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ORIGINAL ARTICLE

Measurement of Odour in On-Site Sanitation Systems in Low-Income Settings

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Abstract The objective assessment of the level of odour in on-site sanitation systems is required when evaluating emerging technology options and maintenance practices. The purpose of this study was to measure the concentrations of hydrogen sulphide and ammonia as surrogates of odour using a portable gas detector, and assess whether the concentrations of the compounds correlate with the perception of users of the facilities. The Aeroqual 500 portable gas detector with hydrogen sulphide and ammonia sensor heads was used to measure the concentrations of the compounds in 88 private and seven communal latrines sampled from a peri-urban community in Ghana. The odour perception of 189 and 165 users of private and communal latrines, respectively, was assessed on an ordinal scale. It was found that the concentrations of hydrogen sulphide and ammonia measured with the gas detector reflected the known variation of odour levels among different technology options and the perceptions of the latrine users. The concentrations of hydrogen sulphide measured in the water closet, ventilated improved pit (VIP) and the simple pit latrines were 0.01, 0.03 and 0.13 ppm, respectively; those of ammonia were undetected for the water closet, and 0.30 and 3.27 ppm for the VIP and simple pit latrines, respectively. The Pearson correlation coefficient between hydrogen sulphide concentrations and user perception of odour (−0.234) was significant at 5 % level ($p = 0.022$) but that for ammonia was not. The results indicate that a portable hydrogen

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sulphide detector may be employed to objectively assess the effectiveness of new latrine designs and maintenance practices aimed at reducing odour in latrines.

Keywords Odour measurement · Odour perception · Latrine · On-site sanitation · Ghana

1 Background

On-site sanitation systems are the most affordable and often the most technically feasible for many households and communities in low-income countries. They are simple and inexpensive to construct, operate and maintain (Brikké and Bredero 2003; Franceys et al. 1992). When properly constructed, they qualify as improved sanitation technologies (Karnib 2014). However, their quality of service is frequently undermined by the occurrence of offensive odour, especially the dry sanitation systems. For instance, the simple pit latrine is recognised as the cheapest and commonest form of sanitation for many households in low-income areas but it has the tendency to generate offensive odour and breed insects (Cotton et al. 1995; Franceys et al. 1992). Offensive odours create a barrier to consistent latrine usage and lead to open defecation (Obeng et al. 2015).

The odour of human excreta has been attributed to, among others, sulphur- and nitrogen-containing compounds, notably hydrogen sulphide and ammonia, and other organic compounds such as phenols, p-cresol, indole and a variety of carboxylic acids (Lin et al. 2013; Moore et al. 1987; Sato et al. 2002). Technological innovations over the years have sought to minimise or eliminate the offensive odours of these compounds from latrines to offer the user a better level of comfort. Such innovations have included the removal of the volatile compounds through venting systems as used in the ventilated improved pit (VIP) latrine (Mara 1984; Ryan and Mara 1983a), and the application of a water seal, i.e., a layer of water in a bent pipe section, in the water closet to prevent the volatile compounds from escaping from excreta retention systems (Brikké and Bredero 2003; Harvey et al. 2002).

Nevertheless, the generation of offensive odours in some on-site sanitation systems, particularly the pit latrines, remains a critical determinant of latrine uptake and consistent usage among low-income households (Appiah and Oduro-Kwarteng 2011; Keraita et al. 2013). This justifies continuing research to optimise mechanisms for controlling odours in latrines. In view of this, it is essential to have an objective means of measuring the level of odour to serve as a basis for assessing the efficiency of odour improvement techniques (Hudson et al. 2008; Sundberg et al. 2012). Objective measurement of odour levels would address the weakness of the sole reliance on the subjective perception of latrine users which has previously been employed and recommended for latrine improvement research (Ryan and Mara 1983b).

There exist various methods and techniques for measuring the concentration or intensity of odour. These include the olfactometric method of *dilution-to-threshold* which measures the total effect of odour as detected by humans (Gostelow and Parson 2000). Essentially, the method expresses odour intensity in terms of the number of dilutions with odourless air required to reduce the odour concentration to the threshold detectable by the human nose (Capelli et al. 2013). Commonly referred to as dynamic olfactometry, this method has been adopted in standard practices such as the European Union's *Air Quality – Determination of Odour Concentration by Dynamic Olfactometry* (EN 13725 2003) and the United States' *Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits* (ASTM E679 2011).

Another olfactometric method is the *referencing method* in which a series of concentrations of n-butanol is used as a standard Odour Intensity Referencing Scale (OIRS) to which an odour monitor or pollution inspector compares the odour intensity of a sample (McGinley 2002; Powers 2004). It is employed in standard practices such as the United States' *Standard Practice for Referencing Suprathreshold Odor Intensity* (ASTM E544 2010). Besides these, odour may also be measured using the *ranking method* in which panellists rank samples on an ordinal scale (Powers 2004). This method has been recommended for latrine improvement research for assessing latrine users' perception of the odour intensity after introducing an odour control technique (Ryan and Mara 1983b).

Common to all of the above methods is the use of human agents for the assessment of odour intensity. This raises concerns about the reliability and reproducibility of these methods due to the potential variability in the sensitivity of an individual assessor or a panel of assessors (Powers 2004). In response to these limitations, more recent methods have sought to eliminate the subjective judgement of human assessors. These include the use of surrogate compounds and the electronic nose. Compounds whose concentrations correlate well with odour measures are used as surrogates or proxies for odour intensity (Powers 2004). Even though the applications of surrogate compounds and electronic sensors are more objective, they are criticised as measuring mere concentrations of compounds rather than a representation of the experience of odour sensation perceived by humans (Powers 2004; Sironi et al. 2007). Notwithstanding, they offer the most objective means for assessing changes in the concentrations of volatile compounds for research purposes. Electronic noses have a complex human-nose-like structure to mimic the human sense of smell by employing a pattern recognition system to recognise simple and complex odours (Gardner and Bartlett 1994; Pearce 1997; Sankaran et al. 2012).

Nevertheless, the use of the electronic nose is still an emerging technology whose applications have only received attention in industrialised countries due to their high cost. For environmental sanitation research in low-income countries there still remains the challenge of how to objectively determine the level of odour in latrines, in order to assess the effectiveness of new latrine designs and maintenance practices. In this regard, the emergence of portable gas detectors for real-time measurements of concentrations of volatile excreta constituents offers an opportunity to advance the use of surrogate compounds for odour measurement in latrines. The question of the concentrations of the surrogate compound not being representative of the experience of odour sensation perceived by humans could be potentially resolved by comparing the results with the latrine users' perception of odour and benchmarking the concentrations of the surrogate compound with respect to latrine users' perception of odour.

The objective of this study was to employ a portable gas detector to measure the concentrations of hydrogen sulphide and ammonia as surrogates for odour in different on-site latrine technologies in a Ghanaian peri-urban community and to assess the correlation between the concentrations of the compounds and the human perception of odour as indicated by users of the latrines.

2 Methods

2.1 Study Setting

The study was conducted in Prampram, a Ghanaian peri-urban community situated between 5°45′—6°05′N and 0°05′—0°20′W along the coast of the Gulf of Guinea. It has a population of 7800 comprising 1635 households whose main occupations are fishing, farming and trading (DHRC 2012). The climate is tropical with absolute maximum temperature reaching 40 °C and average annual rainfall 762.5 mm (NPDA 2012).

Water supply and environmental sanitation in Prampram is not different from the pattern in many Ghanaian peri-urban towns. With no sewerage infrastructure existing in the community, all residents depend on on-site sanitation technologies. The commonest sanitation technologies are dry systems such as the traditional pit and the ventilated improved pit latrine. Prampram is an old traditional community where the residents practise the extended family system. This, coupled with multiple tenancies of houses, encourages the sharing of latrines in compounds. As compared to national averages, latrine coverage in Prampram is low. Only about 15 % of households have access to latrines in their compounds (Obeng et al. 2015). The rest depend on communal latrines or practice open defecation on the beaches and in the bushes. There were seven communal latrines in the community comprising five ventilated improved pit latrines, one water closet and one pour flush toilet.

2.2 Sampling of Latrines and Study Participants

A total of 88 private latrines were identified from a household database obtained from the Dodowa Health Research Centre, which maintains a demographic and health surveillance system in the community. The selected latrines included 41 household latrines (i.e., used exclusively by one household) and 47 latrines shared by two or more households in their compound. All seven public toilets used in the community were also included in the study.

For each private latrine, up to five users who had used the latrine on the day of the survey were selected to respond to an orally administered survey. They comprised of the owner of the latrine, two other adults (male and female) above the age of 18 and young users (male and female) between the ages of 13 and 18. Thus, 1 to 5 users per latrine, making a total of 189, responded to the survey.

For communal latrines, study participants were selected from those who visited the facility on the day of the survey. 10 % of male and female users were sampled guided by user head counts previously conducted at the communal latrines. The first user at the age of 13 or above to exit the facility at the start of a session and willing to participate in the study was enrolled in the orally administered survey. Thereafter, the next user was surveyed until the number of male and female respondents reached 10 % of the average daily patronage. A total of 165 users were surveyed from the seven communal latrines.

2.3 Assessment of User Perception of Odour

The perceptions of users of the level of odour in the latrines they used were assessed using the ranking method (Powers 2004; Ryan and Mara 1983b). Study participants were asked to indicate their perception of the level of odour on a three-level ordinal scale: "the odour level is bad or very intense", "the odour level is moderate or acceptable" and "there is no bad odour". The survey tool, prepared in English, was administered orally in the local Dangme language with the help of a native interpreter. However, respondents who could speak English were surveyed in that language and their responses were recorded by a field assistant. For communal latrines, the users were surveyed immediately after using the facilities. Users of private latrines were surveyed in their respective houses. They were asked to indicate how they perceived the level of odour in their latrines based on the ordinal scale described above.

2.4 Measurement of Hydrogen Sulphide and Ammonia Concentrations

Concentrations of hydrogen sulphide and ammonia were measured using the Aeroqual Series 500 portable gas detector with gas sensitive electrochemical (GSE) hydrogen sulphide and ammonia sensor heads. The hydrogen sulphide sensor head had a detection range of 0–10 ppm, a minimum detection limit of 0.01 ppm and an accuracy of $<\pm$ 0.05 ppm (in concentrations from 0 to 0.5 ppm) or $<\pm$ 10 % (in concentrations from 0.5 to 10 ppm). On the other hand, the ammonia sensor head had a detection range of 0–100 ppm, a detection limit of 0.2 ppm and an accuracy of ±0.5 ppm + 10 %. The device was produced by Aeroqual Limited of New Zealand. This device was selected on the basis of cost, portability, simplicity of operation, and ability to detect levels of the surrogate compounds below the recommended threshold for annoyance. The device was initially calibrated and used within the validity period of the calibration certificate. In each latrine the device fitted with the hydrogen sulphide sensor head was positioned at the edge of the seat or squat hole and was allowed to warm up for 10 min before logging the concentration of hydrogen sulphide for 10 continuous minutes with data logging at 1 min intervals. The hydrogen sulphide sensor head was then replaced with the ammonia sensor head and the procedure was repeated to measure the concentration of ammonia. Each latrine was monitored once within the months of June and August. During data logging, the door of the cubicle was closed just as when the latrine is used.

2.5 Data Analysis

The concentrations of the surrogate gases were calculated for various typologies of latrines that are known to exhibit certain patterns of odour levels such as dry and wet sanitation systems. The three levels of odour perception, i.e., 'bad or very intensive odour', 'moderate or acceptable odour' and 'no bad odour' were assigned numerical values of −1, 0 and 1, respectively. For each latrine, an average or composite perception (CP: $-1 \leq CP \leq 1$) was calculated and used for further analysis. The Pearson correlation coefficient between the average concentrations of the surrogate compounds and composite perception of each latrine was determined to assess whether the concentrations of the compounds correlated with or reflected the latrine users' perception of odour. The latrines were then classified into three depending on whether the composite perception fell within the lower, middle or upper third of the range of perception as shown in Table 1.

Subsequently, the means of concentrations of the surrogate compounds for latrines in the different ranges of composite perception and different typologies were calculated and compared using analysis of variance (ANOVA) to verify whether they were statistically different.

Table 1 Classification of latrines based on composite user perception in Prampram, Ghana

Classification	Composite user perception
Bad or very intensive odour	$CP < -0.33$
Moderate or acceptable odour	$-0.33 \leq CP \leq 0.33$
No bad odour	$CP > 0.33$

3 Results

3.1 Overview of Concentrations of Hydrogen Sulphide and Ammonia in Latrines

Table 2 summarises the results of the concentrations of hydrogen sulphide and ammonia measured in the sanitation facilities. The results show the pattern observed among latrines of different technologies and sharing status.

The concentrations of both hydrogen sulphide and ammonia varied significantly among the different types of technologies used at home by single or multiple households. For each surrogate compound, the concentrations were lowest in water closet (WC) technologies, moderate in ventilated improved pit (VIP) latrines and highest in traditional pit latrines, with the difference being significant at 1 % level for each compound.

Generally, latrines used exclusively by single households had lower concentrations of both hydrogen sulphide and ammonia as compared to those shared at home by multiple households but the differences were not statistically significant at 5 % level. On the contrary, communal

Table 2 Concentrations of hydrogen sulphide and ammonia measured in latrines in Prampram

Typologies	N	Hydrogen sulphide concentration (ppm)		Ammonia concentration (ppm)	
		Mean (SD)	F/t-statistic (*p*-value)	Mean (SD)	F/t-statistic (*p*-value)
Technology type (household & shared latrines only)					
WC	13	0.01 (0.02)	F = 4.972	0.00	F = 6.461
VIP	70	0.03 (0.06)	(0.009)**	0.30 (1.39)	(0.002)**
Simple pit	5	0.13 (0.22)		3.27 (6.26)	
Total	88				
Sharing status (all technologies)					
Single household	41	0.02 (0.04)	t = 1.632	0.29 (1.68)	t = 0.348
Shared by multiple households at home	47	0.04 (0.10)	(0.205)	0.54 (2.18)	(0.557)
Total	88				
Sharing status (VIP technologies only)					
Single household	29	0.02 (0.04)	t = 0.622	0.41 (2.00)	t = 0.497
Shared by multiple households	41	0.03 (0.07)	(0.536)	0.22 (0.71)	(0.622)
Total	70				
Private versus communal (all technologies)					
Private (Single or multiple households)	88	0.03 (0.08)	t = 4.209	0.42 (1.96)	t = 4.512
Communal	7	0.10 (0.13)	(0.043)*	2.15 (3.31)	(0.036)*
Total	95				
Private versus communal (VIP technologies only)					
Private (Household or shared at home)	70	0.03 (0.06)	t = 3.252	0.30 (1.39)	t = 3.645
Communal	5	0.13 (0.14)	(0.002)**	2.99 (3.66)	(0.000)**
Total	75				

N number in sample, *SD* standard deviation

* Significant at 5 % level

** Significant at 1 % level

facilities had significantly higher levels of both hydrogen sulphide and ammonia as compared to those used at home by one or more households. The comparison of the levels of the surrogates among household, shared and communal latrines did not consider the distribution of the different types of technologies within these categories of ownership due to the low numbers some of the technology types (simple pit and WC technologies) within some of the categories of ownership. However, when the analysis was done for only VIP latrines which dominated each of the ownership categories, the same trend was observed as when it was done for all technology options, i.e., single household latrines were not significantly different from multiple-household shared latrines whereas communal latrines had significantly higher concentrations than those used privately at home by one or more households.

3.2 Concentrations of Surrogate Compounds and User Perception of Odour

Table 3 shows that the concentration of hydrogen sulphide significantly varies among latrines in the three categories of composite perception. A similar trend was observed for ammonia but the variation in the concentration of ammonia was not statistically significant. A plot of the concentrations of the surrogate compounds measured in each latrine against the composite odour perception of the latrine users is shown in Fig. 1.

Latrines perceived by the users as having a bad or very intensive odour (with composite perception, $CP < -0.33$) had the highest levels of both hydrogen sulphide (Mean = 0.10 ppm; SD = 0.13 ppm) and ammonia (Mean = 2.17 ppm; SD = 3.30 ppm) whereas those perceived as having no bad odour ($CP > 0.33$) had the lowest for hydrogen sulphide (Mean = 0.01 ppm; SD = 0.01 ppm) and ammonia (Mean = 0.09 ppm; SD = 0.4 ppm). Latrines with odour levels perceived to be moderate or acceptable ($-0.33 \leq CP \leq 0.33$) were in-between with mean hydrogen sulphide and ammonia concentrations being 0.04 ppm and 0.52 ppm, respectively. The variance among the mean concentrations of hydrogen sulphide in the three categories of perception was significant at 5 % level ($p = 0.045$) but the difference among ammonia concentrations was not significant at 5 % level ($p = 0.067$).

As shown in Table 4, the Pearson correlation coefficient between hydrogen sulphide concentrations measured in the latrines and the composite perception of the users of the latrines was evaluated as −0.234, which is significant at 5 % level ($p = 0.022$) while that for

Table 3 Concentrations of surrogate compounds for latrines of different user perception of odour

Perception of odour	N	Hydrogen sulphide concentration (ppm)		Ammonia concentration (ppm)	
		Mean (SD)	F-statistic (p-value)	Mean (SD)	F-statistic (p-value)
Bad or very intensive odour ($CP < -0.33$)	7	0.10 (0.13)	3.513	2.17 (3.30)	2.662
Moderate or acceptable odour ($-0.33 \leq CP \leq 0.33$)	67	0.04 (0.09)	(0.045)*	0.52 (2.25)	(0.067)
No bad odour ($CP > 0.33$)	21	0.01 (0.02)		0.05 (0.22)	
Total	95				

N number in sample, *SD* standard deviation

* Significant at 5 % level

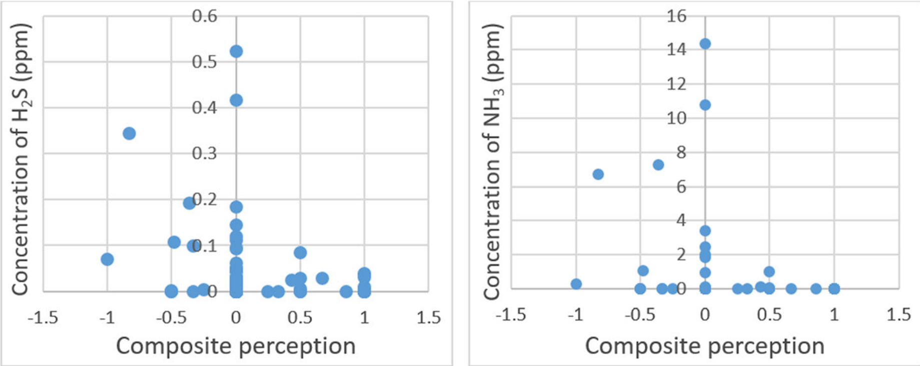

Fig. 1 Plots of concentrations of hydrogen sulphide (*left*) and ammonia (*right*) versus composite odour perception

ammonia was −0.185, which is not significant at 5 % ($p = 0.072$). It was also noted that the concentration of hydrogen sulphide had a significant correlation with that of ammonia.

4 Discussion

The significant variation in the concentrations of hydrogen sulphide and ammonia measured in the different latrine technologies is consistent with the known differences in odour levels associated with those sanitation technologies. While the simple pit latrine is known to be most associated with bad odours, the water closet toilet with a well maintained water seal has no odour problems (Brikké and Bredero 2003; Cotton et al. 1995; Franceys et al. 1992). The ventilated improved pit latrine has an odour control capability in-between that of the simple pit latrine and the water closet. Although this sanitation technology is expected to be capable of achieving odourless conditions with a vent pipe of appropriate dimensions (Ryan and Mara 1983a), it is often found with some level of odour due to improper design and construction. This was observed among some of the latrines studied in Prampram.

The significantly higher concentrations of the volatile compounds measured in communal latrines is also a confirmation of previously reported high levels of odour perceived by users of communal latrines in Ghana as compared to latrines used at home (Appiah and Oduro-Kwarteng 2011). The results also show that the concentrations of the volatile compounds in latrines used by single households and those shared at home by multiple households are not significantly different. This gives credence to recent arguments that latrines shared by two or more households

Table 4 Correlation matrix among hydrogen sulphide, ammonia and user perception

Variable	Pearson correlation coefficient (p-value)		
	Hydrogen sulphide	Ammonia	Composite perception
Hydrogen sulphide	1	0.365 (0.000)**	−0.234 (0.022)*
Ammonia		1	−0.185 (0.072)
Perception of odour			1

* Correlation is significant at the 5 % level (2-tailed); ** Correlation is significant at the 1 % level (2-tailed)

should be considered as improved because they are not necessarily worse than those used by single households (Obeng et al. 2015). In response to this, the WHO and UNICEF's Joint Monitoring Programme's formulation of the post-2015 Millennium Development Goal (MDG) target on sanitation emphasises access to sanitation at home irrespective of its sharing status as opposed to the previous target that required each household to have its own sanitation facility. Nevertheless, the results demonstrate that communal latrines could have significantly higher levels of odour that may be a barrier to consistent usage as reported by Obeng et al. (2015).

The results show that the concentration of hydrogen sulphide is a better surrogate of the level of odour as compared to that of ammonia. Given the significant correlation between hydrogen sulphide concentration and odour perception, the concentration of the compound may be adopted as a surrogate for the level of odour in latrines. The mean concentrations of the compound for the three different ranges of odour perception are consistent with current guidelines for the avoidance of annoyance. A guideline value of 0.1 ppm (1.5 mg/m^3) is recommended for long-term exposure (averaging time of 24 h) to prevent adverse health effects (WHO 2000). However, for avoidance of "substantial complaints about odour annoyance", it is recommended that the concentration of the compound should not be allowed to exceed 0.05 ppm (7 $\mu g/m^3$) for a 30-min averaging period (WHO 2000). The results of this study show that latrines perceived to have a moderate or acceptable level of odour had an average hydrogen sulphide concentration of 0.04 ppm. This suggests that a higher level of hydrogen sulphide may not be tolerated in a latrine than what is generally recommended for prevention of odour annoyance in the environment.

To reduce high odour on simple pit and improved pit latrines, various substances, mostly absorbents, have been reported as being added to excreta by households in low-income countries. These odour-inhibiting substances include sawdust, wood ash, dry grass, husks, peat moss, etc. (Brikké and Bredero 2003; Franceys et al. 1992). Generally, the odour level on a simple pit latrine may be reduced by upgrading it to a ventilated improved pit latrine with the installation of a vent pipe of an appropriate height and diameter as recommended by Ryan and Mara (1983a). It is also important to ensure that windows in the superstructure of a ventilated improved pit latrine are provided only in the windward side of the latrine while all other sides are effectively sealed. This ensures that the air which enters the superstructure through the windward side does not escape through openings in other sides but is forced down the pit to 'flush out' malodorous volatile substance through the vent pipe into the atmosphere (Ryan and Mara 1983a). For the water closet technology, maintaining the water seal generally prevents malodours in the toilet room. In addition to all these, regular cleaning and hygienic usage of facilities are key requirement of odour reduction.

In this study, users of household latrines indicated how they perceived the level of odour in their latrines at the last time they used it on the day of the survey. With this approach, a potential source of error could be the respondents' tendency to indicate a perceived odour level based on historical experience rather than the odour level on the day of the visit. This potential error could be avoided in future studies by requesting users to enter the latrine before being surveyed. They would then indicate how they perceived the level of the odour at that instant.

5 Conclusions

The concentrations of hydrogen sulphide and ammonia measured with the gas detector reflected the known variation of odour levels among different technology options and the perception of the latrine users. The concentrations of hydrogen sulphide measured in the water closet, ventilated improved pit (VIP) and the simple pit latrines were 0.01, 0.03 and 0.13 ppm, respectively, with those of ammonia being undetected for the water closet, and 0.30 and 3.27 ppm for the VIP and simple pit latrines, respectively. The observed correlation between the concentration of hydrogen sulphide and the perception of the latrine users was statistically significant at 5 % confidence level but that of ammonia was not significant at that level. It is encouraging to note that, the average level of hydrogen sulphide measured in VIP latrines shared at home (0.03 ppm) was less than the WHO recommended level for prevention of odour annoyance (0.05 ppm). This suggests that, apart from the water closet, the VIP has the potential of providing a satisfactory level of odour to its users. On the average, a hydrogen sulphide concentration of 0.04 ppm was perceived by the latrine users as being tolerable or acceptable. The results imply that a portable gas detector like the Aeroqual 500 has the potential for monitoring the levels of odorous gases in sanitation facilities to reflect the perception of users, with hydrogen sulphide concentrations being a more reliable surrogate for odour levels than those of ammonia.

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