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Odour emissions from a municipal solid waste dumping area that are at the moderate stage of disintegration

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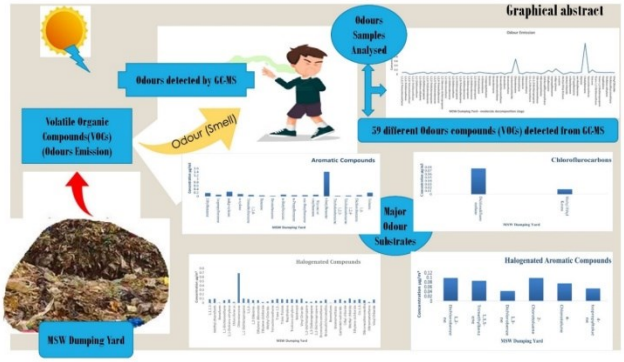
Graphical abstract



Abstract

Odour is a major concern as they are termed hazardous to the surroundings as well as life forms when they are exposed to the environment. Odour emission is also one of the indicators of environmental changes that impact the environment. Among the different sources of odour emission, in the dumping yard itself different types and ages of waste are dumped in the municipal solid waste (MSW) dumping yards. This study aims to relate odour emission and concentration changes caused by different weather patterns. Different periods of waste (fresh waste, moderate waste, and ripened waste) and weather seasons (summer and winter) affect the odour concentrations. Mixtures of gases and intolerable odours are major components of the MSW dumping yard. The odour concentration was monitored in the different periods of waste (moderate wastes) at different locations in the MSW dumping yard. In this study, it was found that meteorological conditions are also one of the main influences on odour concentrations in the environment. In this study, a comprehensive investigation about odour pollution from a local MSW dumping yard has been performed. The odour concentration indicates that the maximum range of aromatic hydrocarbon chemical compounds (volatile organic compounds) reported was T-butylbenzene at 1.41µg/m^3 and the minimum range was Sec-butylbenzene at 0.07µg/m^3. This study will provide information on odour emissions in urban areas and how VOC (Volatile Organic Compounds) components are present and affect the dumping yards surrounding those areas.

Keywords: MSW dumping yard, VOCs, odour emission, odour concentration

1. Introduction

Municipal solid waste dumping yards release gases into the atmosphere when waste is disposed of. As a result of the atmospheric emissions, the odours may also be unpleasant, which might irritate nearby residents. The production of municipal solid trash has increased in every developing country as a result of urban sprawl and the advancement of behavioral changes. Odour emissions, which are a concern in cities as well as rural areas, are one of the environmental problems caused by the availability of MSW disposal sites (Capelli *et al*., 2011). Odour emission has both high and low concentrations that humans and other animals can detect through olfaction and can be split into two categories: pleasant and unpleasant odours. Volatile organic (VO) substances and Benzene, Toluene, Ethylbenzene and Xylene, BTEX from the various age categories of waste in the dumping yards are mostly to blame for the odour emission from those areas (Scaglia *et al*., 2011). The MSW dumping yard's early phase of decomposition, which includes waste transfers from one location to another during transportation to the dumping yard, is when the odour emission first becomes noticeable (Haobo Tan *et al*., 2017). The huge percentage of odorant substances released by MSW dumping yard gases are present at various levels of concentration, so they contain both saturated and unsaturated hydrocarbons, acidic hydrocarbons and organic alcohols, aromatic hydrocarbons, halogenated substances, volatile sulphur substances like methyl mercaptan (MM) and dimethyl sulphide (DMS), as well as inorganic substances (Allen *et al*., 2011). The components in the waste and

those created during its degradation volatilize, releasing the VOCs into the air (Keller.J.2013). Volatile organic compounds (VOCs), greenhouse effect gases (CO_2, CH_4, and N_2O), ammonia, and hydrogen sulphide are generated in MSW disposal sites as a result of complex metabolic interactions involving aerobic, anoxic, and anaerobic organic matter (Krzymien *et al*., 1999; Zhu *et al*., 2016, and C.A. Rincon *et al*., 2019). (Scaglia *et al*., 2011) explained that the gases from dump sites are frequently linked to unpleasant odours, adverse health outcomes, and effects on the environment. Odorous emissions can make dumping yard workers and residents who live close to waste treatment facilities uneasy and depressed (Muller *et al*., 2004). In the regions around dumping yards, odours are the main reason residents complain (Schlegelmilch *et al*., 2005). Being that most dumping sites are located close to residential areas, the odours emitted from such dumps usually prompt additional concern (Yan Zhao *et al*., 2015). Gas chromatography-mass spectrometry (GC-MS) analysis of more than 140 chemicals, of which more than 90 were common to all seven landfills, was performed on the VOCs at seven different waste disposal sites in the UK (Allen *et al*., 2011). The in-situ sampling method used in this investigation was done on waste that was of a moderately old age and was taken from a MSW dumping yard in Chennai, Tamil Nadu. Analytical and sensory tools are mostly used to monitor the odorous gas samples (Capelli *et al*., 2008). The sensory method currently used to quantify odour intensity (OC in OUE m^3) is dynamic olfactometry (Laor *et al*., 2014). (EN 13725, 2003) demonstrates how a gaseous sample is diluted with unscented air to measure the concentration at which 50% of a calibrated human panellist can detect an odour provocation in order to assess odour concentration. The major goal of applying experimental approaches for evaluating odours is to identify the primary odour producers from complex gas mixtures of volatile compounds (Gallego *et al*., 2012). Chemical concentrations of compounds can be weighed according to suitable odour detection thresholds (ODTs) to determine the substances that are closer to the limits of odour perception (Capelli *et al*., 2008). The odour dispersion pattern and concentration of the observed odorous substances were assessed and compared. The finding offers important information that can be used to understand the effects of the MSW dumping yard's odour component. In order to determine the odour concentration at MSW dumping yard was measured using a BDX II abatement air sampler and an ADT probe, and it was analyzed with a GC-MS Agilent 6890 N series.

2. Materials and methods

2.1. Collection and storage of materials at MSW

Six different sampling locations are collected from solid waste dumping yard at local urban area. Organic substrates were divided into waste from different vegetable markets, street side tree trimming wastes, drainage sludge's, household wastes and food wastes from restaurants based on the origins and compositions of the waste. Table 1 indicates the classification and sources of the substrates (C.A. Rincon *et al*., 2019).

Table 1. MSW Dumping Yard collected materials: composition and source

S.No	Type of wastes	Substrates	Composition
1	Vegetable markets	Green Wastes from market waste bins Damaged Vegetable, fruits wastes from bins etc	Markets and Restaurant's
2	Bio wastes	Fruits and cooked vegetables, meat, food, bakery items etc	Restaurant's
3	Household wastes	Culinary waste, commercial food waste, fruit and veggie peelings, etc.	Houses
4	Farms (Cow, Pig, Horse Poultry)	Cereals and food wastes, slurry and manure	Farms
5	Green wastes	Leaves, grass, and brush	Garden

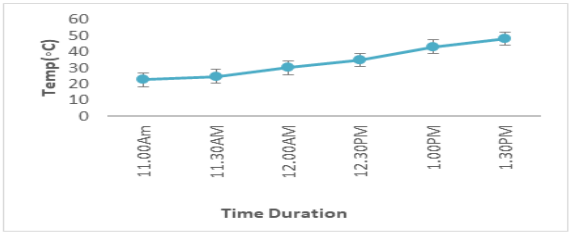


Figure 1. Temperature Duration at the MSW Dumping Yard

2.2. Temperature and wind factor

The temperature variations in MSW dumping yard during waste composting are shown in Figure 1. The operational composting conditions and the temperature rise had a serious influence; The temperature difference was a meteorological aspect that had an impact on the odour concentration (C.A. Rincon *et al.,* 2019). The investigation's results showed that the distribution of odour concentration was higher at stations with lower temperatures than it was at those with higher ones, despite the insufficient model that was used to characterize this relationship. It was discovered that stations with low temperatures, approximately 25°C, had the greatest concentration of fragrance dispersion (Pooja. and Pawar *et al.,* 2015). According to the quantity and mass of compounds released, the principal chemical families were alcohols, nitrogen compounds, sulphur compounds, alkanes, aromatic compounds, chlorofluorocarbons, halogenated compounds, and halogenated aromatic hydrocarbons. Their emission peaks lined up with temperature fluctuations and the compost's biological activity as a result (Blazy *et al.,* 2014).

The slower wind speeds have a higher odour concentration than the faster ones. When the temperature of the atmosphere was steady and accumulated in places with severe weather, this phenomenon occurred. The dispersion of concentrated gas and odour was influenced by wind velocity (Pooja V. Pawar *et al*., 2015 and Zaini, 2012).

2.3. Monitoring of different gaseous samples and chemical analysis

The geological formations and topography of the study area are taken into consideration when collecting odour samples in order to detect the spatial and temporal changes in the ambient air. The samples are collected in three different places from dumping yard. The collected samples were immediately brought to the laboratory at particular temperature. Since odour is present in ambient air, air samples containing odour causing compounds will be collected near the solid waste dumping yard at different distance. Using a BDX II Abatement Air Sampler Pump, ambient air containing the odour causing compounds, will be collected in the ADT Sampling Probe in the flow rate of 0.5-3.0 LPM. BDX II Abatement Air Sampler is a portable instrument and Built-in electronic flow control adjustment with rechargeable battery pack. Using a ADT PROBE Compatible with electronically-tagged or untagged tubes in 9.1cm. ADT Sample Probe was used for collecting VOCs in the solid waste dumping yard. After sampling the mouth of the tube will be tied up tightly and labelled to indicate the details of sampling point with date and time. This Sampling tube will be taken to the laboratory to find out the odour concentration. (Mochalski *et al*., 2009). Figures 2a and b shows the BDX II Abatement Air Sampler and ADT PROBE.

(a) BDX II Abatement Air Sampler (b) ADT PROBE

Figure 2. (a) BDX II Abatement Air Sampler and (b) ADT PROBE

2.4. Measurement of volatile organic compounds (VOCs)

Odour measurement using olfactory sensory methods, which make use of the human sense of smell, as well as instrumental methods, which employ tools like gas chromatographs to quantify the concentration of odorous gases in ppm was conducted by (Yoshiharu iwasaki ,1972). (Fabio Di Francesco *et al*., 2000) investigated the several methods that have been used to gauge the effect of odorous emissions on the populace, sometimes to confirm the veracity of complaints made by the public and other times to prevent them from happening. GC/MS analysis of the air quality produced a list of the compounds and their concentrations. Using this method is expensive and time-consuming, and the results don't really reveal much about individuals' views. Only in circumstances where the presence of toxic chemicals is suspected can the GC/MS be used. The procedures to ascertain the perceptual threshold, the strength of the olfactory experience, and the hedonic tone are detailed in a number of guidelines. Measurements of CH_4, CO_2, and N_2O emissions at Chennai's KDG and PGD landfills were made in December 2003 and September 2004, according to (Arvind K. Jha *et al*., 2007). The age (2-4 years) of MSW at the surface layer and the height of deposition (between 5 and 15 feet) at the landfill's units and periphery were used as criteria for choosing sampling points. Gas samples were collected at 15-minute intervals at each location with 50-ml syringes using a chamber technique for 45 minutes. Temperatures at the study sites were also measured, both ambient and MSW. MSW soil samples were collected in order to measure moisture content. A gas chromatograph (GC; SRI, USA, Model 8610 C) flame ionisation detector connected with a mechanizer was used to analyse gas samples for CH_4 and CO_2. The concentrations of N_2O were measured using a GC-electron capture detector. Calibration gas standards of CH_4 (5.63 ppmv), CO_2 (500 ppmv), and N_2O (0.31 ppmv) were employed during sample analysis. Annual emissions were computed by calculating the emission fluxes of these gases and multiplying them by the area of landfills. In December 2008 and June 2009, Manju Rawat *et al*. (2011) studied methane samples from three landfill regions in Delhi. Using a flame ionisation detector (FID), gas chromatography was employed to evaluate these samples. Continuous measurements were made of the temperature of the atmosphere and the landfill's 5 cm depth. To examine the gas samples, a Porapak Q column was used in the FID of a gas chromatography (GC). The temperatures of the soil and atmosphere were measured with a thermometer that had been calibrated.

2.5. Instruments to be used in measurement

On certain occasions, odour is measured using a gas chromatograph (GC). Gas chromatography equipment from Agilent, model 6890 N. In order to measure the concentrations of VOCs, a single flame ionization detector (FID) column was utilized. The sample is injected using a single 100 PSI (pounds per square inch) EPC split-less injection port at the specified temperature. Additionally used are the 6890 injector, Pentium computer, and 17-inch flat panel monitor for the auto sampler. The Agilent model 6890 N series GC (gas chromatography system) appears in Figure 3.

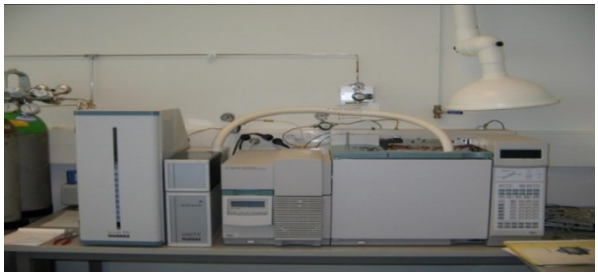


Figure 3. Agilent model 6890 N series gas chromatography system

3. Results and discussion

3.1. Odour emissions are chemically analyzed

The identification of 59 compounds across various compounds from the MSW dump yard of five different substrates was achieved (Table 2). Alkanes, aromatic compounds, chlorofluorocarbons, halogenated compounds, and halogenated aromatic hydrocarbons were also discovered; however, they were only seen in the gaseous samples collected from the MSW dumping yard. The contact of the substrates with solvents, gasoline, and fungicides at the various farms' drop-off locations is the cause of the occurrence of these xenobiotic compounds in vegetable market waste (Fang *et al*., 2013).

BTEX (toluene, benzene, ethyl-benzene, and xylene) have reportedly been often found in the emissions from MSW, according to our analysis (Komilis *et al*., 2004 and Scaglia *et al*., 2011). drainage sewage sludge (Y. Li Zhu*et al*., 2016) and food waste (Mao *et al*., 2006; Tsai *et al*., 2008) solid waste dumping yard. Hence, certain elements may have made it difficult to identify BTEX while these organic composites were being composted (Eitzer, 1995). Because we collected our data in the summer, when temperatures were fairly high and little microbial activity was present, the peak VOC emissions coincided with mild decomposition. The findings demonstrate that the dumping yard product unit had fairly VOC emission concentrations, particularly for the aromatic and halogenated compounds. VOCs would have been produced as the composting materials decomposed through biological decomposition (Shao *et al*., 2017).

Table 2. Identified odour emission at the municipal solid waste dumping yard

59 Different Volatile organic compounds (odour emissions)			
Aromatic Compounds	**Chlorofluorocarbons**	**Halogenated Compound**	
Ethylbenzene	Dichlorodifluoromethane	Tetrachloroethene	Methyl chloride
Isopropylbenzene	Methyl Ethyl Ketone	Trans-1,2-Dichloroethene	Ethylene dichloride
m&p-xylenes	**Halogenated Compound**	Trans-Telone	Cis-1,3-Dichloropropene
o-xylene	1,1,2,2-Tetrachloroethane	Napthalene	Dibromochloromethane
1,2,4-Trimethylbenzene	Methyl chloroform	Trichloro ethylene	Dibromomethane
Benzene	Bonoform	Westrosol	Vinyl Chloride
Bromobenzene	1,1-Dichloroethane	Vinyl Chloride	**Halogenated aromatic hydrocarbon**
n-Butylbenzene	1,1-Dichloro ethylene	1,2-Dichloropropane	1,2-Dichlorobenzene
n-Propylbenzene	Chloroform or trichloromethane	1,3-Dichoropropane	1,3,5-Trimethylbenzene
sec-Butylbenzene	Chlorobenzene	2,2-Dichloropropane	1,3-Dichlorobenzene
Styrene	1,1-Dichloropropene	Bromochloromethane	2-Chorotoluene
t-butylbenzene	1,2,3-Tricholoropropane	Bromodichloromethane	4-Chlorotolune
1,2,3-Tricholorobenzene	1,2-Dibromo-3chloropropane	Bromoform	4-Isopropyltoluene
1,2,4-Tricholorobenzene	Ethylene dibromide	Bromomethane	
1,4-Dichlorobenzene	Ethylene dichloride	Carbontetrachloride	
Toluene	Methyl Chloride	Ethyl chloride	

3.2. Role of 59 different VOCs at MSW

A summary of the VOC emission characteristics is given in this section. 59 VOCs were identified in the samples taken from the MSW dumping yard, including alkanes, aromatic compounds (AC), chlorofluorocarbons (CFC), halogenated compounds (HC), and halogenated aromatic hydrocarbons (HAC).

In the month of March 2022, 1.41 µg/m^3 of all oxygenated compounds were determined to be at their greatest concentration therefore, that of alkanes, aromatic compounds, chlorofluorocarbons, halogenated compounds, and halogenated aromatic hydrocarbons. Dorado *et al*. (2014) and Guodi Zheng *et al*. (2018) produced similar results. When MSW is composted, some VOCs are released, suggesting that the season had an effect on these emissions. (Figure 4). The VOC emissions peaked during the MSW dumping yard because our samples were taken at the beginning of March 2022, when the ambient temperature was quite low and microorganism's metabolism during MSW transportation would have been slow. The findings showed that the composting process unit's VOC emission concentrations were generally high, particularly for aromatic and halogenated compounds. The composting procedures delayed anaerobic degradation, which would have generated VOCs.

3.3. Role of alkanes

A partially degraded MSW dumping site yielded 59 various odorous compounds that were identified by GC-MS, with about 13 different types of higher alkanes. Alkane concentrations may have been high, which are mostly linked to the breakdown of organic waste in the MSW dumping yard**.** (Onwosi *et al*., 2017 and Komlilish *et al*., 2004). The concentration of alkane was low, indicating that it would almost be consumed during the second stage of the degradation of organic matter. The breakdown of organic waste and some other mixed wastes are sources of alkanes, primarily in the solid waste dumping yard. So, the composition of the solid waste dumping yard can be used to explain the peculiarities of alkane emission in the investigations. Alkane emissions were consequently high at the beginning of the composting period (Zhang *et al*., 2012).

3.4. Role of aromatic compounds

Figure 5a shows the carbon and hydrogen involved in the MSW dumping yard. A total of 16 aromatic compounds were found in the samples, as can be seen in Figure 5b. The majority of the concentration of aromatic compounds was made up mostly of t-butylbenzene, which made up 11% on average. The t-butylbenzene concentration in the sample is 1.41 µg/m^3. Similar outcomes were discovered (Moreno *et al*., 2014). This study provides information regarding VOC exposures to sec-butylbenzene and tert-butylbenzene are eating, inhaling, and skin contact. Several of these substances are known to irritate mucous membranes, the eyes, and the skin, making them lung aspiration hazards. California Office of Environmental Health Hazard Assessment (OEHHA). That raw waste emits a higher level of t-butylbenzene than aged compost. T-butylbenzene is frequently released when the odours in detergents and other home furnishings are disturbed. These food containers, plastics, and papers break down in the MSW disposal yard as an intermediary step in the decomposition of organic waste. The samples contained toluene, ethylbenzene, m- and p-xylenezes, o-xylene, sec-butylbenzene, and t-butylbenzene the main aromatic compounds. Contributing factors of BTEX emissions at landfill sites include the decomposition of organic debris and organic compounds generally present in solid waste dumping yards.

Figure 4. The total amount of 59 volatile organic compounds (VOCs) released at the municipal solid waste composting unit

3.5. Role of chlorofluorocarbons

There were two chlorofluorocarbons found in the samples. Due to the presence of chlorofluorocarbons in the dumping yard, MSW is typically generated by halogen exchange beginning with chlorinated methanes and ethanes. Figure 6 represents the concentrations of the various classes of chlorofluorocarbons.

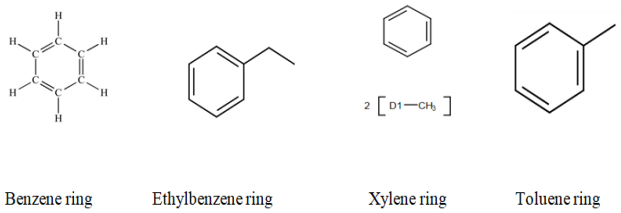


Figure 5a. BTEX Rings (source: nih.gov)

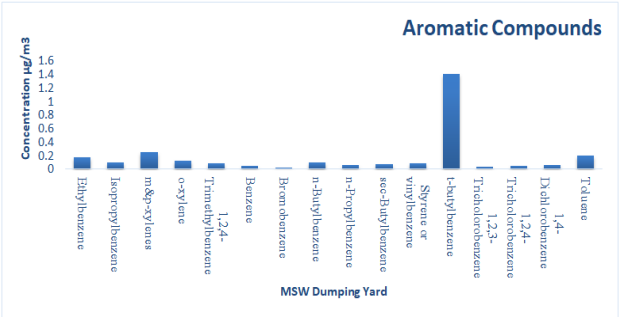


Figure 5b. Role of Aromatic Compounds at MSW dumping yard

Dichlorodifluoromethane and methyl ethyl ketone were discovered to be at relatively high concentrations. The MSW dumping yard samples contained the greatest dichlorodifluoromethane emission concentration (0.07 µg/m^3). (Guodi Zheng et.al 2018; and Pierucci *et al*., 2005). When MSW undergoes composting, minimal amounts of methyl ethyl ketone emissions were earlier observed (Mustafa *et al*., 2017). In the presence of wood stains, moderate domestic wastes emit methyl ethyl ketone (Moreno *et al*., 2014). The ozone barrier is being destroyed, which results in climate change, by chlorofluorocarbons (Scheutz *et al*., 2008).

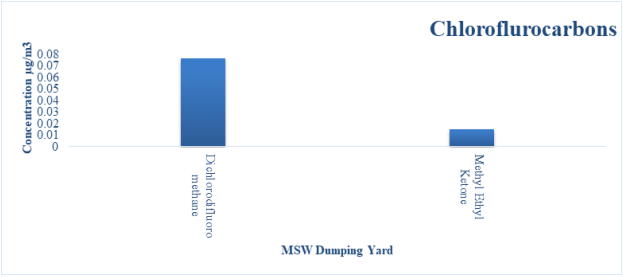


Figure 6. Role of Chlorofluorocarbons at MSW Dumping Yard

3.6. Role of halogenated compound

The samples contained 35 halogenated chemicals, according to the analysis. According to Figure 7 samples taken from an MSW disposal yard had the highest concentration of halogenated compounds. The MSW disposal yard samples contained chlorobenzene emissions in concentrations of 0.7 µg/m^3. Other halogenated compounds like methyl chloroform, naphthalene, vinyl chloride, and trans-Telone are presented in the range of 0.1µg/m^3. This might have been brought on by the dumping yard unit's comparatively high concentrations of chloroform and 1,2-dichloroethane emissions. These two

compounds are primarily created when non-biodegradable and quickly biodegradable substances are broken down (Liu *et al.*, 2009). In general, it seems that halogenated compounds found in dumps are connected to the solvents that are frequently used in urban and industrial sources as antiseptics and cleaners (Dincer *et al.*, 2006).

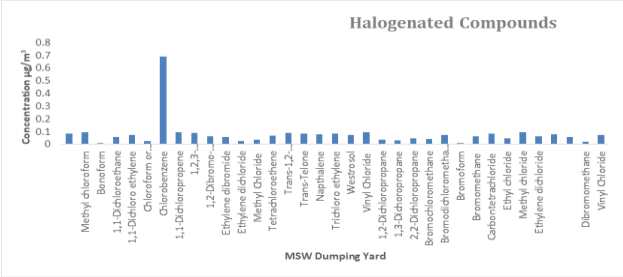


Figure 7. Role of Halogenated Compounds at MSW Dumping Yard

3.7. Role of halogenated aromatic hydrocarbon

The samples contained six halogenated compounds, which were found. The MSW dumping yard samples included the highest amount of halogenated aromatic hydrocarbon compounds, as seen in Figure 8. The MSW disposal yard samples contained 1, 2-dichlorobenzene and 2, 4-dichlorotoluene emissions at concentrations of 0.1 µg/m^3 (Pierucci *et al.*, 2005)

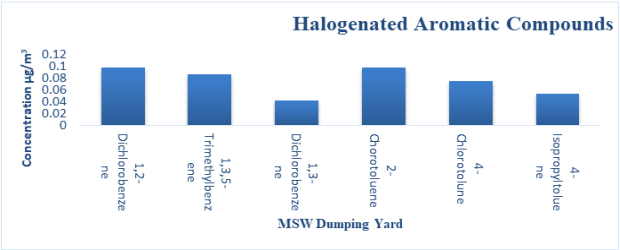


Figure 8. Role of Halogenated Aromatic Hydrocarbon at MSW Dumping Yard

4. Conclusions

In this study, a comprehensive investigation about odour pollution from a local MSW dumping yard has been performed. The VOCs emissions generated by different locations of an MSW dumping yard were collected and analysis was done on the samples. A major influence of meteorological conditions on odour concentrations was also observed during the summer when temperatures were fairly high and microbial activity was relatively low. Peak VOC emissions coincided with mild decomposition, suggesting that the maximum range of aromatic hydrocarbon compounds reported is 1.41 µg/m^3 as a result of T-butylbenzene, while Sec-butylbenzene is reported as 0.07 µg/m^3. The chemical composition of gas emissions from composting varied extensively depending on the kind of substrate and operational conditions. BTEX and oxygenated compounds generally have a considerable impact on the total mass emissions of natural matrices containing vegetable and food feedstock, such as household, municipal solid waste, and green wastes. The strong odour influence of emissions created during the MSW composting yard of raw substrates, such as vegetable waste and food waste, was shown by their odour emission. Although BTEX contributed just a small amount of chemicals, its odorous potential was highlighted. These identified odorous chemicals could help in the implementation and design of odour reduction techniques. The effectiveness and cost of odour monitoring programmes can both be improved by reducing the number of target compounds. Future studies should examine the odour pollution from a local MSW dumping yard in relation to the different types of waste (fresh waste and ripened waste) and weather seasons (summer and winter) that affect odour concentrations.

References

Allen T., Singh R.P., Tyagi V.V., Ibrahim M.H. and Kothari R. (2011). An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario, *Renewable and Sustainable Energy Reviews*, **15**(9), 4797–4808. https://doi.org/10.1016/j.rser.2011.07.071.

Blazy V., de Guardi A., Benoist J.C., Daumoin M., Lemasle M., Wolbert D. and Barrington S. (2014). Odorous gaseous emissions as influence by process condition for the forced aeration composting of pig slaughterhouse sludge. *Waste Management*. (Oxford) **34**, 1125–1138.

Capelli L., Sironi S., Del Rosso R., Céntola P. and I Grande M. (2008). A comparative and critical evaluation of odour assessment methods on a landfill site. *Atmospheric. Environment*. **42**, 7050–7058. https://doi.org/10.1016/j.atmosenv.2008.06.009.

Capelli L., Sironi S., Del Rosso R., Centola P., Rossi A. and Austeri C. (2011). Odour impact assessment in urban areas: Case study of the City of Terni, *Procedia Environmental Sciences*, **4**, 151–157. https://doi.org/10.1016/j.proenv.2011.03.018.

Dincer F., Odabasi M. and Muezzinoglu A. (2006). Chemical characterization of odorous gases at a landfill site by gas chromatography-mass spectrometry. *Journal of Chromatography A* 1122, 222e229.

Domingo J.L. and Nadal M. (2009). Domestic Waste Composting Facilities: A review of Human Health Risks, *Environment International*, **35**(2), 382–389. https://doi.org/10.1016/j.envint.2008.07.004.

Dorado A.D., Husni S., Pascual G., Puigdellivol C. and Gabriel D. (2014). Inventory and treatment of compost maturation emissions in a municipal solid waste treatment facility. *Waste Management*. (Oxford) **34**, 344–351.

Eitzer B. (1995). Emissions of volatile organic chemicals from municipal solid waste composting facilities. *Environmental Science Technology*. **29,** 896–902. https://doi.org/10.1021/es00004a009.

EN 13725. (2003). Air Quality–Determination of odor concentration by dynamic olfactometry. AFNOR.

Fang J., Zhang H., Yang N., Shao L. and He P. (2013). Gaseous pollutants emitted from a mechanical biological treatment plant for municipal solid waste: Odor assessment and photochemical reactivity. *Journal of Air Waste Management. Association*. **63**, 1287–1297. https:// doi.org/10.1080/10962247.2013.822439.

Gallego E., Roca F.J., Perales J.F., Sánchez. and Esplugas P G. (2012). Characterization and determination of the odorous charge in the indoor air of a waste treatment facility through

the evaluation of volatile organic compounds (VOCs) using TD-GC/MS. *Waste Management*. **32**, 2469–2481. https://doi.org/10.1016/j.wasman.2012.07.010.

Keller J., Oderbolz D.C., Aksoyoglu S., Barmpadimos I., Steinbrecher R., Skjoth C.A., Plab-Dulmer C. and Prevot A.S.H. (2013). A comprehensive emission inventory of biogenic volatile organic compounds in Europe: Improved seasonality and land-cover, *Atmospheric Chemistry and Physics*, **13**(4), 1689–1712. https://doi.org/10.5194/acp-13-1689-2013.

Komilis D.P., Ham R.K., Park J.K. (2004). Emission of volatile organic compounds during composting of municipal solid wastes. *Water Resources*. **38**, 1707–1714. https://doi.org/10.1016/j.watres.2003.12.039.

Krzymien M., Day M., Shaw K. and Zaremba L. (1999). An investigation of odors and volatile organic compounds released during composting, *Journal of the Air & Waste Management Association*, **49**(7), 804–813. https://doi.org/10.1080/10473289.1999.10463845.

Laor Y., Parker D and Pag T. (2014). Measurement, prediction, and monitoring of odors in the environment: A critical review. *Reviews in Chemical Engineering*. **30**, 139–166. https://doi.org/10. 1515/revce-2013-0026.

Liu Q., Li M., Chen R., Li Z., Qian G., An T., Fu J and Sheng G. (2009). Biofiltration treatment of odors from municipal solid waste treatment plants. *Waste Management*. (Oxford) 29, 2051–2058.

Mao I.F., Tsai C.J., Shen S.H., Lin T.F., Chen W.K and Chen M.L. (2006). Critical components of odors in evaluating the performance of food waste composting plants. *Science Total Environment* **370**, 323–329. https://doi.org/10.1016/j.scitotenv.2006.06.016.

Mochalski P., Wzorek B., Sliwka I and Amann A. (2009). Suitability of different polymer bags for storage of volatile sulphur compounds relevant to breath analysis. *Journal Chromatography B Analytical Technologies Biomedical Life Science*. **877**, 189–196. https://doi.org/10. 1016/j.jchromb.2008.12.003.

Moreno A.I., Arnaiz N., Font R and Carratala A. (2014). Chemical characterization of emissions from a municipal solid waste treatment plant. *Waste Management*. (Oxford) **34**, 2393–2399.

Müller T., Thiben R., Braun R., Dott W. and Fischer G. (2004). (M) VOC and composting facilities part 2: (M) VOC dispersal in the environment, *Environmental Science and Pollution Research*, **11**(3), 152–157. https://doi.org/10.1007/bf02979669.

Mustafa M.F., Liu Y., Duan Z., Guo H., Xu S., Wang H. and Lu W. (2017). Volatile compounds emission and health risk assessment during composting of organic fraction of municipal solid waste. *Journal of Hazardous Materials*, **327**, 35–43.

Naddeo V., Zarra T., Oliva G., Chiavola A., Vivarelli A. and Cardona G. (2018). Odour impact assessment of a large municipal solid waste landfill under different working phases *Global Nest Journal*, **3**, 20(3), 654–658. https://doi.org/10.30955/gnj.002770.

National Institutes of Health. U.S. Department of Health and Human Services. https://www.nih.gov/.

Nie E., Zheng G., Shao Z., Yang J. and Chen T. (2018). Emission characteristics and health risk assessment of volatile organic compounds produced during municipal solid waste composting, *Waste Management*, **79**, 188–195. https://doi.org/10.1016/j.wasman.2018.07.024.

Nie E., Zheng G., Shao Z., Yang J. and Chen T. (2018). Emission characteristics and health risk assessment of volatile organic compounds produced during municipal solid waste composting, *Waste Management*, **79**, 188–195. https://doi.org/10.1016/j.wasman.2018.07.024.

Oehha.ca.gov.

Onwosi C.O., Igbokwe V.C., Odimba J.N., Eke I.E., Nwankwoala M., Iroh I.N. and Ezeogu L.I. (2017). Composting technology in waste stabilization: on the methods, challenges and future prospects. *Journal of Environmental Management*, **190**, 140–157. https://doi.org/10.1016/j.jenvman.2016.12.051.

Pawar P., Pooja T., Latake P. and Ranveer C. (2015). Odour Pollution and Its Measurement *International Journal for Research in Applied Science & Engineering Technology*. **3** (XII), December 2015 ISSN: 2321–9653.

Pierucci P., Porazzi E., Martinez M.P., Adani F., Carati C., Rubino F.M., Colombi A., Calcaterra E. and Benfenati E. (2005). Volatile organic compounds produced during the aerobic biological processing of municipal solid waste in a pilot plant. *Chemosphere,* **59**, 423e430.

Rincon C.A., De Guardia A., Couvert A., Le Roux S., Soutrel I, Daumoin M. and Benoist J.C. (2019). Chemical and odor characterization of gas emissions released during composting of solid wastes and digestates, *Journal of Environmental Management*, **233**, 39–53. https://doi.org/10.1016/j.jenvman.2018.12.009.

Scaglia B., Orzi V., Artola a., Font X., Davoli E., Sanchez. and Adani F. (2011). Odours and volatile organic compounds emitted from municipal solid waste at different stage of decomposition and relationship with biological stability. *Bioresource Technology*. **102**, 4638–4645. https://doi.org/10.1016/j.biortech.2011.01.016.

Scheutz C., Bogner J., Chanton J.P., Blake D., Morcet M., Aran C and Kjeldsen P. (2008). Atmospheric emissions and attenuation of non-methane organic compounds in cover soils at a French landfill. *Waste Management*, **28**, 1892–1908.

Schlegelmilch M., Streese J., Biedermann W., Herold T. and Stegmann T. (2005). Odour control at Biowaste Composting Facilities, *Waste Management*, **25**(9), 917–927. https://doi.org/10.1016/j.wasman.2005.07.011.

Shao Z.Z., Zheng G.D., Wang Y.G., Gao D., Zhu Y.L., Chen T.B and Nie E.Q. (2017). Emission characteristics and ozone formation potential of VOCs from a municipal solid waste composting plant. *Environment. Science*. **38**, 1783–1791.

Tan H., Zhao Y., Ling Y., Wang Y. and Wang X. (2017). Emission characteristics and variation of volatile odorous compounds in the initial decomposition stage of municipal solid waste, *Waste Management*, **68**, 677–687. https://doi.org/10.1016/j.wasman.2017.07.015.

Tsai C.J., Chen M.L., Ye A. Di, Chou M.S., Shen S.H and Mao I.F. (2008). The relationship of odor concentration and the critical components emitted from food waste composting plants. *Atmospheric. Environment*. **42**, 8246–8251. https://doi.org/10.1016/j.atmosenv. 2008.07.055.

Zaini S. (2012). The influence of pollution odours from the landfill operation based on the physical measurement and perception of sensitive receivers. PhD Thesis, UKM, Bangi.

Zhang Y.Y., Yue D.B., Liu J.G., Lu P., Wang Y., Liu J and Nie Y.F. (2012). Release of non-methane organic compounds during simulated landfilling of aerobically pretreated municipal solid waste. *Journal Environment Management*, **101**, 54–58. https://doi.org/10.1016/j.wasman.2012.11.008.

Zhao Y., Lu W. and Wang H. (2015). Volatile trace compounds released from municipal solid waste at the Transfer Stage: Evaluation of environmental impacts and odour pollution, *Journal of Hazardous Materials*, **300**, 695–701. https://doi.org/10.1016/j.jhazmat.2015.07.081.

Zhu Y., Zheng G D., Gao D., Chen T., Wu F.K., Niu M J., Zou K.H. and hua K. (2016). Odor composition analysis and odor indicator selection during sewage sludge composting. *Journal of the Air and Waste Management Association*, **66**, 930–940. https://doi.org/10.1080/ 10962247.2016.1188865.

ZhuY.L., Zheng G.D., Gao D., Chen T.B., Wu F.K., Niu M.J. and Zou K. (2016). Odor composition analysis and odor indicator selection during sewage sludge composting, *Journal of the Air and Waste Management Association*, **66**(9), 930–940. https://doi.org/10.1080/10962247.2016.1188865.