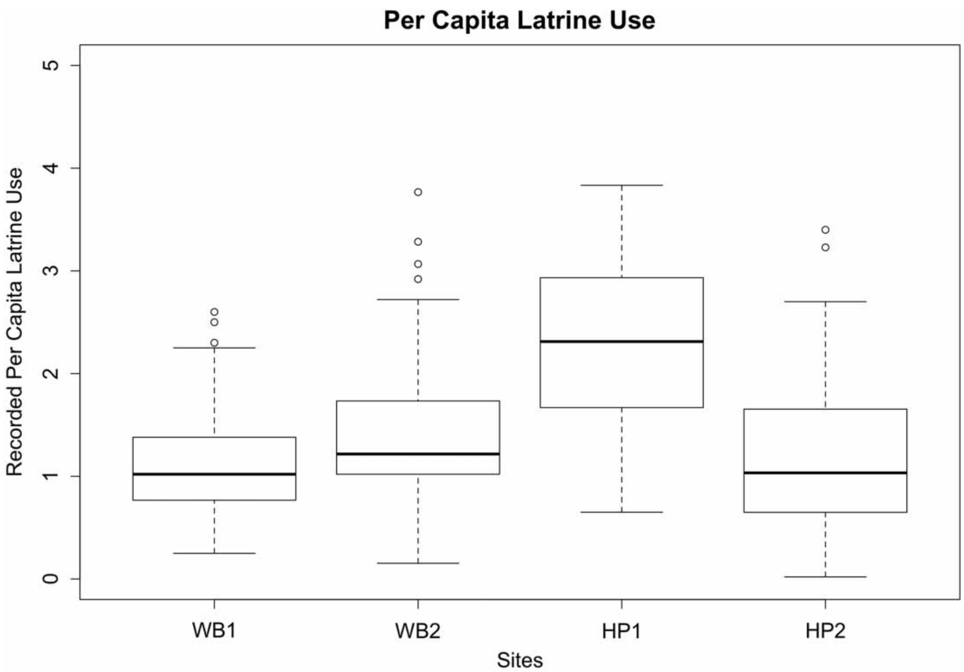

Figure 4 | Per capita latrine use per day by GP.

Table 3 | Mean per capita per day latrine use based on PLUM data by GP and state

GP	Recorded per capita use	Wilcox ranked sum difference
WB	1.29	
WB1	1.14	0.25
WB2	1.46	
HP	1.71	
HP1	2.27	1.13
HP2	1.18	
Overall average	1.51	

According to Clasen *et al.* (2012), a 3 minute separation between usage events was arbitrarily chosen for the algorithm. We repeated this 3 minute separation between usage events. If separate usage events occurred within less than 3 minutes of each other, the algorithm would analyze them as one usage event. Thus, under-reporting during high traffic times may occur with the current analytical algorithm.

Across all four study sites, usage frequency per capita per day averaged 1.51, which is in keeping with norms for Western and non-Western populations (Palit *et al.* 2012). There was a slightly significant difference between WB1 (1.14) and WB2 (1.46), of about 0.245 uses per person per day. Between the two states, there was slight significance for WB (1.29) and HP (1.71) of about 0.34 uses per person per day. No statistically significant differences in per capita usage events by study site were recorded with the exception of the two sites within HP. The influence of the high per capita toilet use in HP1 likely influenced both the state differences *and* the intra-HP differences.

DISCUSSION

In this section, we discuss the insights on mean per capita usage, toilet type, and time of day of usage gained by using combined quantitative and qualitative methods.

Mean per capita usage

Initially, the data analysis suggested that WB2 per capita toilet usage was lower than WB1, but interviews led us to expect that WB2 toilet use should have been the same or higher. In WB2, the majority of households owned toilets for more than 10 years, while in WB1 the majority owned toilets for less than 10 years (see Figure 5). Length of time of sustained intervention and toilet ownership meant that WB2 informants were more likely than those in WB1 to speak in terms of having a 'toilet habit'. We recalculated PLUM installations using fractions of days (as recorded in fieldnotes) to get a more accurate per capita reading than the initial calculation that used whole numbers for days reported. With this adjustment, WB2 (1.46) per capita use was higher than WB1 (1.14) – a slight significant difference. Ethnography alerted us to subtleties in reported toilet usage within NGP villages, and the discrepancy between partial days and full days of installation for PLUM analysis.

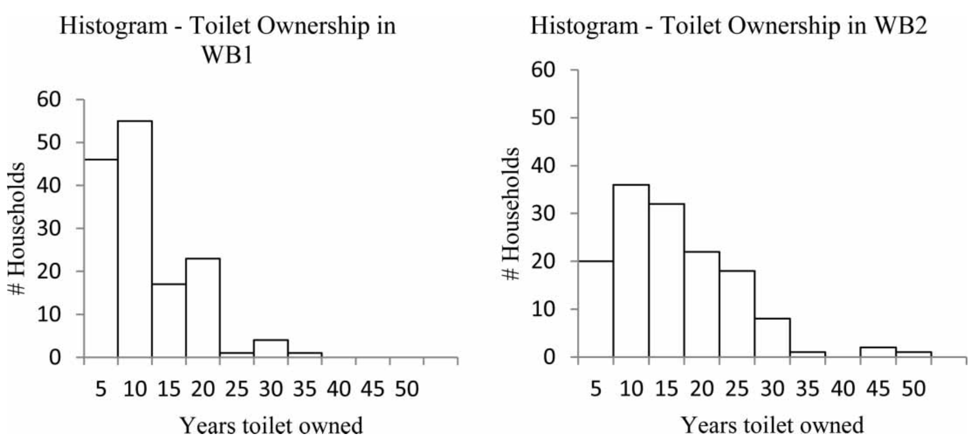

Figure 5 | Histogram of toilet ownership in WB.

The differences in mean per capita toilet usage between WB and HP were expected. In WB1 and WB2, toilets were only used for defecation and bathing after defecation. This was due to the ritual impurity of the toilet cabin, we were told, necessitating bathing and changing one's clothing after defecating inside the cabin. Urination took place outside in the family compound or nearby jungle. Family compounds nearly always had a pond, so most members bathed in the pond. For modesty's sake, some women would wash in the cabin itself. As this woman explained her reason for needing a taller, brick and mortar toilet cabin, 'My daughter cannot stand in the cabin and change her clothes now. People passing by will watch. Is this not a problem? She has to come with wet clothes inside the house.' Previous research has noted the ways in which beliefs about impurity/disgust around feces in the South Asian context influenced sanitation behaviors (Srinivas 2002; Drangert & Nawab 2011). Our ethnography brings to light a geographically specific, toilet-using behavior related to ritual impurity beliefs.

Using PLUM data to calculate 'total time in toilet', HP recorded about 32% more movement in a toilet on average than WB. This was consistent with our ethnographic research indicating that HP households use their toilet/bathrooms for other hygiene activities besides defecation. HP respondents did not report that toilet cabins were ritually impure. Instead, IHLs in both HP study sites were often built to take advantage of the single tap in family compounds, serving several purposes: toilet; bathroom; water filling station; and laundry. These larger rooms with easy access to water meant there was more traffic in and out of them, especially by women, for whom gender norms required them to do these tasks.

The differences in mean per capita usage between HP1 and HP2 were also expected. In HP1, 65% of PLUM-accepting households had toilet/bathroom combinations. In HP2, only 23% had toilet/bathroom combinations. When comparing usage events between toilet and toilet/bathrooms across all sites there was a significant difference (*P*-value 0.00003) indicating that toilet types are important data when using PLUM technology. The difference in per capita toilet use based on toilet type indicated 0.6 fewer uses if the toilet type was 'toilet only' – validating our observations that participants spent less time in these toilet types.

We asked household members in HP1 (our last study site) on the day we removed their PLUM to recall the number of times they defecated the previous day. There was a significant difference between the sensor recorded use average of 2.27 uses per person per day, and the reported use of 1.38 for a Wilcox ranked sum mean difference of 0.85 uses. One sensor monitoring weakness is that it does not detect if the IHL is being used for the deposition of human feces. Ethnography supplied an explanation for the difference: HP1 had more toilet/bathrooms and women reported accessing stored water in the toilet/bathroom space multiple times daily. The photographic record verified that the PLUMs were installed close to toilets, but they were likely capturing non-usage events as well as usage events.

Toilet type

We disaggregated PLUM data based on toilet quality in WB: (1) cement pan in cement slab; or (2) porcelain pan in cement slab using the photographic data set and interview data to determine whether lower cost toilets were used less than higher cost ones. Differences in toilet quality showed no significant difference in per capita usage in WB, where most low cost toilets were located across the four study areas. This result agreed with WB interviews; householders reported that low cost toilets were acceptable and in use. Using Barnard *et al.*'s (2013) criteria for functional latrine (i.e., walls over 1.5 meters; door; unbroken, unblocked pan; and functioning connection to pit (if any)), in WB, latrines were functional, even if those latrines had only plastic sheeting for walls and a door, no roof, and a cement pan. If feces could be flushed, these low cost latrines were used; this was verified by PLUM data. This key finding indicates that basic, low cost models that function are acceptable in communities where toilet use is the social norm.

In WB, a GP had to achieve 90% toilet coverage to win an NGP award. At the time that the NGP toilet drive started in the two study areas, a majority of the households could not afford to build toilets on their own. Availability of low cost cement slabs (250 INR, approximately US$5), free or subsidized pit digging, and walls of plastic sheeting supported widespread, rapid building. In WB2, 50–55% of the households were still using cement pans. In WB1, 40–45% had cement pans or largely subsidized porcelain pans.

There was a clear trajectory of toilet habituation in the region as one elderly man in WB2 explained, 'Earlier people used to go for open defecation OD, then khata paikhana (pit latrine, wooden slab) was built, then plate (pour flush to pit latrine, cement pan) came into existence. Now as people are making money, they are building sanitary paikhana (pour flush to pit latrine, porcelain pan).' As his brief history relates, a significant factor in getting people to stop defecating in the open was enabling them to build pour flush latrines, even those considered temporary, as cement pan latrines were. Plate latrines were a great improvement over pit latrines with wooden slabs or having to practice open defecation. Low cost latrines were less than ideal because they needed periodic reconstruction of toilet cabins, high water tables meant shallow pits (usually 3–4 rings deep) needed to be re-dug, composted, or emptied, but they did not stink, as drop pit toilets did (see also Kvarnstroem *et al.* 2011; Barnard *et al.* 2013). Families in WB that could afford better toilets built with porcelain pans and brick walls built them, but for those who could not, plate latrines were acceptable and were still in use decades after being built.

Pit latrines in HP were larger and had the advantage of well-draining soils and a low water table; few families had ever emptied their pits. Most latrines had porcelain pans with cement slabs, and many families spent disposable income on tanks with piped water supply, decorative tiles, and occasionally, toilet seats.

Peak usage times and occupation

PLUM data verified our ethnographic finding that most household members primarily defecated in the morning (Figure 6). Data also showed a smaller but distinct peak in the evening hours. Sensors do not detect who is using the unit, a problem for per capita usage figures if household numbers fluctuate daily, but the reason households consented to installation. Using ethnography to establish family members' out-of-house routines can narrow the range of individual users throughout the day. For example, men in WB who worked as cycle-cab drivers left their houses early in the mornings and reported defecating elsewhere. Eliminating members of certain occupations as toilet users during peak hours could give more accurate mean per capita usage figures. Information on peak usage times can also assist with: knowing when to station structured observation in future studies verifying toilet usage (e.g., HP peak times were later in the morning than WB peak times (Clasen *et al.* 2012)); capturing off-peak, high usage times (e.g., incidences of diarrhea); and informing shared toilet policy by providing information on peak time, mean per capita per hour figures (i.e., turnover rates).

CONCLUSIONS

A failure to understand sanitation behavior can result in policies that do not meet the needs of target populations. Given high rates of open defecation in India and recently revitalized efforts to end the practice, more research is needed that measures toilet usage and explains the reasons for use and non-use. We purposefully selected unique cases to study successful sanitation uptake, intending our findings to provide new insights, guide further research, and inform interventions. We used ethnography to 'get at' the everyday lived context of study populations' toilet practices by asking people about their values, meanings, and routines. PLUMs counted 'practices', validated interviewees' reporting, and highlighted the significance of specific behaviors.

Our mixed method approach facilitated the general findings that political will, political ecology, and social pressure supported the building and sustained usage of toilets in the study sites (O'Reilly & Louis 2014). Specifically, subsidies were necessary for poor households in WB to build, but these subsidized, low cost toilets were still in use decades after they were built. Contrary to findings that Indians believe latrines are expensive (Coffey *et al.* 2014), or that pit latrines are not sustainable (Kvarnstroem *et al.* 2011), low cost, improved sanitation was used sustainably. We attribute their sustainability to local governments and NGOs in WB that invested in educating families how to manage pit latrines after they filled. As Barnard *et al.* (2013) also found, length of time of ownership mattered for toilet use; users spoke of developing a toilet habit that both supported, and was supported by, social norms in the study areas (see O'Reilly & Louis 2014).

PLUM analysis brought to light our finding that in rural WB toilets were used only for defecation. Due to our immersion in WB, using toilets only for defecating became

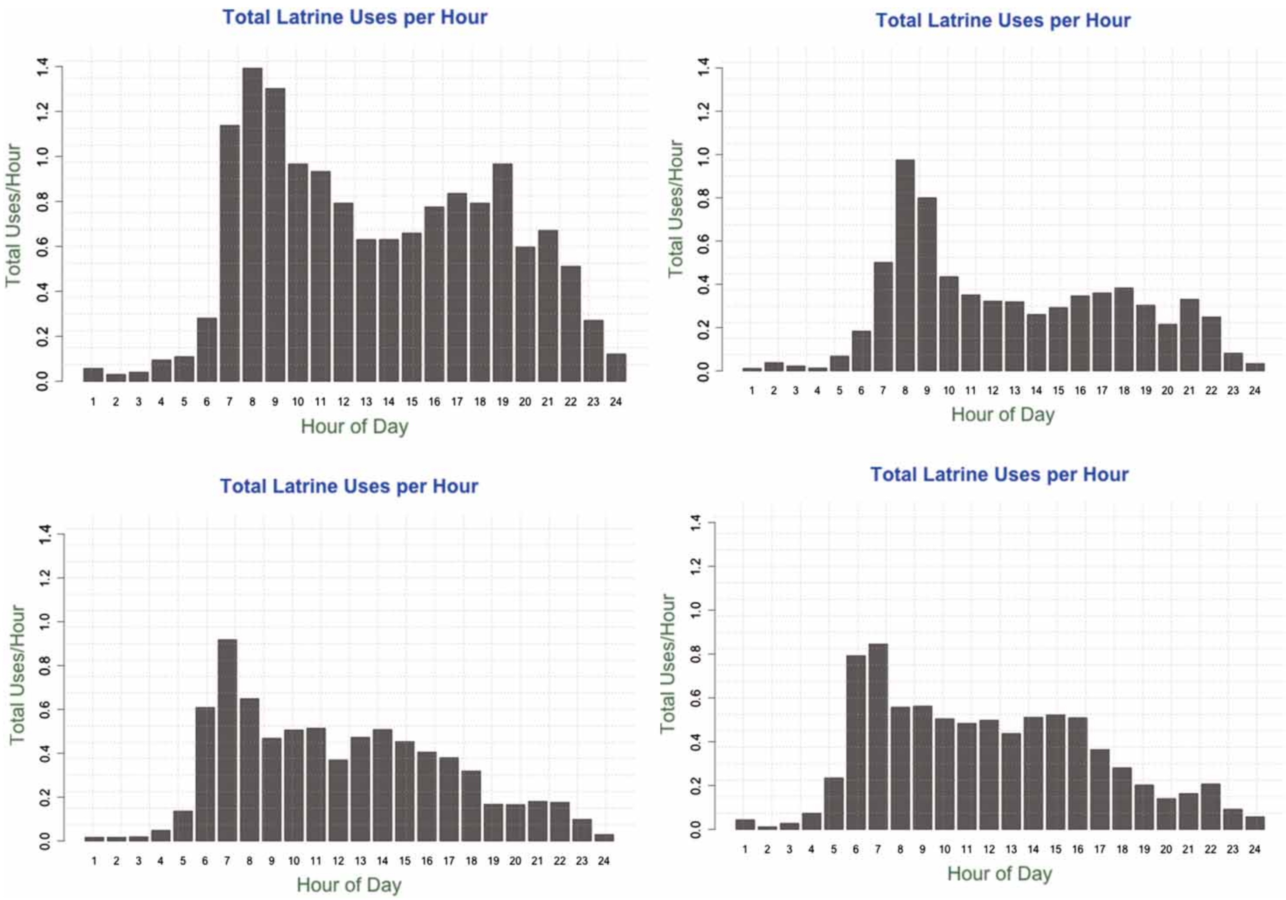

Figure 6 | Time of day usage for all GPs.

normalized. In seeking to explain the differences in mean per capita usage based on PLUM results, we re-discovered WB beliefs of pollution that limited toilet use to defecation. Without the ethnography we could not have explained the PLUM results for WB; without the PLUMs, defecation-only toilet use would have been overlooked. An understanding that a toilet cabin is a polluting space presents new challenges for solving problems such as the disposal of child feces (Jenkins *et al.* 2014) or needing privacy for urination. Currently, PLUMs detect motion in and out of the toilet cabin without information on what occurred inside. Rural WB also presents itself as a place where the PLUM algorithm for usage events might be further refined to assess defecation events since toilets are used only for defecation. Other instruments including audio signal analysis or pressure pads placed near the toilet could also be field tested in WB as further improvement to PLUMs.

As in other studies, we found that not all family members regularly used toilets (Coffey *et al.* 2014; Jenkins *et al.* 2014) but interview data can enable refinement of PLUM data analysis by collecting information on the age and occupation of non-users. This serves the purpose of refining mean per capita usage, and thereby letting us know if the toilet is being used, by how many, and at what time. Standard large-scale survey methods could provide some of the same data (see Barnard *et al.* 2013; Jenkins *et al.* 2014) and be verified by sensor monitoring, but without knowledge of norms and meanings, solutions to problems of non-usage due to occupation and age remain out of reach.

Ethnography relies on trust between the research team and the study community, not just individual interviewees. In small villages in WB and HP occupied by extended families, a misstep could have ended our research at those sites. The question of trust when using combined methodology raises the question as to whether people would be willing to install if they did not live in NGP villages? As stated above, we learned early on that PLUM installations were possible when households were informed that we chose their GP because it was an NGP village – because we knew their toilets were in use. Given the difficulty of installation in places of successful sanitation, installation in locations where populations were informed that they should use toilets but did not, would likely have low PLUM acceptance and could undermine the trust necessary for a rich ethnography.

Ethnography is seldom undertaken as it requires extended field periods and linguistic and cultural fluency, but its strengths lie in discovering new practices, and the surprising, subtle motivations for behaviors. Such discoveries are critical in their own right, but they also can inform other assessment tools. Findings can only be scaled up with caution, because scaling up requires removing norms and meanings from the geographic context where they arose – in this case, tantamount to ignoring the very multi-scalar and intersecting factors (e.g., governance, changing environmental conditions, and processes of social norm development) that produced the conditions of successful sanitation. Similarly, PLUMs are not appropriate for wide-scale measurement of toilet usage in India, given the diversity of behaviors and beliefs across small geographic areas. Nevertheless, the findings from our combined methodology indicate that ethnography and sensor monitoring are important tools in the search for methods to assess toilet usage and behavior.

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