International Journal of Research and Engineering
ISSN: 2348-7860 (O) | 2348-7852 (P) | Vol. 6 No. 3 | June 2019 | PP. 616-625
Digital Object Identifier DOI® http://dx.doi.org/10.21276/ijre.2019.6.3.3

Dispersion Modelling of Odoriferous Compounds from Landfill

ORIGINAL ARTICLE

Author(s): [1]*E. Ravendiran, [2]Ajay Ojha,
[2]Kaustubh Goswami, [2]Md. Nadeem Shaikh
Affiliation(s): [1]Maharashtra Pollution Control Board, Kalpataru Point, Sion, Mumbai, India
[2]Technogreen Environnemental Solutions, Wakadewadi, Pune, India
*Corresponding author: mpcbmstes@gmail.com

***Abstract* - Landfills contain vast quantities of waste as they are sites for deposition of a city's solid waste. This solid waste further undergoes the process of decomposition producing several by-products such as odorous gases and volatile organic compounds. Both of these compounds have potential to severely damage physical and mental health of human. These components were analysed using AERMOD by United States Environmental Protection Agency (USEPA). AERMOD needs uniform and horizontally consistent surface and upper air parameters of meteorology. Along with AERMOD, Landfill Gas Emission Model (LandGEM Version 3.02) was used to form an emission inventory. LandGEM analyses odorous gases and VOCs. The dispersion of odorous gases over areas adjacent to landfill of Pune, India has been estimated from information on advances in emission inventory and field monitoring operation. Four odorous gases namely Total Landfill gas, Methane, Carbon Dioxide and Non Methane Organic Compounds (NMOC) were detected at 17 discrete places and were found within permissible limits.**

Keywords: *landfill; emission; odorous gases; volatile organic compounds; AERMOD;LandGEM*

I. INTRODUCTION

Emission of odorous gases from mixed land use patterns along with landfill in the cities have resulted in nuisance and other problems associated with the setting up of waste treatment facilities in and around cities as studied and documented [2]; [13]; [15]; [19]; [21]; [22]; [26]; [27]; [32]; [34]; [35]; [37]. Odour can be expressed as the "perception of smell" or in scientific terms, "a sensation resulting from the reception of stimulus by the olfactory sensory system" [12]. Whether pleasant or unpleasant, odours are induced by inhaling air-borne volatile organic or inorganic substances. There are several odour generating activities such as tanneries and paint industries. Nevertheless, Municipal Solid Waste (MSW) landfill is also identified as a major source of odour generation. Solid Waste Management Rules 2016 recognize 'odour' as a public nuisance, unlike air pollutants such as particulate matter, CO, CO2, SO2, where there are specified standards for compliance. Most commonly reported odour-producing compounds are Hydrogen Sulphide which has a rotten egg odour and Ammonia with a sharp pungent odour. Carbon Disulphide, Mercaptane, product of decomposition of proteins especially of animal origin [30]. Phenols and some petroleum hydrocarbons are other common odorants. Most offensive odour is created by the anaerobic decay of wet organic matter such as flesh, manure, fodder or silage [31]. Odour originating from livestock manure is the result of 168 odour-producing compounds [9].

Warm temperatures enhance anaerobic decay and foul odour production [5]. Odour can arise from many sources, most of which such as garbage are man-made. Improper dumping on vacant land is a common phenomenon which leads to foul smell due to putrefaction of dumped garbage. The unscientific design of landfills, increased sewage production and improper sewage treatment practices produce unpleasant odour.

Rising urbanisation is directly proportional to the rise in waste generation and waste management. Landfilling is the most historically used practice for waste treatment and this solution of waste management is now an issue as there are many hazards arising from gases emitted from landfills [4]. Sulphur compounds, oxygenated compounds, nitrogenous compounds, halogenated compounds, aromatics and terpenes are the most abundantly found components and they are strong air pollutants as they have toxic, hazardous and noxious properties [11]; [34]; [36].

These gases cause severe health problems by contaminating local rivers, harming aquatic life quality and diversity and expansion of area beneath the surface leading to contamination of ground water [33]. Children are more prone to environment vulnerability [24]. Odorous gases like methane, carbon dioxide, water vapour and non-methane organic compounds (NMOC). Even when present at low concentration NMOC can cause severe damage to human health [20].

Volatile organic compounds in Municipal Sewage Waste landfills comprise of about 39% NMOCs in United States [8]. People living and working near landfills are vulnerable to contaminated air from landfills via inhalation. If the exposure to such volatile compounds is eternal it can result in health issues like respiratory problems, damage to central nervous system and are carcinogenic [1]; [20]; [25]. Mortality in patients having long term exposure to such odorous gases can be caused by obnoxious reactions like stress on physical as well as mental health which involve respiratory problems, anxiety headache, vomiting, irritation in eye and other health problems [3]; [14]; [16]; [17]; [18]; [28]; [36];. These issues have led to rising concerns and complaints for analysis of odour pollution [23]; [36]; [38].

Among all possible techniques to measure odorous gases, the inspection of surrounding air was done by AERMOD model version 09292 which was used from the open source at USEPA web source (DOS based format) for evaluating emission scenarios and LandGEM Version 3.02 has been used to create emission inventory [15]. In India because of the “Clean Air Initiative Program” started jointly by the MoEF&CC and USEPA an integrated urban air quality modelling methodology is being enhanced in the city of Pune. A proposal to use a Gaussian air pollutant dispersion model, viz. AMS/EPA regulatory model or AERMOD [6] to study the distribution of particulate matter (PM10) in Pune has been put forward [15].

LandGEM estimates the gases emitted from landfills on the basis of the first order decomposition rate equation which measures emissions from decomposition of MSW. The software gives a relatively simple perspective for analysing landfill gas emissions. Field test data can be utilised instead of model defaults whenever accessible. More instruction on EPA test methods can be found in the Clean Air Act (CAA) regulations. LandGEM is dependent on gas produced from landfill waste decomposition. It gives an idea of landfill attributes and can measure up to 4 gases or pollutants such as methane, carbon dioxide, NMOC, total landfill gas and around 46 air pollutants. We have prepared inventories which display tabular emission evaluation of odorous gases.

II. METHODOLOGY

A. Study Domain

Pune is located in the western part of India. Pune has a high rate of population expansion. This exponential increase in Pune metropolis during the last decade has been in terms of area, industry, population, and Pune ranked second in the Smart City scheme of the Central Government, but now resembles a garbage depot. About 2000 to 2100 tonnes of waste is produced daily in Pune city [29]. This is collected and sent to 48 different processing plants, the largest of which is the Uruli - Phursungi garbage depot, which takes in 450 to 500 tonnes of waste every day [29]. Another solid waste composting site is located at Ramtekdi, Hadapsar which is operated by a Mumbai based firm, Rochem Separations Systems (India) Pvt. Ltd. Living standards have put immense pressures on solid waste management system of the local municipal body. The plant was being operated on a Build Operate-Transfer [BOT] basis to process 700 tonnes of dry waste and to generate 10 MW electricity every day [29]. The plant uses gasification/pyrolysis technology to generate electricity from waste. As per National Green Tribunal [NGT] order no. 918, Rochem Separation India Pvt. Ltd is using the facility for manufacturing RDF and keeping the heaps of exposed compost both within and outside facility. Due to uncontrolled burning of RDF and heaps of compost lying unscientifically in and outside the facility, the nearby residents suffer from obnoxious gases [7]. The NGT has directed the Maharashtra Pollution Control Board [MPCB] to carry out ambient air monitoring to ascertain the presence of odorous gases and other parameters of ambient air quality. The MPCB has appointed Technogreen Environmental Solutions [TES] to carry out ambient air monitoring for odorous gases along with other regular parameters of ambient air quality as per National Ambient Air Quality Standards [NAAQS] 2009. No. 86, Ramtekdi, Hadapsar, Pune. The coordinates of the site are 18º 29’ 32.87” N and 73º 55’ 15.77” E. The facility is located at Ramtekdi Industrial area on the outskirts of Pune in an area of approximately 2.5 acres allotted by Pune Municipal Corporation [PMC]. The nearest residential area to the site is Samarth Nagar located at an aerial distance of 0.25km.

Sensitive places located nearby are Ramtekdi temple and Hadapsar Vidyalaya and Jr. College, Hadapsar. The Pune - Solapur highway is located at 1.24km from study site. The facility generates energy from waste. The plant is based on Public Private Partnership (PPP) model of waste to energy.

B. Meteorology

The meteorology was analysed so as to understand the nature and extent of air pollution in the study area. The meteorological conditions at the project site regulate the transport and diffusion of air pollutants released into the atmosphere. In summer the peak temperature may go up to 40°C and the minimum stays between 20 to 25°C. During monsoons, temperatures remain mild around 30°C and night's ranges between 20°C to 22°C. Winter months (November to February) are slightly cold and the minimum temperature can go below 8°C while maximums remain in the higher twenties. To study the current scenario the highest average temperature was observed between February to June 2018. The average temperature in the month of November 2018 varied from 16°C to 31°C.

The second important parameter is wind (wind direction and wind speed). As per secondary data for 2018, a wind rose is presented below in Fig. 1 that shows the predominant wind direction. The wind observed for 24 hours was found to blow from "West to East". The wind direction is responsible for carrying pollutants to the receptor. The dispersion of odour can be assessed from the site by studying the wind direction in that area.

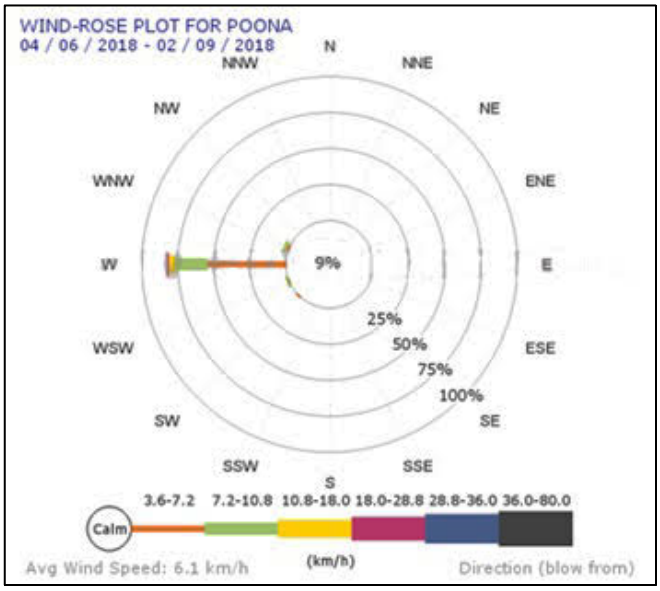

Fig 1. Wind rose plot for Pune

Wind direction can frequently contribute to temporal variation in air pollutant concentrations. Each of the monitoring locations was selected considering the wind direction. Wind showed an average speed of 6.1 km/h. The details of each of these sites at a radial distance of around 100m were mapped for sources during the ground work for selecting the representative sites.

C. Sampling

TES has carried out the above mentioned study in consultation with MPCB officials. With reference to CPCB National Ambient Air Quality Series: NAAQMS/36/2012-13 and study of secondary data along with CPCB protocol, sitting criteria is used as the base for establishment of monitoring networks. Recci survey for location finalization was carried out in consultation with MPCB Officials.

D. Dispersion Modelling

An emission inventory was prepared to understand air contamination in the nearby area. Modelling was carried out by considering a grid of 9 by 9 km around the site to treat the habitation through receptor. Air emissions can cause health and nuisance problems not only in the locality but sometimes away from locality too. Air Dispersion Modelling predicts problems with emissions from a site and helps explore the effects of various solutions.

AERMOD model version 09292 was used from the open source at USEPA web source (DOS-based format) for evaluating emission scenarios. The inputs to the model are defined in five functional pathways. Each of these functional parameters include several options that may be user defined or set as default. AERMOD is able to give appropriate information about emission source identification and control [10]. LandGEM Version 3.02 was used to create emission inventory. It provides comparatively transparent results for examining gas emissions from landfills.

E. Sampling network

As discussed above, a preliminary survey was carried out to design monitoring network with regards to the present study objectives. Based on predominant wind directions and considering flat land around the site, five representative locations were identified for ambient Air monitoring during the study. These representative locations were selected within a radius of 2 km from the site for covering the areas located in upwind, downwind and cross wind directions of the project site to evaluate and understand the pollutants present in nearby environment. Nearest habitants were considered while preparing sampling network.

F. Sampling plan

The Ambient Air monitoring has been done by a Ministry of Environment, Forest and Climate Change (MoEF&CC) recognized laboratory. Ambient Air monitoring was done for 24 hours at each of the five identified locations for two consecutive days. Sampling was carried out on 13th and 14th November, 2018. The sampling plan is presented in Table I.

TABLE I. SAMPLING PLAN

Sr. No.	Location	Sample ID	Wind Direction	Frequency	Parameter
1	Rochem Separation Pvt.Ltd.- Waste Disposal Site.	S1	----		$PM_{2.5}$, PM_{10}, Sulphur Dioxide and Oxides of Nitrogen
2	Eagle- Burgmann India Pvt.Ltd., Near Hadapsar School & Jr. College	S2	Upwind		Ozone, Carbon Monoxide, Ammonia, Lead, Arsenic, Nickel
3	Chopade Audyogik Centre, Samarth Nagar	S3	Downwind	Twice	Benzene Benzo(a)pyrene
4	CO-EFF Friction Rands Industry, Sayad Nagar	S4	Crosswind		Methanol, Methyl Mercaptane (CH_4S)
5	Near Reliance Plaza, Vardhaman	S5	Downwind		H_2S and Total VOCs

The locations identified also include sensitive areas nearby that may be affected due to odorous gases, if any. Also, an emission inventory of 9 × 9 km was created to treat the habitation through receptor and predict odour causing gases while carrying out modelling of gases.

G. Sampling Methodology

Ambient air monitoring was carried out on a 24 hour basis over two consecutive days. Sampling at five locations was carried out with help of different instruments with reference to National Ambient Air Quality guidelines. Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Particulate Matter ($PM_{2.5}$), Particulate Matter (PM_{10}), Lead (Pb), Benzene (C_6H_6), and Benzo(a)Pyrene (BaP). Only the particulate phase was analysed using IS: 5182, whereas Volatile Organic Carbon, Methanol Methyl Mercaptane, Hydrogen Sulphide (H_2S) were analysed using digital analyser. Air sampling was carried out for the above parameters using Fine Dust Samplers. Sampling was carried out over an averaging period of 24 hours. Instantaneous readings for Volatile Organic Compounds (VOCs) and other groups of air pollutants having odour were also recorded. Sampling of Methyl Mercaptane which has a typical rotten cabbage smell was also undertaken. These components were analysed using sensor based instruments. Readings through sensor based instruments were taken on an hourly basis. Average results of the same are presented in Table II. There are no standards for these compounds. However samples collected from each of the locations have been tagged using standard format. These samples were then preserved at 4°C and transported to the laboratory. Thereafter, these samples were analysed for specific parameters as per the standard protocol. This method is used for assessing odorous compounds. Instruments used were also calibrated from authorized laboratory.

III. RESULTS AND DISCUSSION

TES has carried out Ambient Air monitoring and odorous gasses monitoring for a period of 24 hours at five locations (S1, S2, S3, S4, and S5) and has obtained following results. Details are presented below.

A. Air Quality Standards as per NAAQS

Ambient Air quality monitored at five locations as per National Ambient Air Quality Standards on two consecutive days D1 (13th November, 2018) and D2 (14th November, 2018). The results of the same are presented below.

TABLE II. RESULTS OF AMBIENT AIR MONITORING

Sr. No.	Parameters	Results					Units	Standard limits
		S1	*S2*	*S3*	*S4*	*S5*		
				D1				
1.	Sulphur Dioxide (SO_2)	16.0	36.0	11.7	34.3	23.57	µg/m^3	80
2.	Nitrogen Dioxide (NO_2)	27.3	34.0	22.6	47.6	41.54	µg/m^3	80
3.	Particulate matter (PM_{10})	62.8	86.6	78.2	52.6	184.29	µg/m^3	100
4.	Particulate matter ($PM_{2.5}$)	22.4	44.5	47.9	24.1	79.15	µg/m^3	60
5.	Ozone (O_3)	16.0	20.00	19.5	19.1	23.00	µg/m^3	180
6.	Lead (Pb)	0.09	0.11	0.08	0.16	0.59	µg/m^3	1.0
7.	Carbon Monoxide (CO)	2.29	0.83	2.91	2.20	3.04	µg/m^3	04
8.	Ammonia (NH_3)	21.5	26.9	14.0	24.0	19.83	µg/m^3	400
9.	Benzene (C_6H_6)	BDL	BDL	BDL	BDL	BDL	µg/m^3	5
10.	Benzo-pyrene (BaP)	BDL	BDL	BDL	BDL	BDL	µg/m^3	1
11.	Arsenic (As)	0.11	0.16	0.11	0.19	1.57	µg/m^3	6
12.	Nickel (Ni)	0.25	0.29	0.19	0.85	1.92	µg/m^3	20
				D2				
1.	Sulphur Dioxide (SO_2)	17.2	34.4	12.4	32.5	28.46	µg/m^3	80
2.	Nitrogen Dioxide (NO_2)	26.5	32.1	23.4	49.2	39.87	µg/m^3	80
3.	Particulate matter (PM_{10})	64.1	82.4	76.4	54.1	176.49	µg/m^3	100
4.	Particulate matter ($PM_{2.5}$)	21.4	42.1	44.2	29.7	82.38	µg/m^3	60
5.	Ozone (O_3)	15.4	18.5	18.6	20.3	21.46	µg/m^3	180
6.	Lead (Pb)	0.07	0.13	0.05	0.18	0.67	µg/m^3	1.0
7.	Carbon Monoxide (CO)	2.35	0.78	2.14	2.14	2.96	µg/m^3	04
8.	Ammonia (NH_3)	19.8	24.3	13.4	21.4	17.41	µg/m^3	400
9.	Benzene (C_6H_6)	BDL	BDL	BDL	BDL	BDL	µg/m^3	5
10.	Benzo-pyrene (BaP)	BDL	BDL	BDL	BDL	BDL	µg/m^3	1
11.	Arsenic (As)	0.14	0.12	0.14	0.17	1.34	µg/m^3	6
12.	Nickel (Ni)	0.19	0.27	0.13	0.67	1.56	µg/m^3	20

Carbon Monoxide was analysed through gas analyser on an hourly basis. Hourly observations of the same are presented in Fig. 2 for day 1 (D1) and day 2 (D2) respectively.

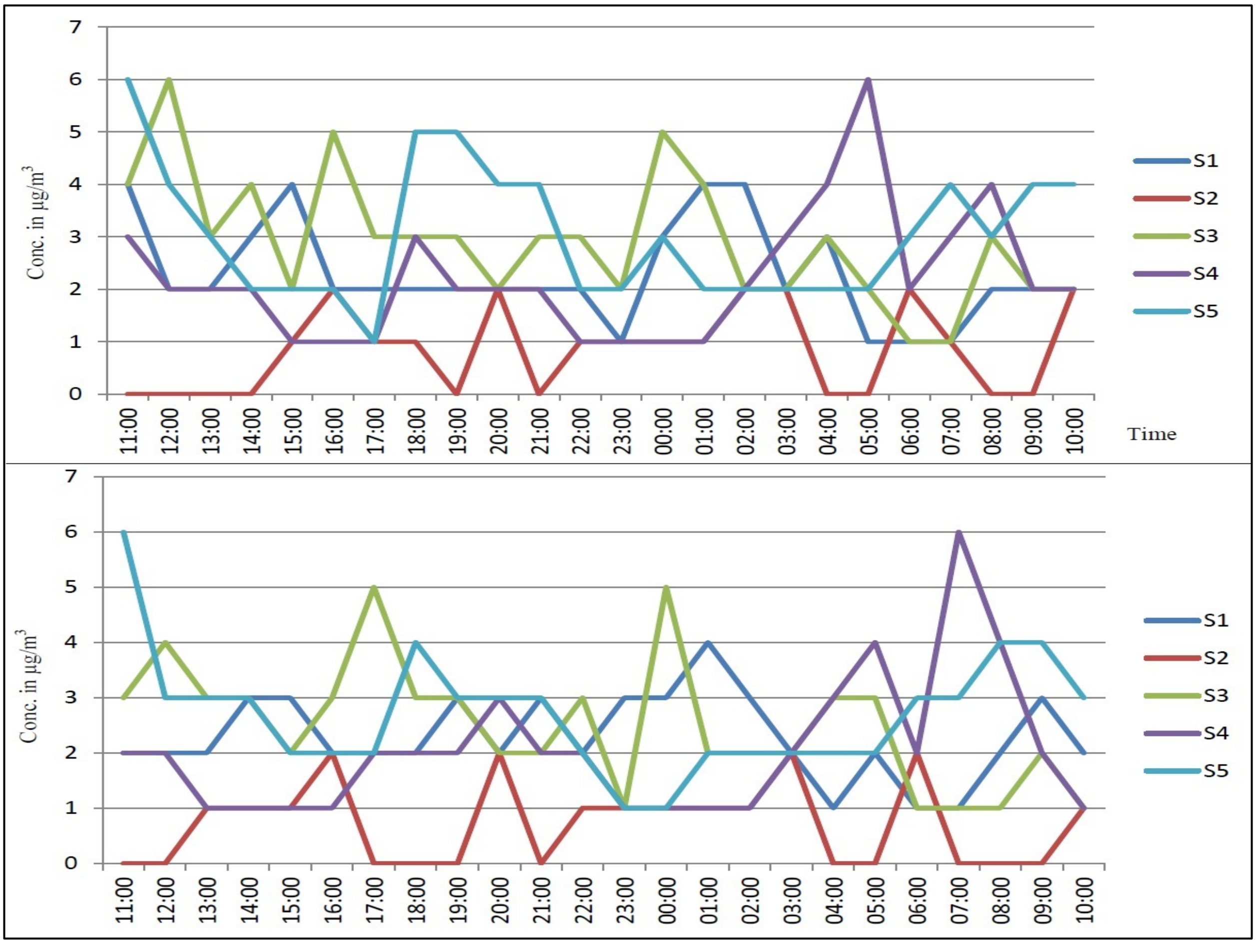

Fig. 2. Concentration of Carbon Monoxide on D1 and D2.

B. *VOC and Odorous gases*

A grid of 9km × 9km was created to study the concentrations of various odorous pollutants surrounding the project site. A total of 52 odorous gases were studied. In line with discrete points, the detailed study for each odorous compound is presented in the figures below. Out of the 52 gases modeled, concentrations of only 4 gases were observed. The emission factor obtained was 1.13 E-04 gm/m2/s. The results of said study are presented in Table III.

TABLE III. CONCENTRATION IN 9 X 9 KM GRID (mg/m3)

Id	Gas / Pollutant	Maximum	Minimum	Mean
POL001	Total landfill gas	10.76107	0.02346	1.73E-01
POL002	Methane	2.86644	0.00625	4.62E-02
POL003	Carbon dioxide	7.87558	0.01717	1.27E-01
POL004	NMOC	0.1238	0.00027	2.00E-03

Total landfill gas, methane, carbon dioxide and NMOC were four odorous gases, the concentrations of which were recorded. Concentrations at 17 discrete points plotted and dispersion modeling of these gases is given.

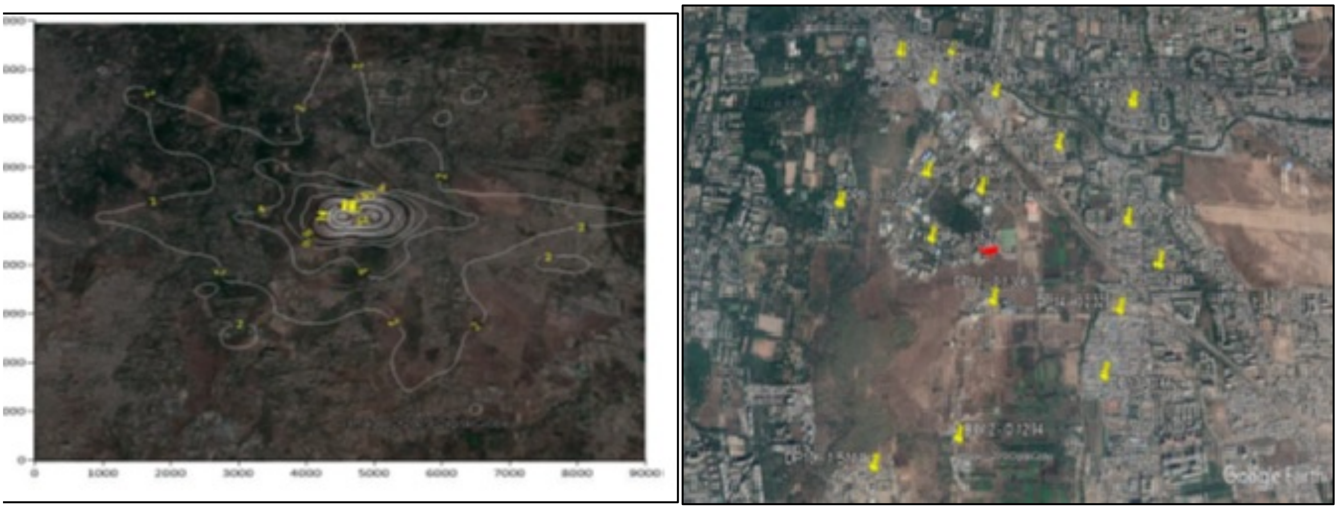

Fig. 3. Concentration and Dispersion (µg/m3): Total Landfill Gas.

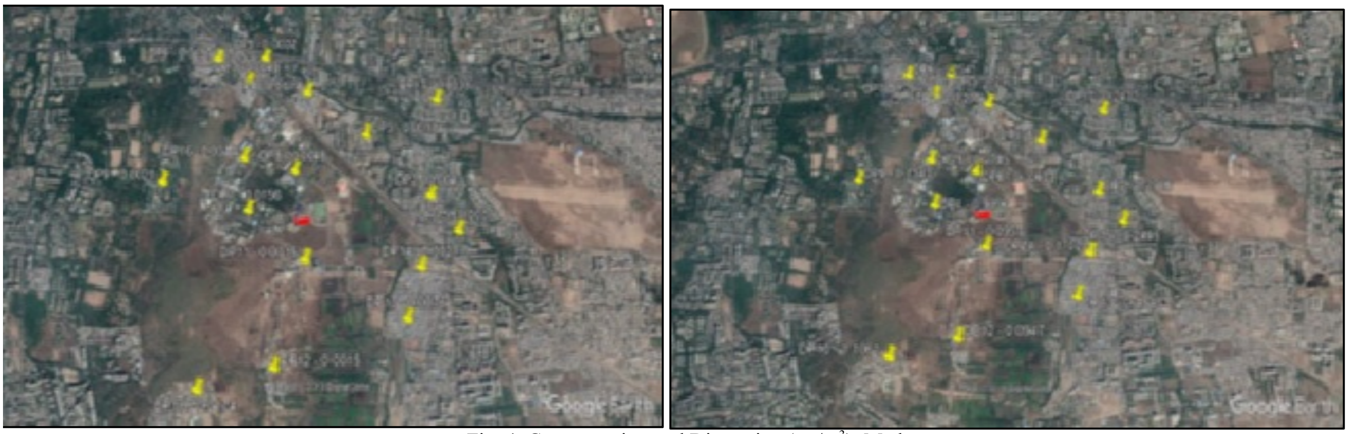

Fig. 4. Concentration and Dispersion (µg/m^3): Methane

Fig. 5. Concentration and Dispersion (µg/m^3): Carbon Dioxide

Fig. 6. Concentration and Dispersion (µg/m3): NMOC

VOC and odorous gasses were also carried on hourly basis for two consecutive days i.e. D1 and D2 the results are represented below.

TABLE IV. RESULTS OF ODOROUS GASES

Sr. No.	Parameters	Results					Units	Standard limits as per OSHA
		S1	*S2*	*S3*	*S4*	*S5*		
D1								
1	Methanol	28.1	0.36	20.1	0.0	3.70	ppm	N.S
2	Methyl Mercaptane (CH_4S)	0.03	0.02	0.04	0.0	0.0	ppm	10
3	Hydrogen Sulphide (H_2S)	0.11	0.02	0.02	0.0	0.00	ppm	20
4	Total VOCs	0.34	0.00	0.11	0.0	0.0	ppm	N.S
D2								
1	Methanol	27.4	0.39	18.6	0.0	2.57	ppm	N.S
2	Methyl Mercaptane (CH_4S)	0.03	0.03	0.04	0.0	0.0	ppm	10
3	Hydrogen Sulphide (H_2S)	0.12	0.01	0.02	0.0	0.00	ppm	20
4	Total VOCs	0.31	0.0	0.08	0.0	0.0	ppm	N.S

All the above parameters were also analysed on hourly basis to study the variations and obtain optimum results. The observations on D1 and D2 are presented in below.

TABLE V. AVERAGE VALUES OF ODOROUS GASES AND VOCS

Locations	S1		S2		S3		S4		S5	
Time	*D1*	*D2*	*D1*	*D2*	*D1*	*D2*	*D1*	*D2*	*D1*	*D2*
Methanol	28.1	27.50	0.4	0.4	20.1	20.0	0.0	0.0	3.7	3.5
Methyl Mercaptane	0.03	0.04	0.02	0.05	0.04	0.04	0.00	0.00	0.00	0.00
Hydrogen Sulphide	0.11	0.10	0.02	0.03	0.02	0.02	0.00	0.00	0.008	0.008
VOCs	0.34	0.32	0.00	0.00	0.11	0.10	0.00	0.00	0.00	0.00

The Central Pollution Control Board (CPCB) most commonly reports hydrogen sulphide (rotten egg odour), ammonia (sharp pungent odour) and mercaptane as odour producing compounds. These odorous gases were also monitored at all locations. It is observed that all such parameters are well within permissible limits. It can also be stated that no odorous gases were noted.

IV. CONCLUSION

The size of particles is directly linked to their potential of causing health problems. Small particles less than 10 micrometers in diameter pose the greatest threat as they can get deep into the lungs and some may even get into the bloodstream. Fine particulate matter (PM2.5) is the main cause of reduced visibility (haze). Particles can be carried over long distances by wind and then settle on the ground or water.

Model outputs were obtained for emissions of 52 pollutants in each of the 500m × 500m receptor grid spread across 9 sq.km gridded impact zone around the proposed site.

The results of these emissions for each grid were plotted in SURFER by taking into consideration the location of X and Y coordinates of each grid versus the emission values for the respective grid. Contour maps were plotted for each of the pollutants for a variety of source groups as discussed earlier representing the impact of each of these sources. Only four pollutants show measurable concentrations viz. Total Landfill Gases, Methane, Carbon Dioxide, and NMOC. However all odorous gases are well within the prescribed limits. The maximum concentration of odorous gases was observed near Samarth Nagar that is located at approximately 300m away from the site.

V. DECLARATION

All authors have disclosed no conflicts of interest.

ACKNOWLEDGMENT

We are grateful to Dr. E. Ravendiran (Member Secretary, MPCB) and the Scientific Officers of MPCB for providing us their support, assistance, point of view and guidance throughout the research.

REFERENCES

[1] Bruce, N., Ng, K.T.W. and Richter, A., 2017. Alternative carbon dioxide modelling approaches accounting for high residual gases in LandGEM. Environmental Science and Pollution Research, 24(16), pp.14322-14336.

[2] Cangialosi, F., Intini, G. and Colucci, D., 2018. On Line Monitoring of Odour Nuisance at a Sanitary Landfill for Non- Hazardous Waste. Chemical Engineering Transactions, 68, pp.127-132

[3] Capelli, L., Sironi, S., Del Rosso, R., Céntola, P., Rossi, A. and Austeri, C., 2011. Odour impact assessment in urban areas: case study of the city of Terni. Procedia Environmental Sciences, 4, pp.151-157

[4] Chan, J.K.H., 2016. The ethics of working with wicked urban waste problems: The case of Singapore's Semakau Landfill. Landscape and Urban Planning, 154, pp.123-131.

[5] Christy, P.M., Gopinath, L.R. and Divya, D., 2014. A review on anaerobic decomposition and enhancement of biogas production through enzymes and microorganisms. Renewable and Sustainable Energy Reviews, 34, pp.167-173.

[6] Cimorelli, A & G. Perry, S & Venkatram, Akula & C. Weil, J & Paine, Robert & B. Wilson, R & F. Lee, R & D. Peters, W & W. Brode, R & Paumier, Jim. (2004). Aermod: Description of model formulation. US Environmental Protection Agency.

[7] Czajczyńska, D., Nannou, T., Anguilano, L., Krzyżyńska, R., Ghazal, H., Spencer, N. and Jouhara, H., 2017. Potentials of pyrolysis processes in the waste management sector. Energy Procedia, 123, pp.387-394.

[8] Durmusoglu, E., Taspinar, F. and Karademir, A., 2010. Health risk assessment of BTEX emissions in the landfill environment. Journal of hazardous materials, 176(1-3), pp.870-877.

[9] Fang, J.J., Yang, N., Cen, D.Y., Shao, L.M. and He, P.J., 2012. Odor compounds from different sources of landfill: characterization and source identification. Waste Management, 32(7), pp.1401-1410.

[10] Gaffney, P., MacDonald, T., Benjamin, M., Core, J. and Ojha, A., 2007. India PM10 emission inventory training and capacity building programs: EPA efforts for developing a sustainable foundation. California: Envirnonment Protection Agency.

[11] Gallego, E., Perales, J.F., Roca, F.J. and Guardino, X., 2014. Surface emission determination of volatile organic compounds (VOC) from a closed industrial waste landfill using a self-designed static flux chamber. Science of the Total Environment, 470, pp.587-599.

[12] Ghatpande, A.S. and Reisert, J., 2011. Olfactory receptor neuron responses coding for rapid odour sampling. The Journal of physiology, 589(9), pp.2261-2273.

[13] Guo, H., Duan, Z., Zhao, Y., Liu, Y., Mustafa, M.F., Lu, W. and Wang, H., 2017. Characteristics of volatile compound emission and odor pollution from municipal solid waste treating/disposal facilities of a city in Eastern China. Environmental Science and Pollution Research, 24(22), pp.18383-18391.

[14] Hayes, J.E., Stevenson, R.J. and Stuetz, R.M., 2014. The impact of malodour on communities: A review of assessment techniques. Science of the Total Environment, 500, pp.395-407..

[15] Kesarkar, A.P., Dalvi, M., Kaginalkar, A. and Ojha, A., 2007. Coupling of the WeatherResearch and Forecasting Model with AERMOD for pollutant dispersion modeling. A case study for PM10 dispersion over Pune, India. Atmospheric Environment, 41(9), pp.1976-1988.

[16] Khafaie, M.A., Salvi, S.S., Ojha, A., Khafaie, B., Gore, S.S. and Yajnik, C.S., 2013. Systemic inflammation (C-reactive protein) in type 2 diabetic patients is associated with ambient air pollution in Pune City, India. Diabetes Care, 36(3), pp.625-630.

[17] Khafaie, M.A., Yajnik, C., Mojadam, M., Khafaie, B., Salvi, S.S., Ojha, A. and Gore, S.S., 2016. Association between ambient temperature and blood biomarker of systemic inflammation in (C-reactive protien) in diabetes patients. Arch Med, 8(3).

[18] Khafaie, M.A., Salvi, S.S., Yajnik, C.S., Ojha, A., Khafaie, B. and Gore, S.D., 2017. Air pollution and respiratory health among diabetic and non-diabetic subjects in Pune, India—results from the Wellcome Trust Genetic Study. Environmental Science and Pollution Research, 24(18), pp.15538-15546.

[19] Lim, J.H., Cha, J.S., Kong, B.J. and Baek, S.H., 2018. Characterization of odorous gases at landfill site and in surrounding areas. Journal of environmental management, 206, pp.291-303.

[20] Liu, Y., Liu, Y., Li, H., Fu, X., Guo, H., Meng, R., Lu, W., Zhao, M. and Wang, H., 2016. Health risk

impacts analysis of fugitive aromatic compounds emissions from the working face of a municipal solid waste landfill in China. Environment International, 97, pp.15-27.

[21] Lou, Z., Wang, M., Zhao, Y. and Huang, R., 2015. The contribution of biowaste disposal to odor emission from landfills. Journal of the Air & Waste Management Association, 65(4), pp.479-484.

[22] Lucernoni, F., Capelli, and Sironi, S., 2017. Comparison of different approaches for the estimation of odour emissions from landfill surfaces. Waste management, 63, pp.345-353.

[23] Lucernoni, F., Tapparo, F., Capelli, L. and Sironi, S., 2016. Evaluation of an Odour Emission Factor (OEF) to estimate odour emissions from landfill surfaces. Atmospheric environment, 144, pp.87-99.

[24] Mukkanawar, U., Kumar, R. and Ojha, A., 2014. Indoor air quality in rural residential area-Pune case study. Int. J. Curr. Microbiol. App Sci, 3(11).

[25] 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, pp.35-43.

[26] Nicolas, J., Craffe, F. and Romain, A.C., 2006. Estimation of odor emission rate from landfill areas using the sniffing team method. Waste Management, 26(11), pp.1259-1269.

[27] Ojha, A., Kumar, R., Boralkar, D., Gargava, P., Gaffeney, P., Benjamin, M. and Mukkannawar, U., 2006. Continual improvement of emission estimates–the Pune experience (2004 to 2006). Better air quality.

[28] Palmiotto, M., Fattore, E., Paiano, V., Celeste, G., Colombo, A. and Davoli, E., 2014. Influence of a municipal solid waste landfill in the surrounding environment: Toxicological risk and odor nuisance effects. Environment International, 68, pp.16-24

[29] PMC, 2019. Pune Municipal Corporation. [ONLINE] Available at: https://www.pmc.gov.in. [Accessed 8 May 2019].

[30] Rappert, S. and Müller, R., 2005. Odor compounds in waste gas emissions from agricultural operations and food industries. Waste Management, 25(9), pp.887-907.

[31] Sharma, M., Kumar, V.N., Katiyar, S.K., Sharma, R., Shukla, B.P. and Sengupta, B., 2004. Effects of particulate air pollution on the respiratory health of subjects who live in three areas in Kanpur, India. Archives of Environmental Health: An International Journal, 59(7), pp.348-358.

[32] Shen, S., Wang, Q., Chen, Y., Zuo, X., He, F., Fei, S. and Xie, H., 2018. Effect of Landfill Odorous Gas on Surrounding Environment: A Field Investigation and Numerical Analysis in a Large-Scale Landfill in Hangzhou, China. Proceedings of the 8th International Congress on Environmental Geotechnics, 2, pp.51-59.

[33] Vallner, L., Gavrilova, O. and Vilu, R., 2015. Environmental risks and problems of the optimal management of an oil shale semi-coke and ash landfill in Kohtla-Järve, Estonia. Science of The Total Environment, 524, pp.400-415.

[34] Wenjing, L., Zhenhan, D., Dong, L., Jimenez, L.M.C., Yanjun, L., Hanwen, G. and Hongtao, W., 2015. Characterization of odor emission on the working face of landfill and establishing of odorous compounds index. Waste management, 42, pp.74-81.

[35] Woo, E.J., Yoo, J.Y. and Park, C.J., 2016. Recycling of Greenhouse Gas and Odor Management in Landfills Near Urban Area. International Journal of Chemical Engineering and Applications, 7(6), p.394.

[36] Wu, C., Liu, J., Zhao, P., Li, W., Yan, L., Piringer, M. and Schauberger, G., 2017. Evaluation of the chemical composition and correlation between the calculated and measured odour concentration of odorous gases from a landfill in Beijing, China. Atmospheric Environment, 164, pp.337-347.

[37] Wu, C., Liu, J., Liu, S., Li, W., Yan, L., Shu, M., Zhao, P., Zhou, P. and Cao, W., 2018. Assessment of the health risks and odor concentration of volatile compounds from a municipal solid waste landfill in China. Chemosphere, 202, pp.1-8

[38] 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, pp.695-701.