EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 50 (2022): 26-38
Journal homepage: https://eqa.unibo.it/

published by

Determination of gas outflow fluxes and study its transport mechanism by the application of flux chamber technique from the two landfill sites of semiarid region of Rajasthan

Priyanka Dwivedi, Devendra Singh Rathore*, Pallavi Gothalkar

Department of Environmental Sciences, Mohanlal Sukhadia University, Udaipur, Rajasthan, India

*Corresponding author E-mail: dsrathoremlsu@gmail.com

Article info
Received 30/5/2022; received in revised form 31/8/2022; accepted 30/10/2022
DOI: 10.6092/issn.2281-4485/14953

Abstract
The investigation was executed to assess outflows of CO2 and CH4 gases from the two landfill sites of Udaipur using commonly applied multiple methodologies for the field to ascertain the accuracy and reliability of data imparted by each of these. To examine the potentiality of each gas discharge quantum for prospective energy that could be used further in waste-to-energy (WtE) projects, a field study was conducted for a period from January 2018 to December 2019 with the division of these landfill sites into segments. The gas samples were recorded onsite at demarked points in each segment by inverting the open portion of the Static Flux Chambers (SFCs) on the landfill surface to stop the ingress of air. This SFC was separately connected with the CO2 and CH4 gas analysers to record their onsite concentrations. The recorded data was further analysed to observe the annual quantitative spatial and temporal variations in the fluxes of these two gases. The mean CO2 and CH4 fluxes of Balicha Landfill Site (BLS) ranged between 932-1876µg/m2/hr and 359-1173µg/m2/hr, respectively. On the other hand the mean CH4 and CO2 fluxes of Titardi Landfill Site (TLS) ranged between 672 - 1483 µg/m2/hr and 157 - 958 µg/m2/hr, respectively. These fluxes emitted from BLS and TLS generated the carbon footprint (CF) of 180000 and 78000 ton of CO2 equivalent (tCO2 eq.) sequentially. In order to ensure the significance of the method used and to get best energy output for the WtE project the obtained gas flux data of both the sites was analysed and compared. This studied data would provide a guideline for the concerned authorities to plan & execute gas extraction operations at these two sites.

Keywords *Anthropogenic, GHG Fluxes, land filling, WtE.*

Introduction

The origination of huge trash quantities in urban and rural areas has led to its predominantly adopted dumping practice at the landfill site, which is the most commonly adopted method for dumping. Currently, some of the landfills in India are overloaded and occupy the trash beyond their available space limit, such as Okhla, Bhalswa, Deonar, Gorai, Pirana, etc. The open dumping of huge quantities of trash in these landfills raises some of the well-versed issues like expansion of the existing dump area, instability of the erected dumps, seepage of the leachate from the trash into the nearby soil, water, and air, and release of noxious odour and gases into the atmosphere. Moreover, excessive accumulation of methane (CH_4) in subsurface trash layers of landfills sometimes leads to explosions and fire. The fraction of organics in municipal solid waste (MSW) is more in the developing world rather than in developed nations. The major concern is that CH_4 emanation from this point source alone contributed about 10-12%, which shares the third largest portion of the total greenhouse gases (GHGs) emanations. It will certainly have a huge impact on the climate in the long term due to its nature of increasing the surface temperature. The significant outflows of potent CH_4

DOI: 10.6092/issn.2281-4485/15427

and carbon dioxide (CO_2) gases into the atmosphere from the landfills in India are quite alarming and have a global warming impact (GWI) on the environment and humans. However, managing the trash material in landfills is considered an indispensable function that is salubrious to urban and rural communities.

About 68 metric tons (MT) of trash are produced in India each year. Due to a consecutive rise in trash volume, it would reach 160.5 MT/yr by the year 2041 (Annepu, 2012). It is either used to reclaim the landfill by bio-mining over it or establishing a waste-to-energy (WtE) facility within the landfill premises for fuel and energy production. As far as the demand for fuel and energy is concerned, cost-effective, environmentally affable technology is being adopted to extract the fuel gases by cleaning and refining the landfill gases (LFGs), which can be used as an alternative fuel for other sectors. These harnessing techniques not only reduce this sector's carbon footprint but also benefit the other sectors by providing them with fuel and energy. Refuge derived fuel (RDF), and solid recovered fuel (SRF) are the high calorific fuels producing technologies for processing landfill trash, which are recently used by the industries.

The MSW degrades with the help of microbial culture, developed during anaerobic and aerobic conditions, which helps in the form of an ample amount of gases and digestate. This digestate is being utilized to make the soil enrich in nutrients. But the main constraint is the digestate produced from mixed trash has impurities of heavy metals and partially decomposed materials. It leads to an increase in acidity and toxicity of the soil after its addition. The presence of asbestos, arsenic, and lead; moreover, the level of natural ingredients in the soil, such as sodium, calcium, phosphorus, etc., were higher than their standard prescribed limits set for agricultural soil (Kupper et al., 2014). However, to tackle this problem, the source segregation strategy for MSW before landfilling has been executed under the ongoing Swachh Bharat Mission (2014), which is to be followed by all Municipal Corporations in India. Their objective is to get the organic portion out of the total MSW, which has been planned for compositing and gasification.

Even now, the old and newly opened landfills remain an epicentre for liberating GHGs and other compounds. The trash in these landfills is harmful; thus, much more effort must be put forth to utilize it as a resource rather than a burden properly. Large gas-capturing projects are enforced in the landfills in metro cities. The impact of GHG is not bound to the regional boundaries; thus, landfills in remote and smaller areas can't be ignored. The fluxes of major ooze-out gases CH_4 and CO_2 should be quantitative, and the mechanism involved from production until its release to the atmosphere must be understood.

The numerous physiochemical factors impact the anaerobic and aerobic phases of the trash in landfills. These factors assist in the generation and reproduction of microbes that act as catalysts during digestion and give rise to the generation of gases and digestate. Sometimes these factors do not act properly, resulting in un-digestate material and stinky odours. The variables like age, composition, density, degradability potential and time of fresh trash lying are needed to understand. Subsequently, other factors like pH, precipitation, direction, the flow of wind, air and surface temperature, moisture, fissures, and diffusivity have influenced the process of fermentation of trash. The alteration in temporal and spatial variables at the time of decaying organic trash certainly fluctuates the quantity and quality of end-products in all seasons. If all of these variables lack in their performance, then the decomposition process is hindered.

The landfills are well known for the predominant discharge of gases, specifically CH_4 and CO_2. The impact potential over 100 years is 25 times more in the case of CH_4 than CO_2. Emanated gases from the landfill are compositely known as LFG, which are emitted through different mechanisms and conditions from the landfills. Before LFG is used as a fuel, it must be evaluated from each landfill site. Therefore different methodologies are being used to estimate the fluxes of each gas, such as static flux chamber (SFC), radial plume (RP); optical path integrated optical sensing (OPIOS), vertical radial plume mapping (VRPM), tracer gas (TG), seismic reflection profiling (SRP) and micro-meteorological methods.

Out of these methodologies of LFG estimation, the static flux chamber (SFC) was used in the present research to capture the surface emanation fluxes of CO_2 and CH_4 gases at Balicha Landfill Site (BLS) and Titardi Landfill Site (TLS). The compositional study was also performed to assess the potential degradability of the organic trash part laid at BLS and TLS. The collection efficiency of each gas and the carbon footprint generated by BLS and TLS were also estimated by using the total estimated CO_2 and CH_4 emanated fluxes from each site.

DOI: 10.6092/issn.2281-4485/15427

Materials and Methods

Description of the investigated landfill sites

The Balicha Landfill Site (BLS) and Titardi Landfill Sites (TLS) are located approximately 19 km and 14 km away from Udaipur city, Rajasthan, respectively, and acquired 54 ha and 19 ha of area respectively. TLS has been closed since 2008 and is currently used for processing plastics and manufacturing compost from the segregated organic matter, which is unloaded daily at this site. Another feature of TLS is an 18m tall erected dump which is capped with polymeric liners. The leachate drains are constructed beneath the dump, and for gases, discharge vents are also built on the top portion of the dump surface. The daily dumping of MSW at BLS and TLS is 160 tons and 30 tons sequentially. However, both sites, BLS and TLS, are totally different from each other regarding their infrastructural setups. TLS is managed and capped; however, BLS is an uncapped, unmanaged open site.

Monitoring of CO_2 and CH_4 gases

The monitoring and sampling of CO_2 and CH_4 gases at both sites, BLS and TLS, were done by adopting the protocol mentioned in the user manual of the US EPA (2013). The zonation of both the sites was done by keeping the view that the more or less availability of the retained trash in each landfill zone is covered properly. The selected zones were further segmented for sampling based on a 45m×45m grid in BLS and a 25m×25m grid in TLS. The zonation and gridding are represented in Figure 1. The centre point of each grid was used for placing the static flux chamber (SFC). About 286 points were sampled in BLS from January 2018 to December 2018, and about 189 points were covered during January 2019 to December 2019 at TLS.

(A) Balicha landfill Site (BLS) *(B) Titardi Landfill Site (TLS)*

Figure 1. *The zonation of sampling sites*

Surface quantification of fluxes of CH_4 and CO_2

A static flux chamber (SFC) was deployed on the surface of the sampling point to ingress the particular volume of gas which was actually the volume of the SFC. The accumulated gas got agitated inside the SFC and developed a pressure which was recorded through the connection of the SFC top orifice with the pipes further connected to the particular analyzer for displaying the inside gas concentration at a time interval of 28-45 min.

The following equation was used to evaluate the flux of each gas (Haro et al., 2019)

$$\varphi = \frac{P \times V \times M}{R \times T \times S} \times \frac{dc}{dt} \qquad [1]$$

Where,

V = volume of the SFC,

T = SFC temperature (°C)

M = the molecular mass of CO_2 and $CH_{4,}$ which is 44 and 16 gm/mol sequentially,

S = the area occupied by SFC (m^2),

P = pressure develop inside the SFC (Pa),

R = gas constant having the value of 8.314 Pa m^3/mol/°C.

The rate of gaseous flux is achieved only when the coefficient of correlation r^2> 0.5 as a linear function, change in gas concentration shall be noticeable at the time of its monitoring, and the time vs concentration gas graph shall represent the data of sampled points at least five or more than that.

DOI: 10.6092/issn.2281-4485/15427

The mechanism of SFC mentioned in the guideline of the environment agency (EA, 2010) is represented in Figure 2.

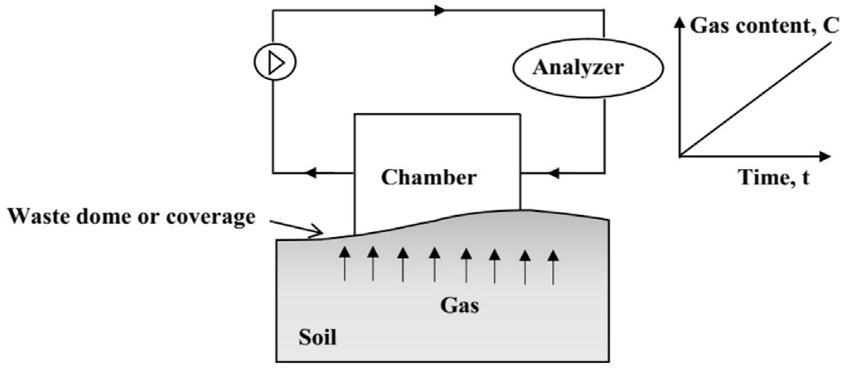

Figure 2
The technique used for the measurement of landfill gas with respect to time on the landfill Surface (EA,2010)

Adequate points for sampling were determined using the following equation:

$$n = 6 + 0.15 \times \sqrt{S} \qquad [2]$$

Where,
n= the number of sampling points,
S= the area of each zone (m^2).

Some variables were considered to evaluate the number of geo referenced points selected for gaseous sampling like heterogeneity in trash as well as morphology of dumpsite, fissures, faults, edge slope, soil cover and the liner materials. In addition to these variables the dumping area was also taken into account in both the landfills. However, these variables are also considered when determining the spacing of one point to the other in a grid. About 286 points were sampled in 30 ha BLS area whereas in case of TLS 189 points were covered in 12 ha area. Repeat samples were collected at these points during the testing period to obtain true representative samples of the particular area. Due to tedious field testing operation sampled points were less than the points evaluated through above given equation. Some other factors like the wind speed and the rainfall severely affects the surface emanations as mentioned by EA (2010); Haro et al. (2019). Therefore, the speed of wind less than 5m/s and the after three days of rain accounted to be favourable for reducing the temporal as well as the spatial ambiguity of the collected gas samples. Simultaneously, five to six SFC has to be placed over the sampling ground in order to get representative fluxes of gases.

Mapping of the gaseous discharges

The natural neighbour interpolation (NNI) technique of surfer 10 software was used for presenting the spatial data fluxes of CO_2 and CH_4. The spatial distribution of dense and weak contours of the CH_4 and CO_2 fluxes throughout the active dump area shown in Figure 3, which represents the centre point observation, tends to have more resemblance with its neighbouring points than the distant located points. The dense contours represented the waste-saturated zone with plenty of biodegradables responsible for fermentation activity that contributed to higher emissions fluxes of CO_2 and CH_4 'hotspots region' as compared to the other zones of the landfill. These hotspot zones were unevenly scattered over the complete landfill area, so random point sampling would not considerably be a worth full option for accounting for the total GHG fluxes from the entire landfill area. The contours of low and negligible fluxes of both these gases were overlapped on the age-old waste and soil enrich regions. Heterogeneity in the fluxes was found at both sites over a given space and time, as mentioned earlier. The equation [3] below calculates the total interpolated area of CO_2 and CH_4 gas emanation.

$$P(x) = \sum_{i=1}^{n} w_i(x) f(xi) \qquad [3]$$

Where,
P(x) = the flux assessment at point x;
w_i= weight at point x;
$f(x_i)$= data known at point x_i;
wi = estimated by finding the surrounding acquired area when x is inserted to constructing squares.
$Wi = \frac{M\ (Xi)}{M(X)}$; M (x) is the volume of a new cell when centred in x while M (xi) is the volume of the confluence between the new cell at x and the old cell at xi.

DOI: 10.6092/issn.2281-4485/15427

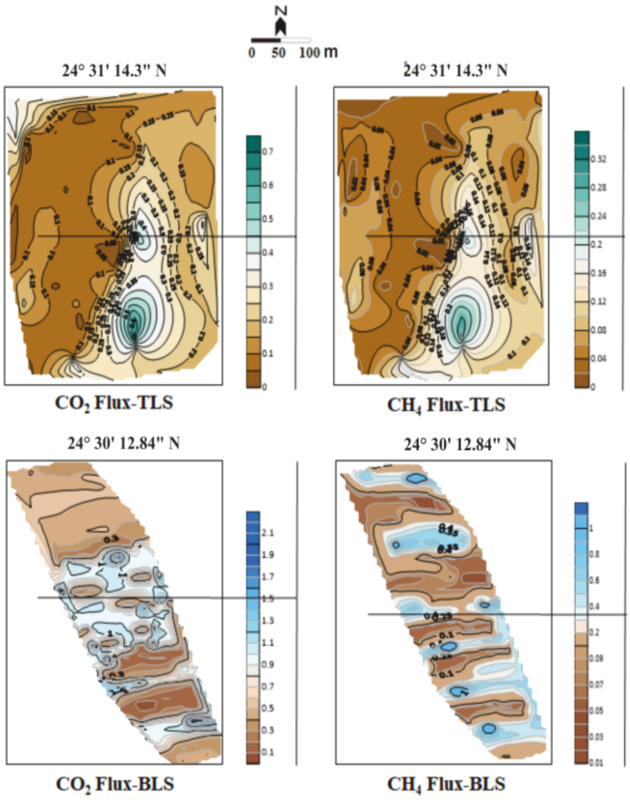

Figure 3
The contour plots show the CO_2 and CH_4 fluxes in µg/m^2/hr using the natural neighbour interpolation technique of surfer 10 software.

Estimation of LFG collection efficiency at TLS and BLS

It is an excellent variable to figure out the potential of LFG emanated from any landfill area which is meant further for engineering, environmental and regulatory standardization. CH_4 collection efficiency has been estimated yet in most of the studies done by Haro et al. (2019); Oonk (2012). The CO_2 efficiency for collection is not assessed therefore, it is estimated below:

The collection efficiency of LFG gases like CO_2 and CH_4 was estimated by following formula:

$$ή = \frac{Q_{CH4}^{Collected}}{Q_{CH4}^{Collected} + \varphi_{CH4}^{Emitted} + \varphi_{CO2}^{Emitted}} \times 100\% \quad [4]$$

Where,

QCH_4= the per annum volume of CH_4 collected;

φCH_4 and φCO_2= the yearly outflow volume of CH_4 and CO_2 in m^3 emanated from landfill (either TLS or BLS), which was evaluated through the integration of each zone discharge of the respective gas in TLS and BLS.

Carbon footprint assessment of each landfill site

The principal ooze out LFG from the landfills is CH_4 and CO_2 into the atmosphere therefore its carbon footprints have to be assessed in order to determine its overall impact.

The following equation assessed the carbon footprints.

$$W = \emptyset_{CH4} \times \rho_{CH4} \times GWP_{CH4} + \emptyset_{CO2} \times \rho_{CO2} \times GWP_{CO2} \quad [5]$$

Where,

W= delineated as total carbon emission in terms of tons of CO_2 equivalent

$ǾCH_4$ & $ǾCO_2$= volume of CH_4 and CO_2 discharged in a year into the atmosphere, including collected volume measured in m^3;

ρCH_4 and ρCO_2= Density of CH_4 and CO_2 measured in Kg/m^3;

GWP CH_4, CO_2 = Global warming potential of CH_4 and CO_2

DOI: 10.6092/issn.2281-4485/15427

Results and Discussion

Compositional assessment of LFG at BLS and TLS

The surface emanation discharges of CO_2 and CH_4 were recorded in the forenoon and afternoon in divided segments of TLS and BLS, which indicated that the average yearly concentration of CO_2 and CH_4 fluctuated between 56-62% and 45-49% respectively, at TLS. Similarly, at BLS, the mean annual concentration of CO_2 and CH_4 was recorded in the range of 52-55% and 42-46%, respectively. BLS was fragmented into A, B, and C zones, while TLS was segmented into M, P, and R zones, as depicted in Figure 1.

The results of CO_2 fluxes indicated its dominance in the B phase of BLS and the R phase of TLS. Besides, an ample quantity of CH_4 existed in the C phase of BLS and the M phase of TLS. These varied observations were found at these landfills due to two main reasons; firstly, the TLS has been inactive since 2008. The trash laid at this site was compacted and covered with polymeric liner material, containing a significant portion of inert constituents. The 10-11 years old organic trash portion released more CO_2 than CH_4, so aerobic fermentation within the compacted trash layers occurred. Secondly, due to differences in the functioning of internal and external factors of the landfill, the propagation of LFG through spatial and temporal phenomenon instilled free spaces inside the sub-dump surface from where LFG sought passage to reach out to the TLS surface, and this happened and observed at many time during monitoring where some segments of this landfill showed the significant release of LFG and some segments showed nonsignificant release of LFG.

On the other hand, BLS has been operational since 2008, and the dumping of mixed trash is being done with no coverage of any material over it; as a result, the stinky foul smell always coming out of the trash piles. The dried trash portion is set on fire at BLS which was discovered to be the primary reason of oozing out of CO_2 and witnessed many times during monitoring. However, some CH_4 saturated zones due to compaction and pressure development inside the degradable trash heaps were noticed with a higher temperature than those measured in other parts of BLS, which strongly validated the ongoing anaerobic activity. The zonation of BLS was done by considering many factors; the temperature rise was one of them. The captured LFG difference also validated the degradation occurring in aerobic or anaerobic activities in those segments. The 8-9 months to 10 years old trash piles were found at BLS, so considerable dominance and variations in CH_4 flux were found.

In contrast, the CO_2 fluxes were higher than CH_4 in some areas at BLS which had freshly disposed trash, determining the occurrence of the aerobic phase. A zone which had higher emanation of either CH_4 or CO_2 is termed as a 'hotspot area' for the respective gas. These high ranges of CO_2 and CH_4 fluxes are attributable to moderate moisture availability for excellent biodegradation of the organics in the MSW. The estimated CO_2 and CH_4 fluxes at different landfills in India and around the world are depicted in Table 1.

CO_2 and CH_4 gases quantification assessment

The evaluated mean volume of CO_2 and CH_4 per annum was observed between 42-54% and 39-44%, respectively at BLS. Similarly, it ranged between 35-39% and 32-45% sequentially, at TLS as represented in Table 2. It indicated that the average volume of CH_4 and CO_2 per annum was found 5-7% and 6-9%, respectively, higher at BLS as compared to TLS. The yearly increment was also recorded at both sites; the gradual percent increase in CH_4 mean volume was found higher in the year 2019 at TLS, while a rise in CO_2 mean volume was observed in 2018 at BLS which might be depends upon the improved microbiological and other chemical reactions that take place in the organic portion of the retained trash of these landfills. In addition, rainfall in 2019 was 3-4% more as compared to 2018 which provided a tremendous driving force to enhance the biochemical processes.

The mean annual volume of CO_2 and CH_4 almost doubled at BLS as compared to TLS during studied period due to their morphological differences as BLS is an open dumping yard while TLS is capped with polymeric liners. Secondly, TLS has been inactive since 2008, while BLS is operational. Thirdly, the degradation in the trash at BLS was totally different from TLS because it had old trash.

Haro et al. (2019) observed the lower gas flow rate in the absence of collection wells for LFG or any kind of pumping system installation. In contrast to their investigation, higher flow rates were obtained at BLS because it is a open dumping site, while lower flow rate was observed at TLS which had adequately

DOI: 10.6092/issn.2281-4485/15427

vented and capped dump. It indicated that the rate of gaseous flow is not solely determined by the capped system and constructing wells over any landfill.

Table1. *The hourly CO_2 and CH_4 fluxes emitted from the degraded organic mixture of varied ages retain at different landfill areas in the world.*

Landfill	Rainfall (mm)	Age-old (Years)	Degradable portion (%)	CO_2 flux (µg/m²/hr)	CH_4 flux (µg/m²/hr)	References
Delhi	734	16	55	NE	9.2-60	Chakraborty et al. (2011)
Varanasi	1100	9	59-62	17.28-281.27	10.73-60.20	Pandey et al. (2014)
Guwahati	1698	7	64.9	58.7-170	28.7-143.1	Gollapalli and Kota,(2018)
Chennai	1197	16	59	0.2-16.1	0.016-0.39	Jha et al. (2008)
Yucatan, Merida, Mexico	NA	20	50-55	NE	1030.6	Riancho et al. (2013)
Thailand	1419	24	60-80	NE	0.38-89.5	Wangyao et al. (2010)
Malaysia	1987	3	70.8	3.5-1911	1112	Abushammala et al. (2016)
Italy	NA	37	55	1257-3146	3.80-8.00	Popita et al. (2015)
Polesgo, Burkina Faso	600-900	20	55-60	3325-5617	657-1210	Haro et al. (2019)
Florida, US	NA	5	NA	NE	37.5	Abichou et al. (2006)
New Hampshire, US	NA	26	NA	NE	8.54-30.90	Czepiel et al. (2003)
In present study at BLS	**690**	**14**	**56-62%**	**932-1876**	**359-1173**	
In present study at TLS	**690**	**25**	**48-54%**	**137-958**	**670-1483**	

NA- Not available; NE- not evaluated

Phase	BLS		Phase	TLS	
	CO_2(%)	CH_4(%)		CO_2(%)	CH_4(%)
Covered trash	-	-	Covered trash age old trash	33	45
Uncovered new trash	54	48	Uncovered new trash	-	-
Uncovered age-old trash	52	44	Uncovered age-old trash	-	-

Table 2. *Trash type, cover material vs landfill gas composition during the studied period*

Quantification of flux rate of emanated LFG

The annual mean LFG flux of BLS was observed high at 2147249±132684 µg/m²/yr in 2018. Likewise, the annual mean of LFG flux at TLS was observed high at 1826557±123752µg/m²/yr. The monthly estimated zonewise LFG fluxes of the year 2018 and 2019 at BLS and TLS respectively is represented in Table 3. Surface fluxes were measured either laterally or vertically in each zone. A laid-out grid pattern was followed to perform the sampling operation at BLS and TLS, as depicted in Figure 1. The LFG fluxes of BLS and TLS were noticed above the threshold value of 416 g/m³/hr (Abichou et al., 2006) which may be due to varying quantum attributed to landfill surface

DOI: 10.6092/issn.2281-4485/15427

cover and other morphology-related factors of landfill site. The LFG flux is also determined by landfill intrinsic factors like age, the compactness of trash layers, the permeability of cover soil, fermentable volume and its ferment ability, temperature and dampness of trash layers and also by extrinsic factors like, diverse geographical areas, rainfall patterns, temperature trends, and compositional commonalities which may be differ site to site worldwide. The world-wide records of CO_2 and CH_4 flux rates acquired by installing the SFC in various landfills are represented in Table 1.

The diffusion of LFG into the atmosphere is regulated by composition of surface soils. The BLS had porous loamy soil with a thickness of 0-30cm, so diffusion of LFG was easy into the atmosphere, whereas TLS is capped with polymeric liners having a thickness of 80cm-1m which showed lower diffusion of LFG. Yilmaz et al. (2021). They estimated around 39.2 and 3070 μg/m^2/hr mean fluxes of CH_4 and CO_2 sequentially at soil cover of 200 mm thickness. Similar findings were observed by Abichou et al. (2006 & 2016), Abushammala et al. (2014), Boeckx et al.(1997), Gebert and Grongroft, (2006) and Humer et al. (2008).

The LFG discharge was observed higher at each zone of BLS from May to August 2018 which may be due to absence of soil cover or polymeric liners over the dumps that cause a serious threat to enviornment. The impelementation of rotational covering and capping system made of impermeable materials like bio-traps, bio-covers, polymeric substances, etc., can reduce the LFG emission. In TLS, LFG discharge was also found significant during the studied years, 2019 due to absence of gas-capturing facility.

Table 3. *The mean annual and hourly fluxes of LFG at BLS and TLS*

	BLS					
Period	An hourly flux of LFG (μg/m^2/hr)			Annual Flux rate of LFG (μg/m^2/yr)		
	Zone-A	Zone-B	Zone-C	Zone-A	Zone-B	Zone-C
January 2018 to April 2018	5.22±0.14	4.68±0.53	6.54±0.26	1578423±122456	1366431±155732	1687742±166427
May 2018 to August 2018	8.79±0.60	6.31±0.72	9.11±0.45	1953764±164822	1582762±109573	2147249±132684
Sept. 2018 to December 2018	6.43±0.21	5.82±0.37	6.89±0.16	1754323±184260	1683953±167469	1857024±188567
	TLS					
Period	An hourly flux of LFG (μg/m^2/hr)			Annual Flux of LFG (μg/m^2/yr)		
	Phase-M	Phase-P	Phase-R	Phase-M	Phase-P	Phase-R
January. 2019 to April 2019	4.63±0.57	3.77±0.29	5.79±0.61	1385539±145680	1247784±131480	1467248±136487
May 2019 to August 2019	6.41±0.38	5.86±0.47	6.73±0.52	1746935±153947	1434892±144653	1826557±123752
September 2019 to December 2019	5.39±0.72	4.79±0.53	5.76±0.49	1594647±173562	1486395±155627	1712492±136746

Ground emanations cartographies of BLS and TLS

The zone-wise mean hourly fluxes of CO_2 and CH_4 from Jan. 2018 to Dec. 2018 at BLS, were found in the range of 932 - 1876 μg/m^2/hr and 359 - 1173μg/m^2/hr respectively. Whereas, the mean hourly CO_2 and CH_4 fluxes of TLS existed between 137 - 958 μg/m^2/hr and 672 - 1483 μg/m^2/hr, respectively during Jan. 2019 to Dec. 2019. Through zonation and gridding of each site, the variegated samples of CH_4 and CO_2 were obtained in all seasons of the year which reflected the gaseous discharge from the particular region and their collective emanation from the landfill area. Each site was marked as three relative zones after evaluation of surface emission, i.e., lower, medium, and dense landfill gas (LFG), which showed temporal and spatial fluctuations.

The higher emanation zone of BLS exhibited CO_2 fluxes at a rate of 1875 - 2346 μg/m^2/hr, whereas, at TLS, it showed CO_2 fluxes between 732 - 976 μg/m^2/hr. Likewise, The medium emanation zone of BLS displayed CO_2 fluxes at a rate of 341-682 μg/m^2/hr,

DOI: 10.6092/issn.2281-4485/15427

whereas, at TLS, it exhibited CO_2 fluxes between 437-759 µg/m²/hr. The lower emanation zone of BLS and TLS showed CO_2 fluxes at <136 µg/m²/hr and <104µg/m²/hr, respectively. The higher, medium and lower emission zones of TLS displayed CH_4 flux at 1560-2780 µg/m²/hr, 1062-1340 µg/m²/hr and <387 µg/m²/hr sequentially. Similarly, it exhibited between 1142-1526 µg/m²/hr, 839-1043 µg/m²/hr, and <443 µg/m²/hr serially at BLS .

The higher, medium and lower emanation of CO_2 fluxes and CH_4 fluxes may be due to morphological difference of each site, heterogeneity in density, compactness, moisture, temperature, degradability potential and age of organic trash which influences the rate of LFG production under aerobic and anaerobic conditions. The diffusivity and advection of CO_2 and CH_4 fluxes emanation is also influenced by the atmospheric conditions (Jha et al., 2008; Aghdam et al., 2019). The alteration in air temperature also regulated the LFG measurements, it was noticed during forenoon and afternoon sampling of LFG at both the sites. In addition to that, LFG efflux was found to be greater in summer season, in comparison of rainy and winter season due to less damp, windy conditions and an increase in porosity of the superficial layer of the landfill surface. These conditions had created a pressure gradient between the landfill surface and under the surface resulting in high gaseous diffusion to the atmosphere. No significant differences in the outflow fluxes of LFG during rainy season and winter season was observed due to similar wind patterns and dampness (Aghdam et al., 2019; Haro et al., 2019). The interpolated area of BLS and TLS where CO_2 and CH_4 fluxes displayed significant variability are represented in Figure 3.

The availability of high CH_4 in interpolated zones of BLS and TLS affirmed the presence of more than 10-year-old trash in which the methanotrophs were less oxidizing CH_4 under aerobic and anaerobic conditions and also the reduction of ammonium to nitrite and nitrate underway (Im et al., 2011; Cao et al., 2021). The medium and low CO_2 and CH_4 fluxes obtained at BLS and TLS was due to some of reasons like fermentation efficiency and slow fermentation rate in compacted sub-surface trash layers. Despite the fermentation process, the formation of impeding agents such as ammonia and aromatic hydrocarbons, furans, and dioxins might produced the low, medium zone of LFG emanations. Moreover, the presence of plastics and other toxic chemicals in the trash also act as a inhibiting agents for LFG production during degradation of trash at the landfills (Abichou et al., 2015; Abedini, 2014; Gollapalli and Kota, 2018). As stated earlier, the intrinsic and extrinsic physico-chemical variables are also responsible for low and medium efflux of CO_2 and CH_4 at both sites.

Collection efficiency (CE) of LFG at BLS and TLS

The collection efficiency (CE) of LFG was ranged between 27% to 33% for BLS and 44% to 49% for TLS. These values were quite contradictory as the management status of TLS is better than BLS which cause lower LFG emanation at TLS. TLS surface LFG discharges are likely caused by cracks in the dump's cover soil, poorly maintained open gas vents, and a lack of a gas collection system. The LFG at TLS was not monitored regularly and TLS was not even covered with mud or liners to reduce surface discharges; therefore LFG discharges at BLS were higher than TLS and due to it the CE of BLS was lower. Based on active, temporary covered, and fully covered landfill cells, (Barlaz et al., 2004) estimated that the CE of LFG was 50%, 75%, and 95%, respectively, indicating that these values do not fall within the range as evaluated for BLS and TLS, inferring that higher emission would have resulted in a lower value of CE consistent with the observation of Aghdam et al. (2019); Fjelsted et al. (2019). They also discovered that summer CE's values were lower than winter CE's due to excess moisture availability in the landfill, which confined the LFG flow over the outer layers of the landfill, preventing gases from escaping into the atmosphere. Whereas, Oonk et al. (2012) assessed around 50% CE and in the studies of Mohsen et al. (2020); Zhenhan et al. (2022) held at Halton and Danish trash dump areas in Canada and Denmark, respectively, where the CE values of LFG ranges from 13 to 86% which is comparable to the CE values of TLS. Borjesson et al. (2009); Themelis and Ulloa, (2007) CE, evaluations were not analogous to as found for TLS. Haro et al. (2019) estimated CE to be around 23 - 27% in tropical managed landfill site of Polesgo and Njoku et al. (2018) calculated CE in the range of 29 - 33 % in Burkina Faso landfill which is relative to the CE evaluated for BLS. EPA also specifically prepared a database i.e. AP-42 mentioned the CE of LFG ranges between 60 to 85% depending upon different types of landfills located in diverse climatic zones. This database, however, does not classify landfills based on infrastructural factors

DOI: 10.6092/issn.2281-4485/15427

such as maintenance, monitoring of with or without gas capture assembly, and cover system that either reduce or enhance CE. Nevertheless this database is being widely cited by investigators. According to Aghdam et al. (2017), in order to improve CE of LFG up to 75% an integrated capturing system would be required against the sites that are deprived of this type of system and only 50% CE is achievable. This integrated LFG capturing system does indeed prevent undesirable discharges and has the potential to be used as energy.

Carbon Footprints (CF) of BLS and TLS

The carbon footprints (CF) were calculated by considering the emission factor (EF) of each gas at BLS and TLS. The CF value was observed 180000 tons of CO_2 equivalent ($tCO_2eq.$) at BLS in 2018 and 78000 tonnes of CO_2 equivalent ($tCO_2eq.$) at TLS in 2019 respectively. The difference in CF value between BLS and TLS is due to the difference in occupied dumping area by each site. BLS have 300000m^{2}area for dumping while TLS have 150000m^2 area for dumping. It showed that about 6000 ton of CO_2 hectare square meters (tCO_2eqhm^2) from BLS and 5200 tCO_2eqhm^2 from TLS were potentially discharged into the environment, which means this point source contributes 4.8 - 5.6%.

According to the IPCC, (2013) report, GHG emissions from this sector contribute between 3.5 and 7% of total GHG emissions from all sources, which is quite concerning. The percentage contribution from these sites is also within the range specified by the IPCC in 2013. Ramachandra et al. (2022) calculated the GHG emissions from MSW to be 55227t CO_2 eq. Another, finding of MEVCC, (2015) depicted that in a landfill site at Burkina Faso, approximately 852000tCO_2 eq was generated in an area of 66200m^2. Chakraborthy et al. (2011) have assessed 450000t CO_2eq from the Gazipur landfill site in Delhi. To reduce the evaluated GHG outflows from BLS and TLS, one of four technologies must be used: first, to divert the organic fraction from these two landfills to produce compost; second, the dried trash constituents would be used in refuge derived fuel (RDF) or solid recovered fuel (SRF) plants to generate heat and electricity; thirdly, trash piles in landfills should be sorted and bio-mined. Finally, the gas capturing facility on the landfill grounds must be operational in order to transform or directly use the fetched gases for other purposes such as CNG, LNG, and so on (Staub et al., 2011; Malakahmad et al., 2017) also suggested the same. In the absence of integrated gasification installation the trash should be flared to transform the CH_4 into CO_2 according to Chen et al. (2010). These initiatives are expected to reduce BLS' carbon footprint from 180000t CO_2 eq to 124300t CO_2 eq and TLS' carbon footprint from 780000t CO_2 eq to 23000t CO_2 eq, resulting in a 57 - 63 % reduction in GHG emissions. The cost of installing a gas capturing system and its transformation techniques, on the other hand, would have been higher than the cost incurred for bio-mining, composting, and RDF. To reduce the demand for non-renewable resources, the alternative resource produced implied in waste-to-energy (WtE) technique, namely gasification, is beneficial for powering vehicles and machinery.

Conclusion

This investigation foregrounded the quantitative emanated fluxes of CH_4 and CO_2 from BLS and TLS using the static flux chamber technique alongwith the use of respective gaseous analyzers. The CH_4 and CO_2 mean emission fluxes evaluated in 2018 at BLS were 1173µg/m^2/hr and 1876 µg/m^2/hr, respectively. Likewise, CO_2 and CH_4 mean emanated fluxes in 2019 were 958 µg/m^2/hr and 1483 µg/m^2/hr serially at TLS. The CH_4 fluxes of TLS were reportedly higher than BLS, while the prevalence of surface CO_2 fluxes of BLS was higher than TLS. Both landfill sites have LFG fluxes higher than the threshold value of 416 µg/m^2/hr prescribed in published articles. The CE values of TLS and BLS ranged between 44-49% and 23-33%, respectively, which also justifies the occurrence of the significant emanations fluxes from these two areas. Therefore, require mitigation strategies to control the surface emanations. This data also provide a basis to integrate the CH_4 fraction either stored or oxidized in these two sites. The LFG emissions are not a surface phenomenon; there are various internal and external factors like composition, age, degradable organic carbón (DOC) and compactness of the trash layers, temperature, humidity, etc.

The obtained results would develop an insight into the site conditions that the concerned authorities could utilize and the stakeholders who wanted to treat and fetch this recoverable energy resource as an option for reducing the carbon footprints and assisting in the conservation of the environment and non-renewable resources of the country.

DOI: 10.6092/issn.2281-4485/15427

References

ABEDINI R.A. (2014) Integrated approach for accurate quantification of methane generation at municipal solid waste landfills. Thesis, University of British Columbia, Vancouver. https://dx.doi.org/10.14288/1.0135641.

ABICHOU T., CHANTON J., POWELSON D., FLEIGER J., ESCORIAZA S., LEI, Y., STERN, J. (2006) Methane flux and its oxidation at two types of intermediate landfill covers. Waste management. 26(11):1305-1312. DOI: 10.1016/j.wasman.2005.11.016.

ABICHOU T., KORMI T., WANG C., MELAOUHIA H., JOHNSON T., DWYER S. (2015) Use of Evapo-transpiration (ET) Landfill Covers to Reduce Methane Emissions from Municipal Solid Waste Landfills. Journal of Water Resource and Protection. 7:1087-1097. DOI: 10.4236/jwarp.2015.713089.

ABICHOU T., KORMI T., MARSH S., WANG C. (2016) Phytocaps for landfill emission reduction in Australia. Geo-Chicago, 222-231. https://doi.org/10.1016/B978-0-323-85763-5.00041-6.

ABUSHAMMALA M.F.M., BASRI N.E.A., KHADUM A.A.H., BASRI H., SHAFIE A.H.E., MASTURA S.S.A. (2014) Evaluation of methane generation rate and potential from selected landfills in Malaysia. International Journal of environmental science and technology, 11:377-384. DOI: 10.1007/s13762-013-0197-0.

ABUSHAMMALA, M.F., BASRI, N.E.A. and YOUNES, M.K. (2016). Seasonal variation of landfill methane and carbon dioxide emissions in a tropical climate. International Journal of Environment and Sustainable Development, 7, 586e590.
https://doi.org/10.18178/ijesd.2016.7.8.844.

AGHDAM, E.F., SCHEUTZ, C., KJELDSEN, P. (2017) Assessment of methane production from shredder waste in landfills: the influence of temperature, moisture and metals. Waste management, 63:226-237. DOI: 10.1016/j.wasman.2016.11.023.

AGHDAM E.F., SCHEUTZ C., KJELDSEN P. (2019) Impact of meteorological parameters on 1 extracted landfill gas composition and flow. Waste management. 87: 905-914. DOI:10.1016/j.wasman.2018.01.045.

ANNEPU R.K. (2012). Report on sustainable solid waste management in India. Waste-to energy research and technology council (WTERT). University of Columbia, New York. https://www.nswai.org/docs/Sustainable%20Solid%20Waste%20Management%20in%20India_Final.pdf.

BARLAZ M.A., GREEN R.B., CHANTON J.P., GOLDSMITH C.D., HATER G.R. (2004) Evaluation of a biologically active cover for mitigation of landfill gas emissions. Environment science and technology. 38(18): 4891-4899. DOI: 10.1021/es049605b

BOECKX P., VAN CLEEMPUT O., VILLARALVO I. (1997) Methane oxidation in soils with different textures and land use. Nutrient Cycling in Agro ecosystems, 49: 91 - 95. https://link.springer.com/content/pdf/10.1023/A:1009706324386.pdf

BORJESSON G., SAMUELSSON J., CHANTON J., ADOLFSSON R., GALLE B., SVENSSON H.B. (2009) A national landfill methane budget for Sweden based on field measurements, and an evaluation of IPCC models. Tellus B: chemical and physical meteorology. 61(2): 424-435. DOI: https://doi.org/10.1111/j.1600-0889.2008.00409.x

CAO Q., LI X., JIANG H., WU H., XIE Z., ZHANG X., LI N., HUANG X., LI Z., LIU X., LI D. (2021) Ammonia removal through combined methane oxidation and nitrification- denitrification and the interaction among the functional microorganisms. Water research. 188(1): 116555. DOI: 10.1016/j.watres.2020.116555

CHAKRABORTY M., SHARMA C., PANDEY J., SINGH N., GUPTA P.K. (2011) Methane emission estimation from landfills in Delhi: A comparative assessment of different methodologies. Atmospheric Environment. 45: 7135-7142.
DOI: 10.1016/j.atmosenv.2011.09.015

DOI: 10.6092/issn.2281-4485/15427

CHEN, D., SUTER, H. C., ISLAM, A. AND EDIS, R. (2010). Influence of nitrification inhibitors on nitrification and nitrous oxide (N_2O) emission from a clay loam soil fertilized with urea. Soil Biology and Biochemistry, 42: 660 - 664. https://doi.org/10.1016/j.soilbio.2009.12.014.

CZEPIEL P.M., SHORTER J.H., MOSHER B. (2003) The influence of atmospheric pressure on landfill methane emissions. Waste Management, 23:593-598. https://doi.org/10.1016/S0956-053X(03)00103-X.

EA - Environment Agency (2010) Guidance on Monitoring Landfill Gas Surface Emissions. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321614/LFTGN07.pdf

FJELSTED L., CHRISTENSEN A.G., LARSEN J. E. (2019) Assessment of a landfill methane emission screening method using an unmanned aerial vehicle mounted thermal infrared camera – A field study. Waste Management, 87:893-904. https://doi.org/10.1016/j.wasman.2018.05.031

GEBERT J., GRONGROFT A. (2006) Passive landfill gas emission - influence of atmospheric pressure and implications for the operation of methane-oxidising bio filters. Waste management, 26:245-251. DOI: 10.1016/j.wasman.2005.01.022

GOLLAPALLI M., KOTA S. H. (2018) Methane emissions from a landfill in north-east India: performance of various landfill gas emission models. Environmental Pollution, 234: 174-180. https://doi.org/10.1016/j.envpol.2017.11.064.

HARO K., OUARMA I., NANA B., BERE A., TUBREOUMYA G. C., KAM S. Z., KOULIDIATI J. (2019) Assessment of CH_4 and CO_2 surface emissions from Polesgo landfill (Ouagadougou, Burkina Faso) based on static chamber method. Advances in Climate Change Research, 10(3):181-191. https://doi.org/10.1016/j.accre.2019.09.002

HUBER-HUMER M., GEBERT J., HILGER H. (2008). Biotic systems to mitigate landfill methane emissions. Waste management and research, 26:33-46. https://doi.org/10.1177/0734242X07087977.

IM J., LEE S.W., BODROSSY L., BARCELONA M.J., SEMRAU J.D. (2011) Field application of nitrogen and phenylacetylene to mitigate greenhouse gas emissions from landfill cover soils: effects on microbial community structure. Applied microbial biotechnology. 89(1): 189-200. DOI: 10.1007/s00253-010-2811-0.

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[STOCKER, T.F., D. QIN, G.-K. PLATTNER, M. TIGNOR, S.K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, V. BEX AND P.M. MIDGLEY (eds.)]. Cambridge University Press, Cambridge and New York. https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf

JHA A. K., SHARMA C., SINGH N., RAMESH R., PURVAJA R., GUPTA P.K. (2008) Greenhouse gas emissions from municipal solid waste management in Indian mega cities: A case study of Chennai landfill sites. Chemosphere (Elsevier). 71(4): 750-758. DOI: 10.1016/j.chemosphere.2007.10.024

KUPPER, T., BURGE, D., BACHMANN, H.B., GUSEWELL, S. AND MAYER, J. (2014). Heavy metals in source-separated compost and digestates, Waste Management, 34(5):867-74. DOI: 10.1016/j.wasman.2014.02.007

MALAKAHMAD A., ABUALQUMBOZ M.S., KUTTY S.R.M. (2017) Assessment of carbon footprint emissions and environmental concerns of solid waste treatment and disposal techniques; case study of Malaysia. Waste Management. 70:282-292. DOI: 10.1016/j.wasman.2017.08.044.

MEVCC - Ministry of Economic Verte et du Changement Climatique (2021) Contribution Prevue determines au niveau National (CPDN) au Burkina Faso, 2021-2025, Burkina Faso. https://unfccc.int/sites/default/files/NDC/2022-06/Rapport%20CDN_BKFA.pdf

DOI: 10.6092/issn.2281-4485/15427

MOHSEN R.A., ABBASSI B., ZYTNER R. (2020) Investigation of fugitive methane and gas collection efficiency in Halton landfill Ontario Canada. Environment monitoring and assessment, 192:326. DOI: 10.1007/s10661-020-08308-z.

MONSTER J., KJELDSEN P., SCHEUTZ C. (2019) Methodologies for measuring fugitive methane emissions from landfills: a review. Waste Management. 87: 835-859. DOI: 10.1016/j.wasman.2018.12.047

NJOKU P.O., ODIYO J.O., DUROWOJU O.S. (2018) A review of landfill gas generation and utilisation in Africa. Open Environmental Sciences, 10: 1-15. DOI: 10.2174/1876325101810010001.

OONK, H. (2012). Efficiency of landfill gas collection for methane emission reduction. Greenhouse Gas Measurement and Management, 2(2-3): 129 - 145. https://doi.org/10.1080/20430779.2012.730798.

PANDEY J., KAUSHIK P., MEHRA M., MASOOD S. (2014). Methane and carbon dioxide emission and leachate characterization from landfills along Ganges river at Varanasi (U.P.), India. Plant Archives, 14 (1):7-13.
http://www.plantarchives.org/PDF/Vol.%2014(1)%20(7-13).pdf.

POPITA G.E., FRUNZETI N., LONESCU A., LAZAR A.L., BACIU C., POVOVICI A., POP C., FAUR V.C., POOROCU M. (2015) Evaluation of carbon dioxide and methane emission from Cluj-Napoca municipal landfill, Romania. Environmental engineering and management journal, 14(8): 1389-1398. DOI: 10.30638/eemj.2015.151.

RAMACHANDRA, T.V., Bharath, H.A., Kulkarni, G. and Han, S.S. (2018) Municipal Solid Waste: Generation, composition and GHG emissions in Bangalore, India. Renewable and Sustainable Energy Reviews, 82(1): 1122-1136. https://doi.org/10.1016/j.rser.2017.09.085.

SAURI-RIANCHO R., MARÍA R., GABRIELA S.E.I. (2013) Superficial methane emissions from a landfill in Merida, Yucatan. Engineering research and technology. 14: 299-310. DOI: 10.1016/S1405-7743(13)72244-3

STAUB M.J., MARCOLINA G., GOURC J.P.(2011) An incremental model to assess the environmental impact of cap cover systems on MSW landfill emissions.Geotextile. Geomembranes. 29: 298-312. DOI: 10.1016/j.geotexmem.2011.01.013.

Press Information Bureau, Government of India Ministry of Urban Development; 18 December, (2014). Guidelines for Swachh Bharat Mission (Gramin). Ministry of Drinking Water and Sanitation. Government of India.
Website. http://www.mdws.nic.in.

THEMELIS N.J., ULLOA P.A. (2007) Methane generation in landfills, Renewable Energy, 32:1243-1257. https://doi.org/10.1016/j.renene.2006.04.020.

U.S. Environmental Protection Agency (USEPA) (2013). Global Mitigation of Non-CO2 Greenhouse Gases: 2010-2030. EPA-430-R-13-011, Washington, DC: US EPA, LMOP. https://www.epa.gov/sites/default/files/2016-06/documents/mac_report_2013.pdf

WANGYAO K., TOWPRAYOON S., CHIEMCHAISRI C. (2010) Application of the IPCC Waste Model to solid waste disposal sites in tropical countries: case study of Thailand. Environment Monitoring and Assessment, 164:32, 249-261. DOI: 10.1007/s10661-009-0889-6.

YILMAZ M., TILJUM J.M., ACKER C., MARTEN B. (2021) Transport mechanisms and emissions of landfill gas through various cover soil configuration in an MSW landfill using a static flux chamber technique. Journal of environmental management. 280: 111677. DOI: 10.1016/j.jenvman.2020.111677.

ZHENHAN D., KJELDSEN P., SCHEUTZ C. (2022) Efficiency of gas collection system at Danish landfills and implications for regulation. Waste management. 139:269-278. https://doi.org/10.1016/j.wasman.2021.12.023.