International Journal of Community Medicine and Public Health
Obiero SO et al. Int J Community Med Public Health. 2026 Jun;13(6):2755-2761
http://www.ijcmph.com
pISSN 2394-6032 | eISSN 2394-6040
DOI: https://dx.doi.org/10.18203/2394-6040.ijcmph20261752

Original Research Article

Occupational exposure levels to sewer gases among informal sewer workers in Nairobi city county, Kenya

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Received: 15 February 2026
Revised: 06 May 2026
Accepted: 11 May 2026

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ABSTRACT

Background: The aim of this study was to evaluate occupational exposure levels to sewer gases among informal sewer sanitation workers in Nairobi City County, Kenya.
Methods: An analytical cross-sectional study design was employed from October, 2023 to August, 2024 adopting quantitative and qualitative data collection methods. Nairobi City County was purposively sampled due to its high proportion of informal sewer sanitation workers. Interviewer-administered questionnaires to workers and semi structured key informant interviews were used to collect qualitative and quantitative data with an observation of exposure levels using EAGLE 2 multi-gas monitor equipment.
Results: Results from the study revealed a 116 (44.7%) cumulative exposure levels to sewer gases among the workers, with exposures to H2S at 91 (35.1%), CO2 at 106 (40.9%) respectively. A mean higher exposure was observed for CO2 and NH3. Majority 221 (85.3%) of the respondents were manual pit emptiers. Moderate level of knowledge was reported among respondents. A high proportion 212 (81.9%) of workers were not in the right PPEs and had not received any training. A negative correlation not statistically significant (p=0.349) was established in examining relationship between the gases. In ANOVA, there was a statistically significant difference in exposure levels among the four groups of sewer workers, F (3,255) =7.803, p<0.001).
Conclusions: The study concludes that 116 (44.7%) of informal sewer sanitation workers in Nairobi City County were exposed to cumulative elevated sewer gas levels beyond the TWA threshold. It is recommended that assessing the health impacts of both short-term and long-term exposure to sewer workers within informal sewer-operations.

Keywords: Exposure, Occupational, Sewer gases

INTRODUCTION

Sewer sanitation workers play an essential role in keeping our environment free from excreta and refuse. However, the role presents with itself immediate risk of exposure to different sewer hazards among them sewer gases such as methane, ammonia, carbon monoxide, hydrogen sulphide and carbon iv oxide.[1] This is alongside occupational exposures to other hazards among them biological, mechanical, physical and psychosocial mainly due to stress, stigma, discrimination and violence. The populations of sanitation workers include toilet cleaners, pit and septic tank emptiers, manhole and sewer cleaners and those working in the sewage and fecal waste management and disposal sites.[2] Sewer sanitation workers are often involved in confined spaces entry during the operation and management of sewer systems. An immediate risk is on exposure to toxic gases produced as a result of decay of organic matter. Exposures to high levels of occupational gases present an adverse effect to the worker's health and safety.[3] On a global scale, over

1.7 billion people lack a safely managed sanitation system which opens up room for informal sewer sanitation actors' operations.[4] In many countries, common accidents are reported as a result of occupational gases leading to loss of consciousness and even death occasioned by asphyxiation.[5,6] In developing countries, there is a reported challenge in quantification of occupational sewer gases exposure among sanitation workers.[6] This is further compounded by a reported low level of compliance among the informal and temporary workers.[7,8] Studies in developing countries have characterized sewer gas exposures primarily focusing on the formal sewer systems. Studies on hydrogen gas exposures in sewer operations and management process have documented high accumulation of the gas in confined spaces of partially full pipelines, manholes, ventilation pipes and sections in contact with air of above 10 ppm (tare weighted average).[9] Available epidemiological evidence of effects on human health due to chronic levels of exposure to H_2S gas of <10 ppm also reveal a higher incidence of respiratory related symptoms of health outcomes that cannot be assumed.[10-12] Build-up of the different gases in confined spaces leads to resultant cumulative exposures to the informal sewer sanitation workers leading to severe accidents and even death.[13,14]

Most studies have examined individual gases exposure such as hydrogen sulphide gas, carbon iv oxide, carbon ii oxide, ammonia and methane. Hydrogen sulphide gas and carbon monoxide as a chemical asphyxiate interfere with the worker's oxygen concentration with potential risk for death and ill health.[15] Further, workers with long term exposures to the chemical asphyxiate gases have a risk of health effects among them vision, sleep disturbances, impaired memory and concentrations.[16] Simple asphyxiate gases such as carbon iv oxide and methane also present substantial risk to the health of the workers. Limited studies have however been conducted on the exposures to the gases outside wastewater and waste management systems and specifically targeting informal operations.[17] Thus, study addressed this gap by assessing occupational exposure levels to the gases of CO2, CH4, CO, H2S and NH3 respectively. This was done in the informal sewer gases emptying confined spaces such as pit latrines, manholes in Nairobi City County. Specifically, the study aimed at quantifying occupational exposure levels, identify exposure patterns and assess potential health risks to the workers while proposing preventive measures to protect workers from exposure effects of the gases. The findings present exposure levels to sewer gases among informal sewer workers relevant to provide a risk profile and intervention measures for the target group.

METHODS

Study design

The study utilized an analytical cross-sectional study design from October, 2023 to August, 2024. This was in line with the intended methods for collecting data on exposure levels of sewer gases in a study population and outcome measured at one point in time. This was ideal since it ensured a complete characterization of aspects on occupational sewer gases exposure levels among informal sewer workers in Nairobi City County.

Study place

The study was carried out in Nairobi City County, Kenya's capital and largest city. Nairobi has a population of over 4.4 million people with the City's sewer infrastructure comprising of a mix of conventional sewer and non-conventional in the informal settlements. Nairobi borders Kiambu County to the North, Machakos to the east and southeast and Kajiado County to the South. The County has 17 sub-counties with more than 150 informal settlements located in the sub-counties of Mathare, Kibra, Ruaraka, Embakasi South and Dagoretti North.[18]

Study participants

The study included informal sewer sanitation workers directly involved in fecal waste operations over the age of eighteen years who consented to participate. The workers were residents of the specified sub counties and had engaged in sewer work over the past 1 year. The study however excluded those not directly involved in sewer sanitation which is defined by excreta management.

Sampling

Nairobi City County was purposively sampled. This was attributed to its vast number of informal settlements and a high number of sewer sanitation workers. Five sub counties with the highest number of informal settlements were purposively chosen. In obtaining research participants, respondents from each sewer emptying units were randomly sampled using computer generated numbers. Key informant interviews were also conducted with three purposively selected experts from public health, environment department and Nairobi Sewerage Company. In obtaining information on occupational sewer gases exposure levels, measurements were taken from 38 selected sewer units which were inclusive of pit latrines, septic tanks and manholes that were chosen at random across the five sub counties in Nairobi City County.

Sample size determination and distribution

Fischer et al,1998 formula of sample size calculation was used to arrive at a sample size of 273 informal sewer workers and 42 sewer emptying sites.

Research instruments

The research used EAGLE 2 gas detection monitor for the measurement of sewer gases exposure levels. Interviewer administered questionnaire was used to collect data from

respondents with key informant interview used to collect qualitative data from participants. The pre-test was carried out at Mavoko, Athi-River in Machakos County using a total of 27 (10% of the sample size of respondents). Level of knowledge on exposure to sewer gases among sanitation workers was measured based on the 5 knowledge items. Each correct answer scored 1 mark while incorrect answer 0 mark. Maximum marks were 5 while minimum 0. Those who scored between 0-2 marks were categorized as low, 3 as moderate and 4-5 as high knowledge levels.

Data management and analysis

Field data underwent cleaning, proper coding and recorded onto excel spreadsheet in Microsoft that was imported to SPSS software version 20.0. Descriptive statistics including means, standard deviations, frequency distributions and percentages were computed to summarize the data. Inferential statistics comprising Pearson Correlation was employed to determine associations between continuous variables, One-way ANOVA to determine differences in means across three or more groups and independent samples t-test to determine the statistically significant differences in dependent variables between two independent groups, with statistical significance set at a 95% confidence interval ($p<0.05$).

Logistical and ethical considerations

The research proposal got approval and authorization from Kenyatta University graduate school. Ethical approval was obtained from the Kenyatta University Ethics and Review Committee (PKU/2796/I1920). Further, research permit to conduct the research was obtained from the National Commission for Science, Technology and Innovation (NACOSTI), Nairobi City County and local leadership. Informed consent was also obtained from the participants. Privacy and confidentiality of information obtained was guaranteed.

RESULTS

A total of 259 sanitation workers participated in the study out of a targeted 277, representing a response rate of 93.5%. On the other hand, observations were made in 38 sewer emptying sites out of the targeted 42 sites representing a 90.5% representation.

Socio-demographic information of participants

Age distribution of respondents indicated the highest number of participants 145 (56%) were between 26-35 years. Out of the 259 respondents, 47 (18.1%) were female while 212 (81.9%) were male. In terms of the respondent's education level, 128 (49.1%) of respondents had achieved primary level, 104 (40.2%) had achieved secondary level, 20 (7.7%) post-secondary education while 7 (2.7%) reported no formal education level. Further, results on the type of sanitation workers revealed 221 (85.3%) were manual pit emptiers, 23 (8.9%) were septic tank emptiers, 8 (manhole, cesspit emptiers) and 7 (2.7%) were mechanical pit emptiers. In terms of duration worked as a sanitation worker, 80 (30.9%) had worked over a duration of between 2-5 years, 69 (26.6%) over a duration of 1-2 years and 62 (23.9%) for more than 5 years while 48 (18.5%) under 1 year (Table 1).

Occupational exposure levels to sewer gases among informal sewer workers

Occupational exposure levels to sewer gases among informal sewer sanitation workers was determined by factoring in exposure levels against OSH PEL-TWA of 10 ppm for H2S, 5000 ppm for CO2, 50 ppm for CO, 25 ppm for NH3 and LEL-5% for CH4 (Table 2). High exposure sites were those with a hazard index of >4 and low exposure sites were those <4. The hazard index approach was utilized based on exposure levels of each gas against OSH permissible exposure limits (PEL). Cumulatively, findings revealed 17 (44.7%) of the sites had cumulative high exposures, while 18 (55.3%) had low cumulative exposures.

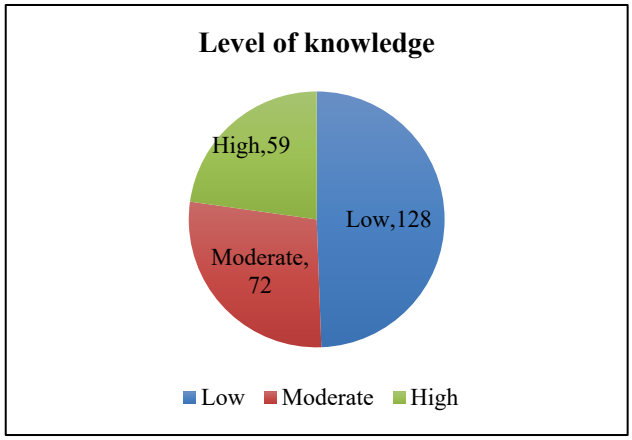

Figure 1: Level of knowledge.

Statistical tests

Pearson correlation analysis between H2S and NH3 revealed no significant association ($r=-0.058$, $p=0.349$). The results mean that sewer emptying sites with high levels of H_2S did not necessarily have high ammonia levels. The study evaluated exposure levels of sewer gases among sewer workers to identify at risk-workers. One-way ANOVA results presented significant differences in H2S exposure levels across different worker categories – manhole, cesspit emptiers, manual pit emptiers, mechanical pit emptiers and septic tank emptier. Across the categories $F(3,255) = 7.803$, $p<0.001$). Mechanical pit emptiers reported the lowest mean exposure levels (6.34, S.D 2.85), while manual pit emptiers recorded a higher mean exposure level (9.27, S.D 1.91) and manhole, cesspit emptier with a mean exposure level (9.46, S.D 1.79). Exposure levels were

highest ranging from 11.60 ppm to 13.20 ppm. On PPE use and exposure to sewer gases, independent samples t-test examined whether there were any statistically significant differences in dependent variables between two different groups those who used PPE and those who did not with H2S gas exposure. Workers in sites where PPE was used had mean exposure of 9.12 with a standard deviation of 1.98 while those in sites where PPE was not used had exposures of 8.98 with a standard deviation of 2.35 ppm. However, the findings were not statistically significant (F=2.400, p=0.123). This suggested that PPE alone did not reduce sewer gas exposures.

Level of knowledge on exposure to sewer gases

Results revealed that 128 (49.4%) had low knowledge, 72 (27.8%) had moderate knowledge and 59 (22.8%) had high knowledge on occupational sewer gases (Figure 1).

Preventive measures and safety practices

Table 5 shows gaps in implementation of safety measures across sanitation worker sites. Use of Personal Protective Equipment (PPE) was the most commonly reported safety measure by 175 (67.6%) of workers. However, 84 (32.4%) of the workers lacked PPE for use. Engineering and administrative controls was the less applied with 46 (17.6%) of participants using them.

Across different worker categories, environmental monitoring and entry permit system were absent in all the sites. Further, results showed limited worker training with 54 (21%) of participants having been trained. In addition, results showed that 57 (21.9%) of the workers implemented barrier and distance controls while 32 (12.3%) of the sites implemented adequate lighting in navigating confined spaces.

Table 1: Socio-demographic information of participants.

		Frequency	(%)
Sex of respondent	Female	47	18.1
	Male	212	81.9
Education	None	7	2.7
	Primary	128	49.4
	Secondary	104	40.2
	College and post college	20	7.7
Age (in years)	Ages 18-25	49	18.9
	Ages 26-35	145	56.0
	Ages 36-45	58	22.4
	Over 46	7	2.7
Type of sanitation worker	Manhole, Cesspit emptier	8	3.1
	Manual pit emptier	221	85.3
	Mechanical pit emptier	7	2.7
	Septic tank emptier	23	8.9
	Total	259	100.0
Duration as a sanitation worker (in years)	Duration of 1-2	69	26.6
	Duration of 2-5	80	30.9
	Under 1	48	18.5
	More than 5	62	23.9

Table 2: Individual sewer gas exposure levels.

	N	Minimum	Maximum	Mean	Std. deviation
H_2S-10 ppm	259	4.30	13.20	9.07	2.10
CO_2 levels- 5000 ppm	259	2960	13834	6616.08	3423.86
CO (50 ppm)	259	7.40	56.30	29.10	13.27
NH_3 25 ppm	259	9.30	53.10	27.54	13.57
CH_4 (LEL-5%)	259	7.80	17.40	11.68	2.65
Valid N (listwise)	259				

Table 3: Summary of statistical analyses.

Analysis type	Variables	Test statistic	P value	Interpretation
Pearson correlation ANOVA	H2S vs NH3	R=-0.058	0.349	No significant association
One-way ANOVA	H2S across worker types	F (3,255)=7.803	0.001	Significant difference
Post-hoc (Turkey HSD) pairwise	Mechanical vs manual	MD=2.929	0.001	Mechanical significantly lower
Pairwise	Manual vs septic	MD=1.409	0.009	Manual Significantly higher
Independent t-tests two sample	PPE use (yes vs no)	t (257) =-0.503	0.615	No statistical difference

Table 4: Preventive measures and safety practices.

Independent variable	Respondent response	Frequency (N)	(%)
Personal protective equipment use	Yes	175	67.6
	No	84	32.4
Work environment monitoring	Yes	0	0
	No	259	100
Training of workers	Yes	54	21
	No	205	69
Entry permit	Yes	0	0
	No	259	100
Engineering and administrative controls	Yes	46	17.6
	No	213	82.4
Barrier and distance controls	Yes	57	21.9
	No	202	78.1
Lighting	Yes	32	12.3
	No	227	87.7

DISCUSSION

This study assessed sewer gas exposure among informal sewer sanitation workers in Nairobi, Kenya. It examined H2S, NH3, NH4, CO and CO2 gases exposure levels and preventive and safety practices implementation. A total of 259 workers were assessed across 38 sampling sites representing different sewer work environments. Results revealed varied exposure levels across different sewer gases with a cumulative 17 (44.7%) of the sites presenting with at least one gas above the recommended exposure levels. H2S concentration levels were in the range of 4.3 to 13.2 ppm (mean 9.07±2.10 ppm). With 31.5% of sites having elevated levels of hydrogen gas of more than 10 ppm OSHA permissible exposure limit (PEL-TWA). CO2 levels showed extreme variations from 2960 to 13834 ppm (mean 6,616±3,424 ppm) the maximum levels were 3 times the recommended OSHA permissible exposure limit. NH3 on the other hand presented concentration levels of 9.30 to 53.10 ppm (mean 27.54±13.27 ppm) with maximum levels more than double the 25 ppm OSHA PEL-TWA. CO ranged from 7.40 to 56.30 ppm (mean 29.10±13.27 ppm) highest exposures above the 50 ppm. CH4 recorded levels below 5% LEL indicating considerable organic decomposition.

Results showed that worker category had a significant influence on sewer gases exposure among the informal workers. H2S exposure levels varied significantly across worker categories with a mean H2S exposure among mechanical pit emptiers (6.34±2.85 ppm) lower than manual pit emptier (9.27±1.91 ppm) and also compared to manhole/cesspit emptiers which reported a mean (9.46±1.79 ppm). Manual emptying is characterized by repetitive physical activities involving lifting, carrying, pulling and pushing. On the other hand, it exposes workers to hazards such as physical strain, musculoskeletal disorders, back pain, joint strain, bruises among others. The study agrees with another one where manual emptiers are majority involved in informal sewer operations.[18]

The findings on varied exposures across worker types align with the hazard control principle with substantial insight into prioritizing hazard elimination against personal protective equipment use. Mechanical pit emptiers are 32% less exposed to lower levels of sewer gases as compared to the manual sewer emptiers. Reduced exposure through mechanization interprets to both short term and long-term benefits through protection from health effects as a result of high sewer gases exposure such as respiratory effects, conjunctivitis, eye defects, reduced concentrations and even convulsions or death at extreme levels.[19,20] On the other hand, other benefits as a result of mechanization include enhanced worker dignity, reduced informal sewer worker stigma and overall improved health and safety of the workers.[21] These findings were similar with study on occupational respiratory hazards exposure among sewage workers which revealed that they were exposed to high risk of the health effects from the gases' exposure.[22] On the contrary, the findings contradicted with insignificant findings in sewer worker groups of those in Trondheim, Norway cesspits, sewer networks and stations.[23] The difference in findings can be attributed to a high reported PPE usage among the category of workers interviewed in Norway.

Knowledge levels significantly influenced exposure to the sewer gases and protective behaviour. While 175 (67.6%) of the workers reported having some form of PPE, there was no reported significant exposure reduction (p=0.615). The results were different with those in Egypt. This can be attributed partly to gaps in knowledge levels where majority reported low knowledge on sewer gas composition and health effects associated with the exposures.[24,25] Effective sewer gas exposure reduction entails largely PPE use and adequate knowledge of gas specific hazards for proper protective measures to thrive.[25,26] Preventive measures also influenced occupational exposure to sewer gases among the informal workers. PPE remained the primary protective measures and safety controls against exposure. This is on the backdrop of other first level measures which missed at all

such as environmental monitoring which further added up to knowledge gap since workers had no knowledge of exposure levels, no entry permits also increased worker's vulnerability to exposures to higher levels of the gases and accident in confined spaces. The findings on preventive and protective measures were in line with other studies in Nairobi, Kenya where workers experienced limited protection as a result of inadequate preventive measures.[27,28] The findings were however not consistent with other studies from Korea and India.[29,30] This can be attributed to disparities in implementing proper occupational safety measures in informal environments such as workers relying on inappropriate PPE for total protection and operating in environments not monitored at all.

The study encountered several limitations among them some respondents were unwilling to participate, however, this was mitigated by clearly explaining the academic purpose of the study and assuring respondents of confidentiality. Further, the study encountered a challenge of informal and inconsistent work routines which impacted on precise measurement of the frequency and duration of exposure to sewer gases. This was however addressed through systematic direct observation of work routines to the nearest approximate exposure durations. Finally, the cross-sectional study design limited the ability to establish causal relationship between sewer gases exposure and health outcomes as the data was only collected at a single point in time.

CONCLUSION

The study establishes that informal sewer sanitation workers in Nairobi City County, Kenya face varied sewer gases exposures with 17 (44.7%) of the sites exceeding permissible exposure limit-tare weighted average thresholds. This is also entwined with reported low knowledge levels among the workers and inadequate PPE utilization. The findings reveal through mechanization, manual workers are able to have reduced exposure by 32%. One-way ANOVA reveals significant statistical differences in H2S exposure across worker types ($F(3,255)$, $p=0.001$ with post-hoc analysis showing mechanical workers experienced lower concentrations than manual workers, $p=0.009$. There is thus a need to mechanize manual sewer work while also conducting hazard-specific training among sanitation workers to close on the knowledge gaps in the informal sector.

Funding: The Initiative for Sanitation Workers (ISW)
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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Cite this article as: Obiero SO, Nyambura AW, Warutere PN. Occupational exposure levels to sewer gases among informal sewer workers in Nairobi city county, Kenya. Int J Community Med Public Health 2026;13:2755-61.