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EXPOSURE TO HYDROGEN SULPHIDE AMONGST SEWAGE WORKERS IN A METROPOLITAN MUNICIPALITY IN GAUTENG PROVINCE, SOUTH AFRICA

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Abstract: The study's objectives were to determine concentration levels of hydrogen sulphide (H_2S) in the working environment and its effects by describing the self-reported health effects and hydrogen sulphide among municipal sewage workers in the City of Johannesburg metropolitan municipality within Gauteng Province. One hundred and fifty-six participants from six different municipal wastewater treatment works were sampled. To determine any relation between self-reported outcomes and hydrogen sulphide exposure, a structured self-administered questionnaire was used. During an eight-hour shift, Drager X-am 5000 gas detectors were used to measure the concentration levels of hydrogen sulphide in the ambient air within three distances from operational sections. Concentration levels of hydrogen sulphide in the ambient air ranged from 0.99 ppm (parts per million) to 39.97 ppm, with a standard deviation (SD) of 8.72 and a mean of 12.83 ppm at a 5-meter distance, in effect the exposure levels were above the international and South African recommended exposure limit for an eight-hour shift. The self-reported health outcomes revealed that 33% of participants suffered from eye irritation, while 35% suffered from tiredness. The results also indicated that 33% of participants experienced headaches. Experiencing a burning sensation in the chest is positively correlated with hydrogen sulphide levels within 10 meters and 15 meters, according to the bivariate analysis. The results provide evidence of a correlation between self-reported outcomes and hydrogen sulphide exposure. The study also highlights that concentration levels of hydrogen sulphide closer to the source are much higher. Despite the current local and international legislation, workers continue to be exposed to higher levels of this harmful gas, thus highlighting the need for interventions.

Keywords: Hydrogen sulphide concentration levels, health outcomes, hydrogen sulphide exposure, risk factors and wastewater treatment works workers

1. Introduction

Wastewater treatment plants have been identified as a potential source of hydrogen sulphide production (Matos, Ferreira, and Matos, 2020). This is demonstrated by its toxicity in the air and in the unpleasant smell it releases in the environment even at significantly lower concentrations. During the wastewater treatment process, organic matter is broken down by bacteria without oxygen, and hydrogen sulphide is produced (Moretti *et al.*, 2020). Hydrogen sulphide has also been identified as a by-product of numerous industrial processes such as sewage treatment, pulp and paper processing, petroleum and

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natural gas drilling and refining operations, and rayon textile manufacturing (Mousa, 2015). Hydrogen sulphide has a low odour threshold, and its smell may be detected below 1 ppm (Friis, 2001).

Through inhalation, hydrogen sulphide enters the human body. As a result, respiratory and gastrointestinal exposure can occur (Saeedi, Najibi and Mohammadi-Bardbori, 2015). Through skin contact with wastewater or sludge is another route of entry. Once inside the body, it quickly spreads to the muscles, lungs, liver and the central nervous system, among other organs. The solubility of hydrogen sulphide is relatively low, allowing it to penetrate deeply into the respiratory tract, causing alveolar injury, which leads to acute pulmonary oedema (Moretti *et al*., 2020). Reed *et al*. (2014) elaborate that acute exposure to hydrogen sulphide has an irritant effect directly to the tissues, causing inflammation of the moist membrane of the eye and the respiratory tract. Mousa (2015) further elaborated that human exposure to hydrogen sulphide is characteristically dose-related and involves the nervous, cardiovascular, and respiratory systems. The second most common cause of fatal gas inhalation exposures in the workplace is hydrogen sulphide. Affected cases often unique and similar to one another because they frequently show distinct toxicological features. In most incidents, casualties occur in two or more, as the rescuers rush to save their co-workers and neglect to protect themselves with self-contained breathing apparatus (Guidotti, 2010). In municipal sewage works, such cases may suffer from headaches lasting for several hours, leg pain and loss of consciousness (Friis, 2001).

The study conducted by Kilburn (2012) found that hydrogen sulphide has the potential to poison the brain and mitochondria by combining with iron in respiratory enzymes and cytochrome oxidases, thus preventing oxidative phosphorylation and increasing hydrogen sulphide intake. Furthermore, this study showed that sensitivity tests conducted on employees who survived from exposure to hydrogen sulphide revealed that they had impaired balance, loss in their visual fields, slowed reaction time, permanent brain dysfunction, cognitive and memory deficits and reduced problem-solving ability. Additionally, the study by Guidotti (2010) revealed that acute exposure to hydrogen sulphide causes a knockdown effect (acute central neurotoxicity), pulmonary oedema, conjunctivitis and odour perception followed by olfactory paralysis. Knockdown is defined as an abrupt loss of consciousness and collapse, which is described as turning off a switch (Guidotti, 2010). Employees who recovered from the knockdown effect explained it as "not an unpleasant sensation" since they woke up without any mental disturbance. Some employees would even resume their duties without disclosing the incident and without seeking medical attention. According to the study, workers who recover from the knockdown effect are at greater risk of developing residual impairment.

Conjunctivitis also known as gas eye, is a superficial inflammation of the cornea and conjunctiva caused by the irritant effect of hydrogen sulphide. It frequently occurs in employees who are exposed to low concentrations for extended periods of time (Guidotti, 2010). Furthermore, the study found that employees may suffer from olfactory paralysis and lose their ability to detect any smell at high exposure levels of hydrogen sulphide. Elwood (2021) and Guidotti (2010) both agree that hydrogen sulphide has a neurotoxic effect, resulting in loss of smell and olfactory paralysis. Research findings by Inserra *et al*. (2004) indicated that hydrogen sulphide targets the nervous system. Permanent neurological damage, loss of consciousness or death may occur at high concentration levels. Employees who were exposed to hydrogen sulphide for a long period of time suffered from irritability, dizziness, fatigue and poor memory. Glas *et al*. (2001) found that chronic exposure to hydrogen sulphide has the potential to cause nervous tissue damage which causes neurological effects. As hydrogen sulphide concentration levels and exposure times increase, cognitive impairment may result (Farahat, Kishk and El-Kholy M, 2008). When exposed to hydrogen sulphide, the gas does not build up in the body but it is absorbed by organs and eliminated as urine thiosulphate. In that way, the increased concentration of urinary thiosulphate indicates continuous daily occupational exposure to hydrogen sulphide among municipal sewage workers (Al-Batanony, El-Shafie and Al-Batanony, 2011).

The rotten egg odour is recognisable up to 30 ppm (Teixeira *et al.*, 2013). According to the study, hydrogen sulphide has a sweet smell at 30 ppm to 100 ppm. At concentration levels above 100, detection ability is affected by rapid temporary paralysis of the olfactory nerves, resulting in loss of the sense of smell (Godoi *et al.*, 2018). At 500 ppm and above, pulmonary oedema, unconsciousness, and death may occur (Colomer *et al.*, 2012).

The lethality exposure-response curve for hydrogen sulphide is remarkably steep. When it comes to hydrogen sulphide, concentration levels are more significant than the time of exposure. Data is insufficient to propose a safe dose of hydrogen sulphide because it gives little margin of safety (Bates *et al.*, 2015). The study examined the recommendations of the three main expert groups of experts on hydrogen sulphide occupational exposure limit (OEL): the Dutch Expert Committee on Occupational Standards (DECOS) in the Netherlands, the Scientific Committee on Occupational Exposure Limits (SCOEL), in Europe, and the American Conference of Government Industrial Hygienists (ACGIH). These limits for hydrogen sulphide occupational exposure differ. The ACGIH recommended the eight-hour exposure limit to be at 1ppm and the short-term exposure limit at 5ppm, while the SCOEL recommended that the eight-hour exposure limit to be 5ppm and the short-term exposure limit to be 10ppm, and the DECOS recommended that the eight-hour exposure limit to be kept at 1.6 ppm without any short-term exposure limit (table 1). Hydrogen sulphide regulation limits were compared in 28 jurisdictions. Two jurisdictions Spain at 1 ppm and the Netherlands at 1.7 ppm, have lower eight-hour limit. Similar to Austria, Spain has a 5-ppm short-term limit. At 5ppm, Austria's short-term and long-term limits similar. South Africa provides for an occupational exposure limit from 2 ppm (as the minimum occupational exposure limit) for an eight-hour limit to 10 ppm for a short-term occupational exposure limit of 15 minutes (Occupational Health and Safety Act 1993: Regulations for Hazardous Chemical Agents, 2021). According to these provisions, South Africa's OEL levels are lower and in line with the OEL recommendations made by the international expert organisations. Wastewater treatment works are governed by the National Environmental Management Act (NEMA), which provides for air quality measurements, norms and standards with the effort to prevent pollution, ecological degradation and sustainable development.

Table 1: Recommendations for Occupational Exposure Limits for Hydrogen Sulphide (Bates *et al*., 2015)

	ACGIH	SCOEL	DECOS
Eight–hour exposure limit	1 ppm	5 ppm	1.6
Short-term exposure limit (STEL)	5 ppm	10 ppm	-

Municipal wastewater treatment works (WWTWs) workers are exposed to extremely high doses of hydrogen sulphide daily. Different literature on the negative health effects of hydrogen sulphide are expressed in various sources. It is clear that exposure to high concentration levels of hydrogen sulphide have a significant impact over the duration of exposure. Based on the currently available scientific evidence, it is uncertain if lower limits will better protect workers' health more than the existing limits used in most countries.

2. Materials and Methods

To achieve the study's aim and objectives, a descriptive cross-sectional analytical approach was adopted. This method examined possible health impacts associated with the work and environment of WWTW workers by combining characteristics from three different study types. The study sought to investigate these effects without causing any immediate disruptions to the environment or the work setting within a short period and without implementing any intervention. Only the six-wastewater treatment works under the City of Johannesburg Metropolitan Municipality were included in the study (figure1). The different sites have different capacities and service various parts of the City of Johannesburg, with Ennerdale WWTWs as the smallest plant of the six with the capacity to treat 20 – 30 million litres of sewage per day for a population of about 72,000 people to Northern WWTWs as the largest, designed to treat 430 million litres of wastewater daily for approximately 1.6 million people.

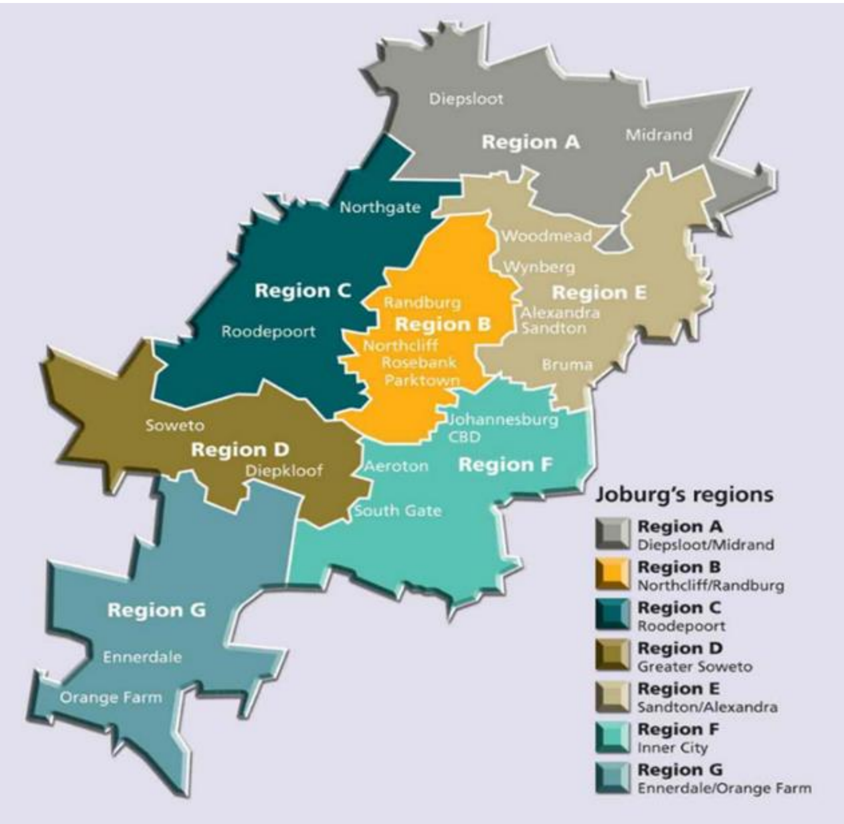

Figure 1: Map of Johannesburg (Mathenge, 2015)

2.1 Population and sampling

The study was conducted among the wastewater treatment workers between the ages of 21 and 65 years old from different units within the plant, such as drivers, process controllers, administrators, lab assistants, general workers, artisans, and process managers in all six-wastewater treatment works under the City of Johannesburg. Employees with varying educational backgrounds ranging from a primary education to those with degrees made up the study population. Participants came from different geographical locations. The names of the sewage workers were given numbers. The number of participants to be contacted was decided using a Random Number Generator. The procedure was carried out until the sample size was attained. The sample size was determined using G-Power statistical software (version 3.0.10), $\alpha = 0.05$, odds ratio=0.3, and $\beta = 0.08$. Given the type of study and analysis, the anticipated sample size for a simple random sample was 113.

2.2 Data collection using questionnaires

The study used a piloted questionnaire that participants completed as form of data collection. In addition to exposure factors, the questionnaire was completed for data on demographic characteristics, housing and health, and lifestyle. At the conclusion of each session, the researcher gathered completed questionnaires and verified that they were complete. Only questionnaires with 80% or higher were accepted for inclusion in the analysis.

2.3 Environmental Sampling of Hydrogen Sulphide Concentrations

Environmental sampling of hydrogen sulphide concentration levels was measured using a Drager X-am 5000, a portable electrochemical cell multi-gas detector. Continuous log recording of chemical concentration at 30-minute intervals was conducted using the multi-gas detector. When hydrogen sulphide was present in the ambient air, oxidation or reduction occurred. An 8-hour shift was used to take measurements. Hydrogen sulphide concentration levels were expressed in parts per million (ppm). The multi-gas detector monitors were positioned at three different points, 5 meters, 10 meters and 15 meters away from each operating areas of each wastewater treatment site in the City of Johannesburg Metropolitan Municipality where the majority of the practical work was carried out.

2.4 Data Analysis

The questionnaire data and the environmental concentration results data were captured using Microsoft Excel spreadsheet where coding and data cleaning was done. The coded data was thereafter imported into statistical software program (SPSS version 18) for data analysis, development and visualisation. In this study percentages were presented for categorical variables, descriptive analyses of means, medians and interquartile ranges were calculated for all continuous variables. To determine whether there were any association between variables, a bivariate analysis was used. The statistical significance was determined using a Pearson's chi-square test. The threshold for statistical significance was set at 5% level of significance.

2.5 Ethical Considerations

The study was approved by the University of Johannesburg, Higher Degree Committee (HDC-01-135-2021) and the Faculty Research Ethics Committee (REC-1358-2022). Furthermore, permission was granted by management of the wastewater treatment plats of the City of Johannesburg.

3. Results and Discussion

The aim of the study was to determine concentration levels of hydrogen sulphide and its effects on self-reported health outcomes among municipal sewage workers in the City of Johannesburg Metropolitan municipality within the Gauteng Province. A key component of the research effort was the gathering and analysis of data related to the exposure of municipal sewage workers to hydrogen sulphide, including the questionnaire and the environmental sampling of concentration levels of hydrogen sulphide in the ambient air. Through this study, the researcher aimed to help the management of the plants by raising awareness of the health effects caused by hydrogen sulphide exposure among municipal sewage workers in wastewater treatment works. A questionnaire was used to gather personal information (data) about each participant in order to identify the factors that contribute to their exposure to hydrogen sulphide. For each of the six sites, environmental sampling of hydrogen sulphide concentration levels was carried out at three different distances within the site. This study includes a detailed discussion and comparison with other studies of the variables that were important in the bivariate analysis.

Hydrogen sulphide concentration levels were measured in each wastewater treatment works at three different distances. The measurements were taken at a 5-meter distance, a 10-meter distance and a 15-meter distance. Concentration levels of hydrogen sulphide were high within a 5-meter distance, with a standard deviation (SD) of 8.72 and a mean of 12.83 ppm. The levels at a 10-meter distance ranged from 0.00 to 16.55 ppm. The lowest measurements were taken at a 15-meter distance with a mean of 0.99 ppm, indicating that the levels of hydrogen sulphide are much higher closer to the source, presenting a higher risk of exposure to wastewater treatment works workers working closer to the source (Table 2).

Table 2: Hydrogen Sulphide Measurements at different distances

	5 Meter Distance	**10 Meter Distance**	**15 Meter Distance**
Mean	12.83 ppm	3.95 ppm	0,99 ppm
Std. Deviation	8,72	4.29	1.48
Range	35.41	16.55	5.27
Minimum	2.56	0.00	0.00
Maximum	37.97	16.55	5.27
Variance	76.11	18.40	2.20

The findings of this study support the study conducted in six different wastewater treatment works in Norway, where 9% of hydrogen sulphide measurements had peaks above 10 ppm, 15% had peaks of 5-10 ppm, 35% had peaks of 1-5 ppm, and 65% had peaks of 0.1- 1 ppm, while 29% of the measurements showed hydrogen sulphide levels to be lower than 0.1 ppm (Austigard, Svendsen and Heldal, 2018). A study conducted in Trondheim municipality in Norway showed similar findings as the current study, where hydrogen sulphide concentration levels were above 10 ppm, 5 ppm, and 0.5 ppm (Austigard, Smedbold and Von Hirsch Svendsen, 2023). Another study conducted in the municipal sewage waste facility in Portugal concurs with the findings of the current study, where hydrogen sulphide concentration levels in the ambient air reached the highest values of between 10.03 ppm to 18.5 ppm, intermediate values of between 5.46 ppm and 9.51 ppm and the lower values at 0.19 ppm (Nunes *et al.*, 2021). The findings of a study conducted in a wastewater treatment works in North Portugal showed concentration levels of hydrogen sulphide to range from 0.1 ppm to 6.0 ppm and the highest concentration level of 235 ppm (Teixeira *et al.*, 2013). This study is in support of the findings of our study.

Exposure to hydrogen sulphide can come from various sources. This study concentrated on the exposure to hydrogen sulphide in wastewater treatment works, other risk factors that participants might be exposed to where they reside, the housing structure that the participants reside in and the fuel used by participants for cooking and heating purposes in their households. The study further looked at the self-reported health effects experienced by the participants because of working in the wastewater treatment works. One hundred and fifty-six wastewater treatment works workers participated in the current study. The study found that the majority of participants (89%) reside in formal structures. It further indicated that 12% resided near the gas plant and 37% of the participants resided near the sewer, these are both sources of hydrogen sulphide. Most participants use gas (19% as cooking fuel, 41% as heating fuel) and electricity (79% as cooking fuel, 56% as heating fuel).

The findings of the study (regarding the self-reported health effects) indicated that 33% of the participants suffer from eye irritation, while 35% suffer from tiredness. The results further revealed that 17% of the participants experienced sore nasal passages and 33% experienced headaches. Tightness in the chest, as well as a burning sensation in the chest, was also reported. The majority of participants reported not to have been suffering from memory loss or muscle and joint pains, at 89% and 99%, respectively.

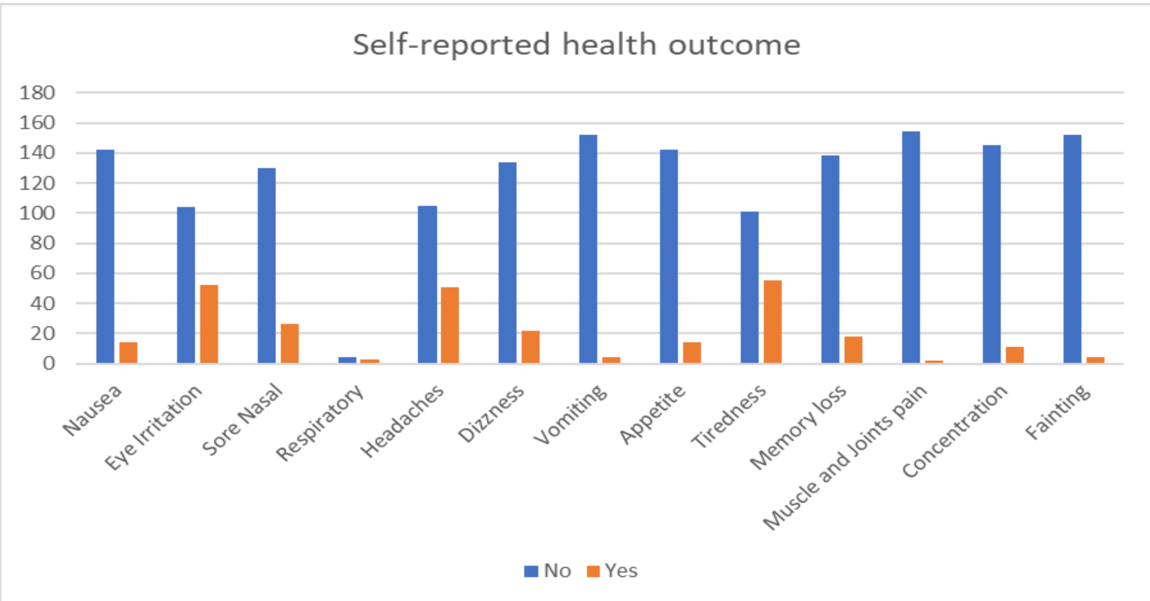

Figure 2: Distribution of self-reported health outcomes

Previous studies have reported similar findings that support the current study. A study conducted in Berket Al-Sabih wastewater treatment works compared an exposed group to the non-exposed group and found that the exposed group presented with symptoms of respiratory problems and body aches (Al-Batanony, El-Shafie and Al-Batanony, 2011). These findings support the current study. Findings of a study conducted on workers in the oil field indicated that the workers suffered from sore nasal passages, fatigue, and headaches (Mousa, 2015); these findings were in support of the current study. The World Health Organisation reviewed studies previously conducted in different countries on chemical safety, which is consistent with the current study. Findings indicated that exposure to hydrogen sulphide causes eye irritation, fatigue, olfactory paralysis, sore nasal passages, headaches, chest pains, and respiratory effects, which include tightness of the chest, difficulty breathing and wheezing, amongst others (Chou *et al.*, 2003). Other studies on communities residing near a source of hydrogen sulphide reported suffering from sore nasal passages and problems with runny noses (Lim *et al.*, 2016). The results indicated that municipal sewage workers who live close to hydrogen sulphide sources are still exposed after their 8-hour shift and indicated a positive relationship with some of the health effects of the current study.

According to this study there was a positive correlation between a tight chest ($r=0.18$; $p=0.02$), sore nasal passages ($r=0.18$; $p=0.03$) and the housing structure. Most participants reported residing in formal structures, and most of these structures are near the wastewater treatment works, the source of hydrogen sulphide (table 3). The results further indicated a relationship between hydrogen sulphide and a burning sensation in the chest at 10-meter and 15-meter distances from the source. Therefore, wastewater treatment works workers do not need to be closer to the source for them to be exposed. A study conducted in North Carolina revealed that people living near confined animal feed operations, another source of hydrogen sulphide, experienced excessive coughing, runny nose, headaches, sore throat, and burning eyes (Kilburn, 2012). These findings were found to be consistent with the current study.

The results of the study clearly indicate the need to engage in discussion with relevant stakeholders, policy makers regarding the current legislation on occupational exposure to hydrogen sulphide verses the experiences in the working environment. To ensure that the information and evidence is accessible, the researcher will write reports to WWTWs management using clear language for easy interpretation of the results and conduct presentations and workshops on the results of the study. ava

Table 3: Other risk factors to health outcome

Risk factor	Number (N)	Per cent (%)
Housing structure		
Formal Structure	139	89%
Informal Structure	17	11%
Surrounding Source of Hydrogen Sulphide		
Gas Plant	19	12%
Oil and Gas Well	3	2%

Refineries	2	1%
Sewer	57	37%
Petrochemical plant	1	1%
None	3	2%
Cooking Fuel		
Electricity	123	79%
Paraffin	3	2%
Wood	1	1%
Gas	29	19%
Heating Fuel		
Electricity	87	56%
Paraffin	4	3%
Wood	1	1%
Gas	64	41%

4. Conclusion

Concentration levels of hydrogen sulphide in the ambient air indicated a peak of up to 16.55 ppm, raising concerns as it is above South Africa's recommended limit of 10 ppm for a short term and 2 ppm for an 8-hour shift. Hydrogen sulphide levels in the ambient air must be continuously monitored in order to ensure that the recommended limits are met and to reduce the risk of exposure to workers. Installing a gas detection system that will automatically sound an alarm when the gas is detected is the best way to prevent accidents because there is no known cure for hydrogen sulphide poisoning.

Continuous awareness programmes on the dangers of hydrogen sulphide exposure, its health effects and the importance of using personal protective equipment to minimise the risk of exposure should be conducted for wastewater treatment plant workers, contractors, subcontractors and management. Continuous medical screening programmes should be conducted for all employees for early identification and diagnosis of underlying health risks caused by hydrogen sulphide.

This study is the first to report on hydrogen sulphide concentration levels and its effects on self-reported health outcomes among municipal sewage workers in the country and in a metropolitan municipality within the Gauteng Province. Results show evidence that wastewater treatment works workers are exposed to hydrogen sulphide in the workplace, and those who reside near a source of hydrogen sulphide are also exposed. There is however a need for future research projects that will sample a bigger size and include network workers. Such research studies should also include blood and urine tests to determine the health effects caused by hydrogen sulphide, as the current study only focused on environmental sampling and self-reported health effects. Through this study, the researcher aimed to contribute to the existing knowledge in South Africa regarding hydrogen sulphide concentration levels in the ambient air and the resulting health effects from exposure. Although the study's findings cannot be generalised to other districts or provinces due to variations in sewage types, population sizes, plant capacities, plant types, treatment processes, and the geographical locations of the plants, the results showed that there is still a risk of exposure even at a 15-meter distance from the source. This is also demonstrated by previous similar studies, highlighting this important aspect of employee safety in the broader public health.

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Declaration of Interest Statement

The authors affirms that they have no conflict of interests.

Authors Disclosure

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