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Case study of hydrogen sulfide release in the sulfate-rich sewage drop structure

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ABSTRACT

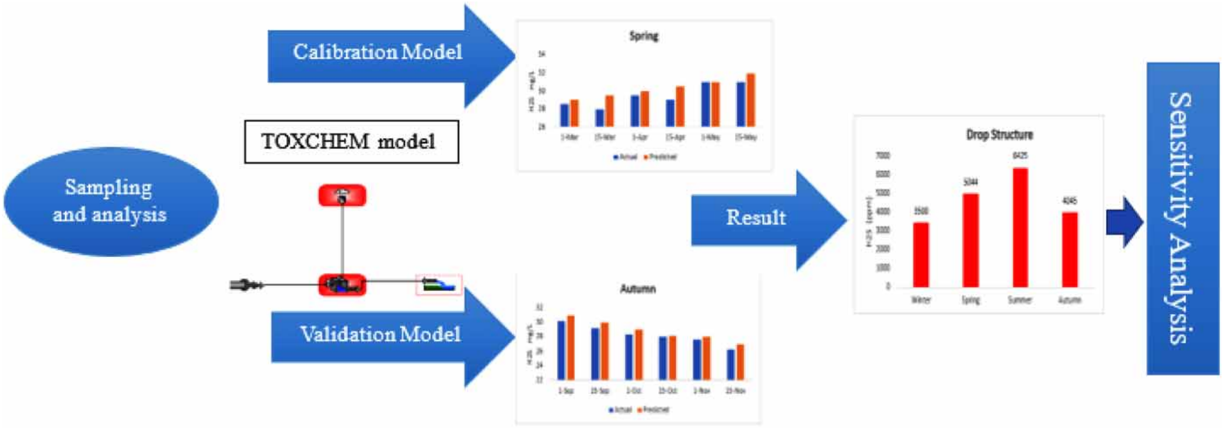
H_2S is one of the principal odor gases released from sewer networks and understanding the rate of H_2S release into sewer air space and ventilation to the atmosphere is crucial for preventing or minimizing odor and corrosion issues in sewer systems. TOXCHEM model was used to simulate the fate of H_2S gas in roads for this study. The model was calibrated for the spring and summer seasons and validated for the remainder of the seasons. The predicted behavior showed good correlation to measurements on real samples following statistical analysis, with R^2, R, and RMSE results between (0.93–0.97), (0.8–0.82), and (0.000438–0.000838), respectively. A sensitivity study was performed to assess the effect of various pH values, drop heights, tailwater depths, stream widths, and sewer ventilation rate levels. The results showed that the emissions concentrations for winter, spring, summer, and autumn reached 3500, 5044, 6425, and 4045 ppm respectively. All the emissions levels from this DS can be considered hazardous, and this was particularly evident during the summer months. This study has helped to clarify the fate and emission of hydrogen sulfide gas at the DS by simulation using a TOXCHEM model.

Key words: drop structure, hydrogen sulfide, H_2S emission, stream width, TOXCHEM model

HIGHLIGHTS

- The drop structure can substantially increase the emission of hydrogen sulfide from the liquid phase to the air phase.
- Discussion of the most important factors that contribute to the emission of H_2S gas in the drop structures.
- Determination of the amount of hydrogen sulfide gas emission in the sulfate-rich wastewater.
- The use of the TOXCHEM model to simulate the emission of hydrogen sulfide gas in the drop structure.

GRAPHICAL ABSTRACT



1. INTRODUCTION

One of the most important pieces of infrastructure for contemporary urban society is the sanitary sewer system (Faris *et al.* 2022). Most sewer design standards primarily optimize the sewer system's liquid phase conveying capacity, without taking sewer air flow into account (Edwini-Bonsu & Steffler 2004). H_2S, which predominately results from anaerobic microbial sulfate respiration in slimes and sediments, is the principal component of the pungent gases found in sewers (Jung *et al.* 2017). It is commonly recognized that H_2S can have negative impacts such as sewer corrosion, odor annoyance, and even risk of death for those tasked with maintaining sewer networks. H_2S and other pungent substances leak into the air through cracks in manhole pick holes, pumping stations, etc., irritating adjacent inhabitants with their pungent stench (Carrera *et al.* 2016). Moreover, sulfide-induced concrete corrosion can result in concrete mass loss, sewer pipe fracture, and finally structural collapse (Vollertsen *et al.* 2008). To maintain sewer systems and enhance neighborhood livability, it is crucial to understand H_2S generation and transit in sewer systems.

Sewer construction features such as junctions, manholes, bends, weirs, and dips disrupt the hydraulic conditions that exist under normal flow conditions and increase turbulence. This is particularly relevant at sewage falls and drops, where phenomena like splashing droplets and entrainment of air in the water phase occur, amplifying the mass transfer between water and air (Qian *et al.* 2017). Hence, this type of structure encourages H_2S stripping (Guo *et al.* 2018).

Previous research has shown that the rate at which air is ventilated from sewers to the atmosphere above ground affects H_2S-related odor issues in sewer systems (Edwini-Bonsu & Steffler 2006). Models have been created for calculating the air flow in the sewer system and studies on the interaction of water and air in sewer pipes have been carried out (Qian *et al.* 2017). Also, drop structures, which are frequently utilized in sewer systems to transport waste from higher to lower elevations, have been shown to be another significant component in ventilation based on laboratory findings and field measurements (Guo *et al.* 2018). However, there have been no studies of hydrogen sulfide gas emission in the drop structure by simulating the parameters using the TOXCHEM model. Furthermore, the impact of stream width on hydrogen sulfide gas emissions in the drop structure has not been covered in any of the studies.

Jung *et al.* (2017) studied the gas transport of H_2S at a waterfall in a discharge manhole. Hydrogen sulfide emission was shown to be strongly influenced by waterfall height, hydrogen sulfide liquid concentration, and fluid velocity. Guo *et al.* (2018) studied the outcomes of a field monitoring study on the H_2S levels in an upstream section of a 3-km-long sanitary sewage system in Edmonton, Alberta, Canada, that features drop structures. Six drop structures were among the 19 manholes that were monitored. The flow rate of sewage and the patterns of diurnal H_2S concentration were shown to be positively correlated. Yang *et al.* (2020) investigated the emission of H_2S and its movement in a sewage trunk with drops. It was discovered that the sewer system's drops had a significant impact on the release of H_2S and that even very modest sulfide levels might locally produce substantial H_2S gas concentrations.

This work for the first time studied the emission of H_2S gas in sewage networks by simulating the TOXCHEM program in the Karbala Governorate.

2. MATERIALS AND METHODS

2.1. Research framework

The research approach describes the full strategy for reaching the research's goals (see Figure 1).

2.2. Site location and description

The Al-Hur region in the Karbala governorate is about 100 km south of Baghdad, the capital of Iraq, and within the coordinates 32.645454°N and 43.973323°E were chosen for the study. Al-Hur has a land area of approximately 2,014.8 hectares and is served by a 300 km long network of sewage pipes with diverse diameters ranging from 250 to 1,000 mm. In this study, locations where hydrogen sulfide gas emissions cause unpleasant odors to be released were chosen to assess the impact of drop structures on H_2S release into the air phase in the pipe. The network is deemed 'recent construction' as it was created between 2006 and 2010, and all pipes are manufactured from unplasticized polyvinyl chloride (UPVC). A drop structure with a diameter of 315 mm and a height of 0.9 m was chosen for the focus of the study.

2.3. Sampling and analysis

In order to examine and study hydrogen sulfide emissions, the drop structure's necessary test parameters were gathered. In accordance with the determinants in the standard procedure for the testing of water and wastewater, the examinations were conducted on average throughout four seasons (Rice *et al.* 2012).

The case study includes 24 experiments, conducted over the course of a full year (2021). Each season saw the completion of six experiments, or two each month on average. Moreover, two samples are taken for each experiment; one before and one after the drop structure.

The values for COD, BOD, TSS, pH, temperature, oil and grease, SO_4, and $H_2S_{(aq)}$ were measured from a sample taken before the drop structure and entered into the TOXCHEM model. The TOXCHEM model was then used to predict values

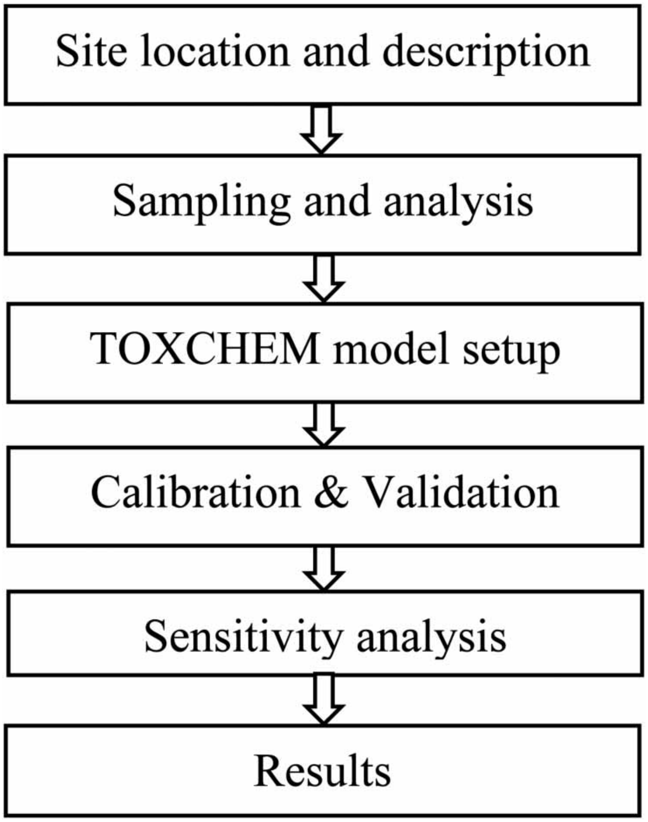


Figure 1 | Study framework.

Table 1 | Characteristics of wastewater

Characteristics of wastewater for a drop structure

Parameters	Spring	St. dev.	Summer	St. dev.	Autumn	St. dev.	Winter	St. dev.
COD (mg/L)	300	±8.94	320	±8.94	280	±17.88	250	±17.88
BOD (mg/L)	160	±14.14	180	±8.94	150	±8.94	170	±14.14
TSS (mg/L)	155	±3.74	167	±2.00	160	±2.28	168	±5.79
pH (unitless)	6.8	±0.09	6.8	±0.14	7.1	±0.09	7	±0.14
Temperature (°C)	22	±2.36	27	±2.36	20	±2.36	17	±0.89
Oil and grease (mg/L)	18	±2.36	27	±2.00	16	±1.41	15	±0.89
SO_4 (mg/L)	600	±58.45	500	±44.72	550	±58.45	800	±44.72
$H_2S_{(aq)}$ (mg/L)	38	±1.41	42	±2.36	35	±2.36	33	±2.83

St. dev., standard deviation.

for $H_2S_{(aq)}$ after the drop structure. The expected value of hydrogen sulfide concentration for each season is represented by the average of these data. Then, the predicted values of $H_2S_{(aq)}$ from the TOXCHEM model were compared with the actual measured values of hydrogen sulfide concentration for each season as shown in Table 1.

2.4. TOXCHEM model

In this investigation, hydrogen sulfide gas emission in a drop structure in the Al-Hur district of the Karbala governorate was examined and studied using the TOXCHEM model. The fate and emission of hazardous organics are represented in numerous unit processes in the TOXCHEM models. In mass balance equations, biodegradation, air stripping (volatilization), and sorption are the three fundamental removal methods that are taken into account. The mass balances on contamination at each unit process serve as the mathematical foundation for the hazardous pollutant process modeling.

The headspace in the drop structure is assumed to be well-mixed and finitely ventilated when modeling the closed drop structure unit process object. To estimate the liquid and gas phase concentrations, the gas-phase steady-state mass balance is used in conjunction with the relationship between influent and effluent contaminant concentration in the liquid and gas phases that was created in the volatilization at drops section (HESS 2012).

To calculate the gas and liquid phase concentrations, the mass balance of the contaminant around the drop structure can be expressed as follows (HESS 2012):

$$Q_g(C_{go} - C_g) + QC_o - QC = 0 \tag{1}$$

where Q_g is the air flow rate through the drop structure, m^3/h, C_{go} is the contaminant concentration in air influent, mg/m^3, C_g is the contaminant concentration in air effluent, mg/m^3, Q is the wastewater flow rate, m^3/h, C_o is the wastewater influent contaminant concentration, mg/m^3, and C is the estimated wastewater effluent contaminant concentration, mg/m^3.

The ventilation air flow rates are considered to be equal to the sewer ventilation rate stated in the input form if the influent air connection is not connected or the influent air flow rate is zero. It is assumed that the sorbed contaminant in the influent cannot volatilize while creating the gas phase mass balance. The following equation is used to correct the mass balance equation's predicted soluble liquid pollutant concentration (HESS 2012):

$$C_{eff}\,(1 + S_{eff}) = C + C_oS_o \tag{2}$$

$$C_{eff} = \frac{C + C_oS_o}{(1 + S_{eff})} \tag{3}$$

where C is the estimated wastewater effluent contaminant concentration, mg/m^3, C_{eff} is the corrected wastewater effluent contaminant concentration, mg/m^3, S_o is the influent sorption term, dimensionless, and S_{eff} is the effluent sorption term, dimensionless.

2.5. Calibration and validation of the TOXCHEM model

Calibration is important since the model has default values that do not accurately reflect the conditions and requirements of the sewage system in Al-Hur city. Therefore, the system needs to be calibrated and adjusted in accordance with the requirements and specifications of the Al-Hur drop structure. Data from the spring and summer seasons, which were acquired for the study drop's testing, were used in this study to calibrate the model. Two further seasons were used to test the model, but their results were not factored into the calibration (Hassan *et al.* 2021).

The following root mean square error (RMSE), determination coefficient (R^2), and correlation coefficient (R) equations were used to statistically compare the predicted output data to the actual (Hussain *et al.* 2022):

$$R^2 = 1 - \frac{SS_E}{SS_T} \tag{4}$$

$$\text{RMSE} = \frac{\overline{(C_O - C_P)^2}}{\overline{C_O}\quad \overline{C_P}} \tag{5}$$

$$R = \frac{\overline{(C_O - \overline{C_O})(C_P - \overline{C_P})}}{\sigma_{C_O}\sigma_{C_P}} \tag{6}$$

where SS_E is the residual sum of squares, SS_T is the total sum of squares, $C_O = \text{mg/L}$ is the actual data, $C_P = \text{mg/L}$ is the modeled data, $\overline{C_O} = \text{mg/L}$ is the average of actual data, $\overline{C_P} = \text{mg/L}$ is the average of modeled data, and σ is the standard deviation over the dataset.

The statistical criteria reasonable limits are $1 \geq R > 0.8$, $1 \geq R^2 \geq 0$, and $0 \leq \text{RMSE} < 1.5$.

2.6. Sensitivity analysis

Sensitivity analysis is a crucial tool for assessing how different process variables affect the fate and emission of H_2S. Sensitivity analysis was performed to understand the fate and emission of H_2S using the main influencing parameters of the drop structure, such as tailwater, drop height, stream width, sewer ventilation rate, and value pH level.

3. RESULTS AND DISCUSSION

3.1. General sewage quality at Al-Hur city

Sewage samples from the drop structure were taken for testing in order to assess the quality of the local sewage. In Table 1, the general sewage quality is displayed and the range for the measured average temperature was between 17 and 27 °C. The network's organic matter decomposition was hastened by the high temperatures in Al-Hur city's sewage (Yang *et al.* 2019). The wastewater is turbid due to the presence of suspended particles, which can occasionally exceed 167 mg/L. Organic or inorganic compounds are among the chemical characteristics of wastewater. According to COD and BOD measurements, the level of organic pollution in the wastewater for Al-Hur city is between 250 and 320 mg/L and 150 and 180 mg/L, respectively. Due to the high amounts of sulfate in the wastewater from Al-Hur city (500 to 800 mg/L), the presence of organic materials, and the anaerobic conditions in the network, sulfate is converted to hydrogen sulfide gas. Al-Hur city's wastewater has extremely high levels of hydrogen sulfide gas, which can reach 33 mg/L in the winter and 42 mg/L in the summer. This causes network-wide technical and environmental issues. As the pH of the effluent was near 7, not all of the hydrogen sulfide concentrations in the network were released. The concentration of oil and grease ranges between 17 and 27 mg/L and in locations where the flow is stable, this fat forms a very thin layer on the surface of the sewage water, which retards the release of hydrogen sulfide gas (Zwain *et al.* 2020).

3.2. Results calibration

The main point of entry into the model for analysis, design, or realistic research is the calibration procedure. Without calibrating the model, the study becomes implausible and meaningless. A drop structure with an average daily flow of 1,250 m^3/day was calibrated for this study for the year 2021. Table 2 shows the required data measured in the drop structure in spring (March, April, and May) and summer (June, July, and August). These values were used to calibrate the TOXCHEM model to predict more realistic results.

Table 2 | Calibration of the TOXCHEM model for the selected study

Classification in TOXCHEM	Parameter	Unit	TOXCHEM default value	Calibration (Spring)	Calibration (Summer)
Wastewater influent	Flow	m^3/day	50,000	1,250	1,200
	TSS	mg/L	200	155	167
	VSS/TSS	%	75	75	75
	Oil and grease	mg/L	–	18	27
	Temperature	°C	15	22	27
	$H_2S_{(aq)}$	mg/L	0	38	42
Drop structure	Tailwater depth	m	0.5	0.1	0.09
	Drop height	m	1.0	0.9	0.9
	Stream width	m	0.5	0.29	0.28
	Sewer ventilation rate	m^3/h	100	90	100
	Local pH value	–	7	6.8	6.8

After entering all the values obtained from the laboratory tests in the TOXCHEM model, and after running the model, the results for the spring and summer seasons were determined and are shown in Table 3.

Figures 2 and 3 show the comparison between the predicted results by the TOXCHEM model and the actual data obtained from samples after the drop structure of water-dissolved $H_2S_{(aq)}$ during the spring and summer seasons, respectively. The predicted results were close to the actual data.

After modifying the influencing parameters of wastewater and drop structure for spring and summer, the outcomes were identical to the R^2, R, and RMSE as shown in Table 4. The table shows all the values of the statistical limits (R^2, R, and RMSE) for the spring and summer seasons, and all values were within the permissible ranges for R^2, R, and RMSE.

Table 3 | Results of the TOXCHEM model for the spring and summer seasons

	Spring		Summer	
Unit	g/day	%	g/day	%
Total incoming	47,500	100	50,400	100
To air	9,590.73	20.191	11,724.1	23.2621
To wastewater	3,799.3	79.809	38675.9	76.7379

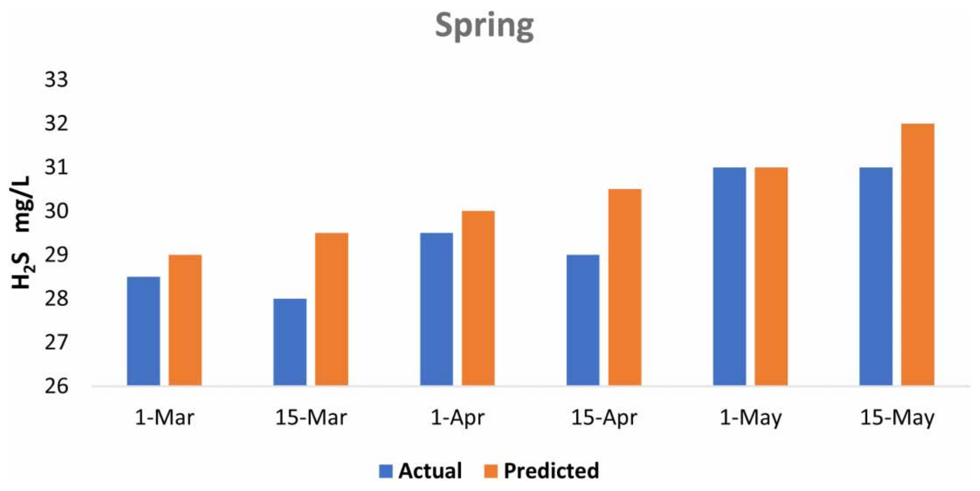


Figure 2 | The calibration (spring) of the actual and predicted values.

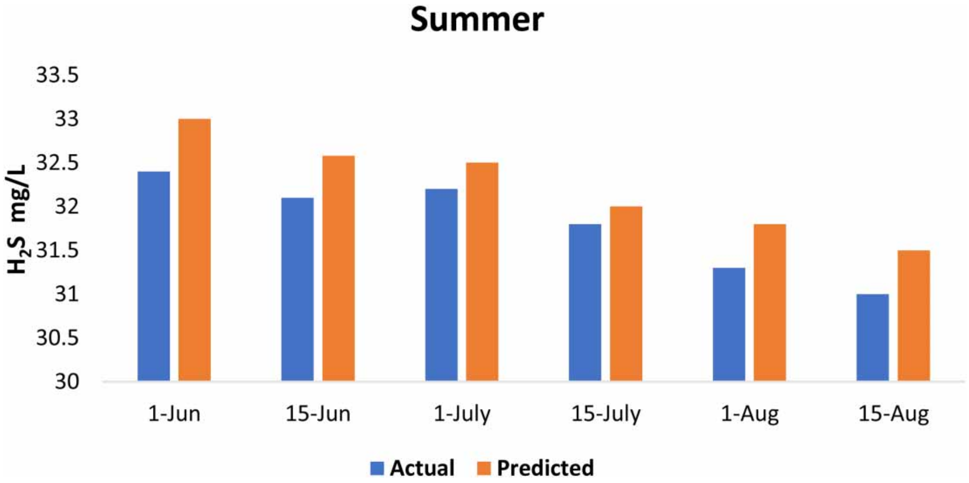


Figure 3 | The calibration (summer) of the actual and predicted values.

Table 4 | RMSE, R^2, and R values after adjustment for calibration

Calibration	Spring (Calibration)	Summer (Calibration)
RMSE	0.000838	0.000598
R^2	0.94	0.93
R	0.81	0.8

3.3. Results validation

The validation of the model comes after the calibration has been established and is successful. Model validation is defined as an agreement within the allowed range between the model's predictions and a different set of data that was not used in the model's construction (Mu'azu *et al.* 2020). After data from the spring and summer seasons were utilized in the calibration, the corresponding values from the autumn and winter seasons were used to validate and compare the anticipated results with the actual outcomes.

Table 5 shows the required data measured in the drop structure in autumn (September, October, and November) and winter (December, January, and February) to validate the TOXCHEM model.

The results for the autumn and winter seasons are provided in Table 6. All the values from the laboratory tests were entered into the TOXCHEM system and the model was run.

Table 5 | Validation of the TOXCHEM model for the selected study

Classification in TOXCHEM	Parameter	Unit	TOXCHEM default value	Validation (Autumn)	Validation (Winter)
Wastewater influent	Flow	m^3/day	50,000	1,250	1,500
	TSS	mg/L	200	160	168
	VSS/TSS	%	75	75	75
	Oil and grease	mg/L	–	16	15
	Temperature	°C	15	20	17
	$H_2S_{(aq)}$	mg/L	–	35	33
Drop structure	Tailwater depth	m	0.5	0.1	0.12
	Drop height	m	1.0	0.9	0.9
	Stream width	m	0.5	0.29	0.3
	Sewer ventilation rate	m^3/h	100	90	80
	Local pH value	–	7	7.1	7

Table 6 | Results of the TOXCHEM model for the autumn and winter seasons

	Autumn		**Winter**	
Unit	**g/day**	**%**	**g/day**	**%**
Total incoming	43,750	100	49,500	100
To air	7,687.08	17.5705	7,982.88	16.127
To wastewater	36,062.9	82.295	41,517.1	83.873

Figures 4 and 5 show the comparison between the predicted results for water-dissolved $H_2S_{(aq)}$ from the TOXCHEM model and the actual data obtained from samples after the drop structure during the autumn and winter seasons, respectively. A slight difference is observed between the predicted and measured values.

The results were identical to the R^2, R, and RMSE as presented in Table 7 even after wastewater and drop structure impacting parameters were changed for autumn and winter. All of the statistical limits (R^2, R, and RMSE) for the autumn and winter seasons are shown in Table 3, and each number is within the ranges that are acceptable for R^2, R, and RMSE.

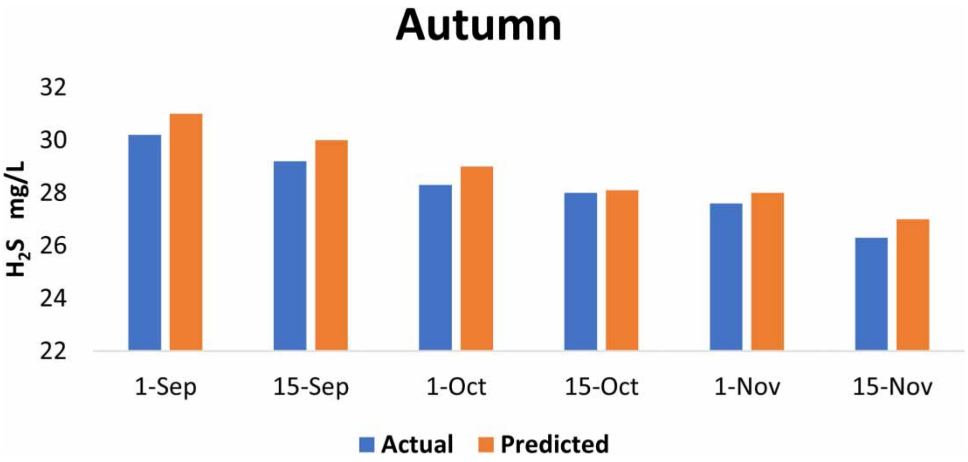


Figure 4 | The validation (autumn) of the actual and predicted values.

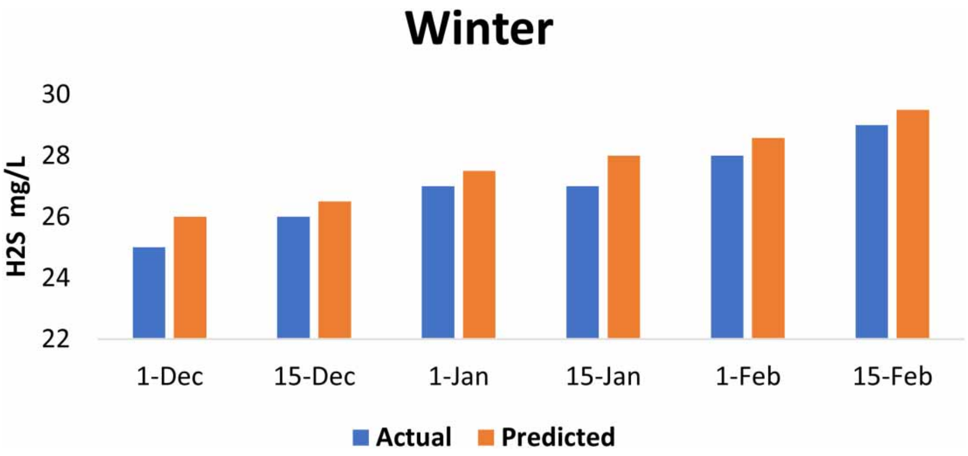


Figure 5 | The validation (winter) of the actual and predicted values.

Table 7 | RMSE, R^2, and R values after adjustment for validation

Validation	Autumn (Validation)	Winter (Validation)
RMSE	0.000438	0.000688
R^2	0.97	0.97
R	0.82	0.82

3.4. The emission of hydrogen sulfide gas in the drop structure

Emission is the term used to describe the mass transfer of H_2S from the liquid to the gas phase. Hydrogen sulfide gas was produced in the study drop structure in appreciable quantities due to the high sulfate content and the anaerobic surroundings. The release of hydrogen sulfide gas has previously been linked to significant issues including release of unpleasant odors and erosion of manholes and other infrastructure. More seriously, it has been implicated as the cause of fatalities involving network maintenance workers (Raveena *et al.* 2020).

The TOXCHEM model calculated the amount of hydrogen sulfide gas released in the gas phase. The seasonal emission of hydrogen sulfide gas is shown in Figure 6. The relatively high temperature of 27 °C, the decreasing pH at a rate of 6.8, and the decrease in flow at a rate of 1,200 m^3/day all contribute to an increase in the emission of hydrogen sulfide gas. The highest emission was in the summer, followed by spring and then autumn. The lowest emission occurred during winter which can be attributed to the lower temperature (typically 17 °C), a steady and neutral pH level of 7, and an increase in the effluent flow to a rate of 1,500 m^3/day. All of the emissions are above 1,000 ppm_v and therefore extremely hazardous. Hydrogen sulfide is considered toxic at breathable concentrations between 500 and 1,000 ppm, but death is not instantaneous. However, at concentrations greater than 1,000 ppm, hydrogen sulfide is rapidly lethal.

3.5. Sensitivity analysis

In each model, there are certain parameters related to the characteristics and quantities of wastewater that can be defined as insensitive, sensitive, and extremely sensitive in terms of the outcomes for both calibration and validation processes (Cao *et al.* 2021). In this study, TSS concentrations, oil and grease ratios, and VSS/TSS ratios were discounted due to their negligible effects but the flow rate and temperature were all recognized as sensitive variables that when altered, affected the results. However, it was discovered that pH was the most sensitive and significant determinant in the outcomes.

For factors related to the characteristics of the drop structure, the tailwater depth, stream width, and sewer ventilation rate were all regarded as sensitive in this investigation and influenced the outcomes when changed. Drop height, however, was found to be the most sensitive and influential structural factor in the results.

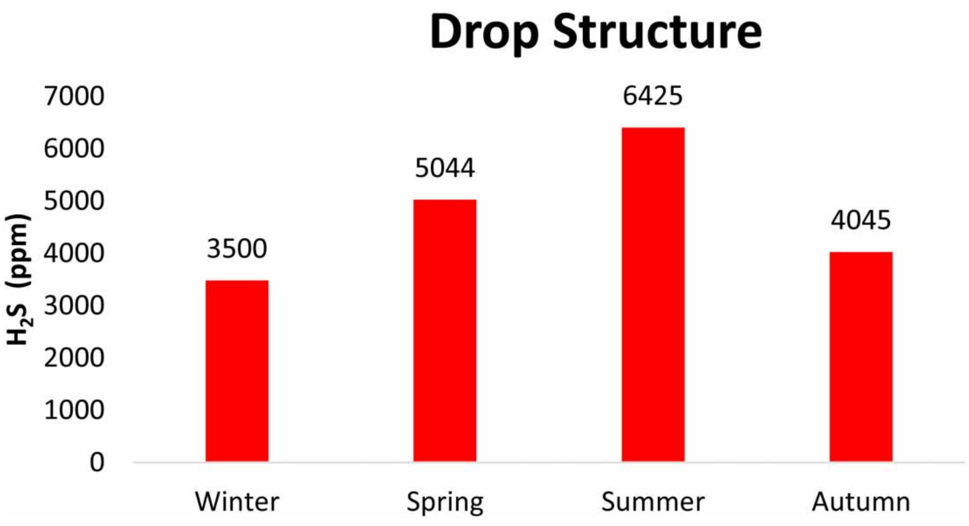


Figure 6 | The emission of H_2S in different seasons.

The sensitivity of pH value was investigated in this study in relation to the quantity and features of this wastewater, on the one hand, and to the sensitivity of the characteristics of the drop structure, on the other hand.

3.5.1. Drop structure parameter

3.5.1.1. Drop height. Figure 7 depicts the influence of drop height on hydrogen sulfide gas emission in the study drop structure. It demonstrates that the emission rate was 3.5% at 0.2 m but when the drop height was increased to 1.6 m, the emission rate jumped to 28%. Increasing the drop height in the drop structure increases the mass transfer coefficient (KL) in wastewater, which leads to an increase in stripping, facilitating the release of hydrogen sulfide gas. These results are supported by Jung *et al.* (2017) who also noted that the stripping of gas increased when the drop height in the drop structure increased.

3.5.1.2. Tailwater depth. Figure 8 depicts the influence of tailwater depth on hydrogen sulfide gas emission in the drop structure study. This shows that the emission rate increased from 17.4 to 24.1% when the tailwater depth was increased

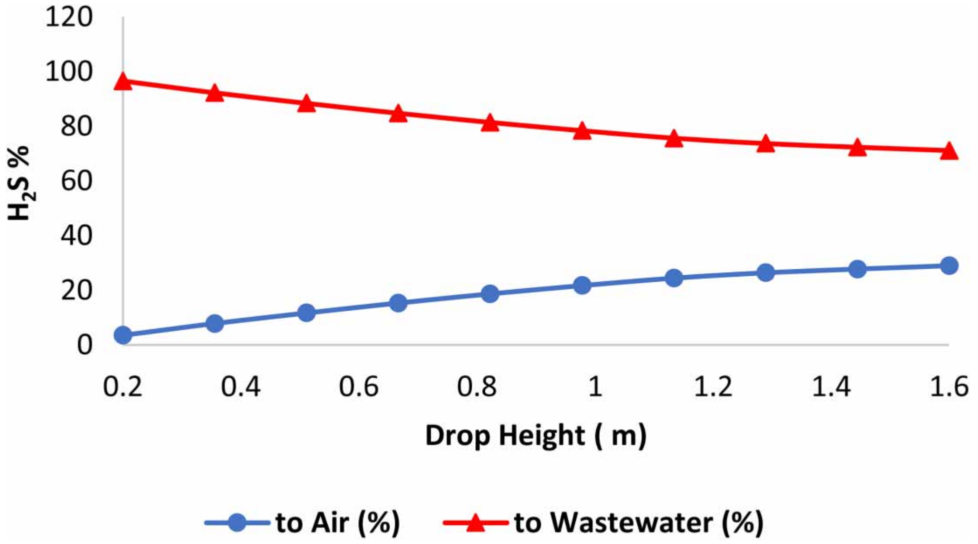


Figure 7 | Sensitivity analysis of drop height on H_2S emission.

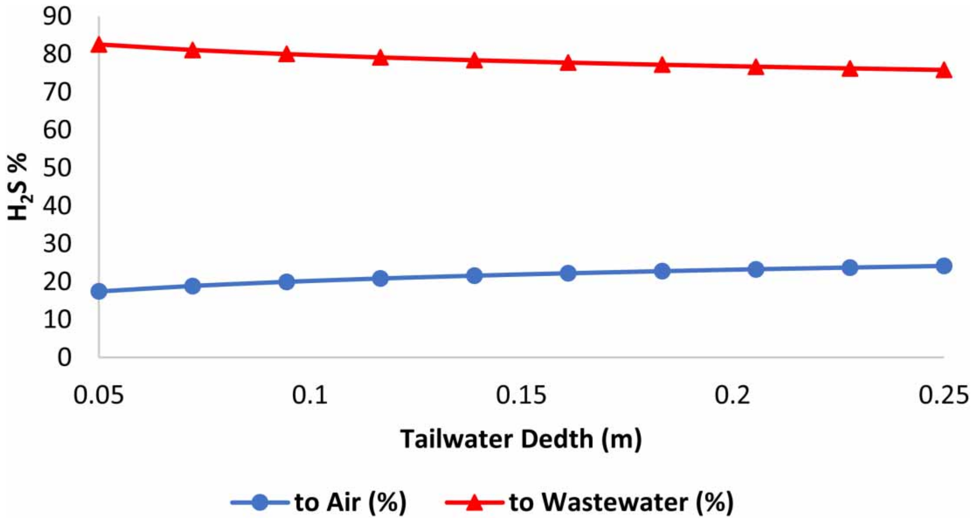


Figure 8 | Sensitivity analysis of tailwater depth on H_2S emission.

from 0.05 to 0.25 m. Increasing the tailwater depth in the drop structure increases the turbulence when wastewater drops, resulting in the release of dissolved H_2S into the gas phase and an increase in stripping. This is in agreement with Yang *et al.* (2020) who reported that the stripping of gas increased when the tailwater depth is increased in the drop structure.

3.5.1.3. Stream width. Figure 9 depicts the influence of stream width on hydrogen sulfide gas emission in the drop structure study. It shows that the emission rate increases from 17 to 20% when the stream is widened from 0.1 to 0.3 m. Increasing the stream width in the drop structure causes the wastewater to drop with more turbulence, which causes more stripping and hence contributes to an increase in the emission of hydrogen sulfide gas. The impact of stream width on hydrogen sulfide gas emissions in the drop structure has not been covered in the previous studies.

3.5.1.4. Sewer ventilation rate. Figure 10 depicts the influence of sewer ventilation rate on hydrogen sulfide gas emission in the drop structure study. It demonstrates that when the sewer ventilation rate was increased from 50 to 140 m^3/h, the

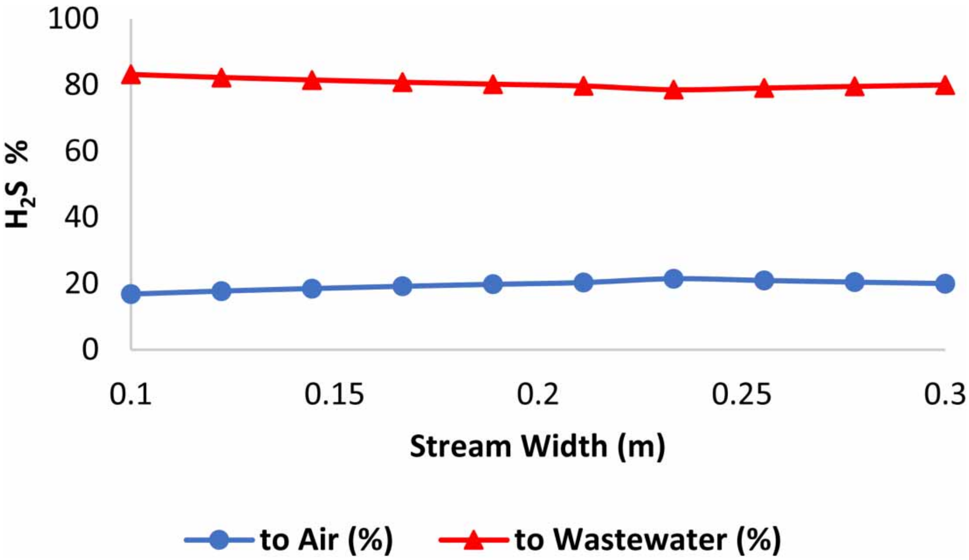


Figure 9 | Sensitivity analysis of stream width on H_2S emission.

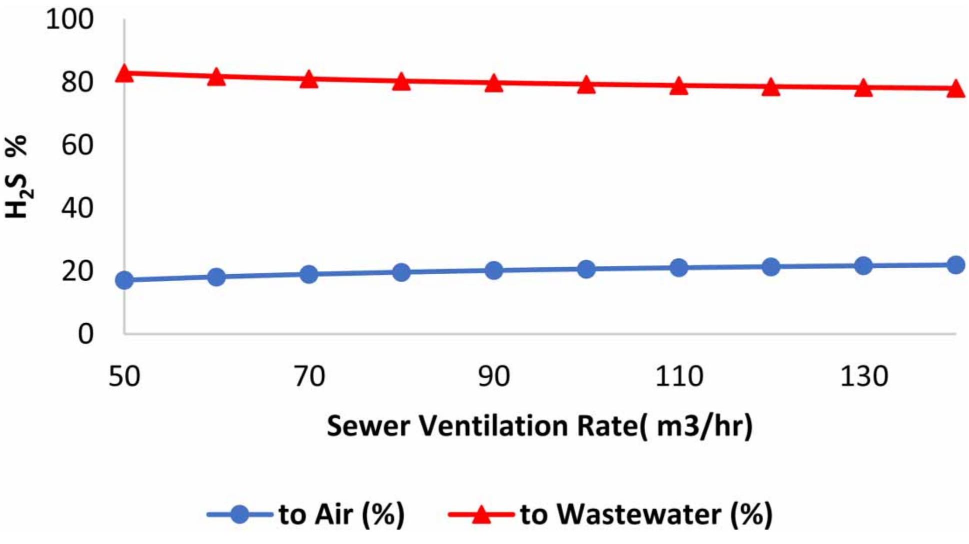


Figure 10 | Sensitivity analysis of sewer ventilation rate on H_2S emission.

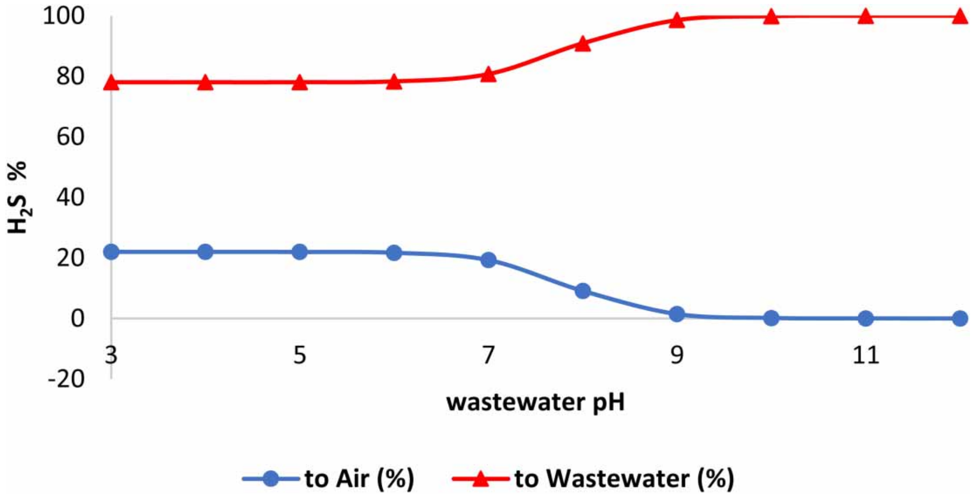


Figure 11 | Sensitivity analysis of pH level on H_2S emission.

emission rate jumped from 17 to 22%. The increase in drop structure's sewage ventilation rate causes more stripping which contributes to the discharge of hydrogen sulfide gas. These results are similar to other workers (Guo *et al.* 2018) who noted that the emission of hydrogen sulfide gas was increased with respect to an increase in the sewer ventilation rate.

3.5.2. Parameters of wastewater

3.5.2.1. pH level. Figure 11 depicts the influence of pH level on hydrogen sulfide gas emission in the drop structure study. It demonstrates that the emission rate increased from 1.4 to 22% when the pH was decreased from 9 to 3. Decreasing the pH level in the drop structure will liberate hydrogen sulfide in the liquid phase, which leads to an increase in stripping and adds to the release of hydrogen sulfide gas. It is interesting to note that the concentration of H_2S in the gaseous phase reaches a maximum at around $pH < 7$ which is close to the reported pKa of hydrogen sulfide of 6.97–7.06 at 25 °C. These results are similar to Wang (2017) who also noted a decrease in the emission of hydrogen sulfide gas due to the increasing pH level.

4. CONCLUSION

A calibrated and validated TOXCHEM analysis was used to ascertain the sensitivity of the parameters influencing hydrogen sulfide gas emission in drop structures. The study was based on statistical analyses of data collected over a year, as well as grab samples collected over a period of 24 days from the inlet and outlet of the drop structure. The most significant factors affecting hydrogen sulfide emission were found to be drop height, pH level, tailwater depth, stream width, and sewer ventilation rate. The drop height and pH were major determinants of H_2S emission in drop structures, according to the TOXCHEM software, and drop height was found to be the most important characteristic. As a result of this study, the following conclusions were reached:

1. The greatest emission of hydrogen sulfide occurs in summer due to the high temperatures, lower pH, and decreased flow. This is followed by spring and then autumn.
2. Increasing the drop height, tailwater depth, stream width, and sewer ventilation rate of the drop structure will raise the emission of hydrogen sulfide gas.
3. Less hydrogen sulfide gas is released in the drop structure at higher pH levels.
4. Emission can be reduced by increasing the pH through the addition of an alkaline substance. The emission becomes close to nil with $pH \geq 10$.

The results of this study will be helpful in creating odor control strategies for sewers and limiting the detrimental effects on human health and sewer infrastructure from H_2S release. However, additional research is required to fully explain some of the observed events, such as the H_2S burst at multiple locations. To further investigate the H_2S creation process and its rates of emission, liquid field samples should also be gathered and examined, as well as sewage biofilm data.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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