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Temperature Influence on the Variability and Emission of CH_4 and CO_2 from a Former Manchester Landfill

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Abstract

Analysis of datasets in time order was carried out to determine the consequence of atmospheric temperature on the changes in CH_4 and CO_2 concentrations at a former landfill site. The Gasclam (in-borehole gas monitor) was used to collect field data of CH_4/CO_2 concentrations and the environmental parameters. The magnitude of the relationship of ground-gas concentration and the barometric temperature was obtained by linear regression analysis. The result reveals variability in CH_4 and CO_2 concentrations with poor positive relationships of 0.016 and 0.014, respectively, with barometric temperature over the whole sampling period. Despite slightly improving the R^2 by taking into account their concentration over single phases of upward and downward limb temperature, single phases of upward limb temperature, and single phases of downward limb temperature, their correlations remained insignificant at a 95% confidence level. The implication is that temperature (just like pressure) is not the dominant influence on CH_4 and CO_2 concentrations changes at this site. Having established barometric pressure and temperature as minor controls, a recommendation was made for the establishment of other potential controls (particularly variations in the site water depth) and their degree of control.

Keywords: Landfill gas, Climate forcing, Climate mitigation policies, Explosive mixture, Asphyxiant, Environmental controls.

Introduction

Landfill gas (LFG) is produced from a process that involves the breakdown of organic waste present in municipal solid waste in the absence of O_2 [1, 2]. LFG generation starts as soon as a landfill starts reception of waste and can have a lifetime of above 30 years after the landfill is closed [2]. The rate of LFG production depends on a number of factors: the content of waste, age of the waste, oxygen content, moisture content, and temperature [3]. A typical LFG comprises approximately 50% methane (CH_4), 45% carbon dioxide (CO_2), 5% nitrogen, and other gases [4].

Landfills have been found to release a considerable proportion of total atmospheric CH_4 worldwide [5]. Globally, landfills were estimated to emit and contribute CH_4 concentrations of between 35 and 69 Tg (teragram)/year to an estimated worldwide emission of about 600 Tg CH_4 to the atmosphere per year [6]. In Europe, in 2006, landfills ranked second among the leading sources of anthropogenic CH_4, releasing about 3373 Gg (gigagram) CH_4 from disposed waste [7]. In the UK, for example, landfills contributed almost 46% of the overall CH_4 emission in 1996 [7]. The amount of CO_2 emitted from soil respiration globally ranged from 68×10^{15} $gCyear^{-1}$ (global Carbon flux per year) [8] to 75×10^{15} $gCyear^{-1}$ [9] and was influenced by the rate of soil respiration [10].

CH_4 is recognised as the second-largest contributor to global warming after CO_2 [7, 11]. This is because, among the persistent greenhouse gases (GHGs), CH_4 has the next most significant climate forcing after CO_2 [12]. However, CH_4 is a more potent GHG because it is 28 to 36 times higher than CO_2 at capturing heat in the atmosphere over a 100-year time scale [13]. Therefore, CH_4 is often a major factor for climate abatement policy-making [11]. It persists in the atmosphere for about ten years [11]. CH_4 causes combustion and can lead to diverse hazards if it moves into and accumulates in a structure. For example, at large concentrations (i.e., about 5%–15% by volume in air), the gas may cause an explosion. It can also lead to suffocation and toxicity in specific circumstances.

Furthermore, CO_2 presents hazards comparable to those of CH_4 [14]. It can constitute a danger of suffocation once it gathers in an enclosure by dislodging the air and resulting in anaerobic conditions [3]. CO_2 can also lead to untoward health consequences, coma, or fatality at comparably trace quantities (at about 5% in the volume of air) [1].

There are well-known cases where ground-gas explosions have lead to fatalities or severe injuries. The blasts resulted specifically from the CH_4 component of the LFG. Some of those incidents are well documented in literature [15, 20].

They also documented in the literature numerous cases of detection of LFG in buildings where the LFG had migrated from the adjacent landfill sites in the UK [15, 17].

Landfill CH_4 and CO_2 concentration measurement are crucial as it aids in the assessment of explosion and toxicity risks. Nevertheless, concentration measurement only is insufficient. Also required is the knowledge of their controls. Knowledge of controls on ground-gas concentration is vital for evolving the best technique for monitoring them and forecasting concentration changes required for management of their risks. To determine how gas concentration will change in the future through their controls needs the knowledge of the process controlling them. The process can be understood with the aid of time continuous data. This kind of data permits both short-term and long-term changes in gas concentration to be detected and rated. Moreover, the relations of gas concentrations and their controls might vary from site to site and may change from time to time. Therefore, time series data is needed for analysis to infer when the concentration may become dangerous.

Gas production, soil permeability, and barometric pressure have been described as the three fundamental controls on ground-gas concentrations [15]. While gas availability is a function of gas production rate, soil permeability determines gas migration rate. While barometric pressure draws or forces the gases to migrate, soil permeability permits the gases to migrate. However, after their study at the same site revealed that atmospheric pressure is not always the dominant control (as claimed earlier) on the ground-gas concentration variability, Nwachukwu and Anonye [15] recommended that the effect of atmospheric temperature, among other factors, be investigated. This work, therefore, is to establish the level of control temperature has on the changes in the concentration and emission of CH_4 and CO_2 in the studied site. In this case, attention will be focused on gas production rate, temperature fluctuations, and soil permeability as three major controls.

Variability in subsurface gas production may result from chemical and biological factors such as pH, moistness, temperature, soil chemical activity, soil micro-organisms (example, microbial breakdown), aerobic and anaerobic states [21, 22]. Any change in these factors can either raise or reduce the volume of the gases produced, their amount in the soil, their migration, and the nature of the hazard they pose.

The effects of variations in temperature, which may lead to variations in the quantity of the subsurface gas, have the likelihood of interfering with the movement of CH4/CO2 in those soil gases near the surface. That is because the soil temperatures remain constant at depth in the UK. However, it is important to recognise that barometric temperature plays a significant part in influencing air pressure [23].

Soil permeability is the gap linking ground-gas and the atmosphere [23]. The relationship of gas concentration and the environmental controls such as temperature can change due to the delay resulting from variations in soil permeability and the rate of gas production/temperature. Permeability can vary with ground cover and depth. Variations in soil permeability are affected by numerous influences such as saturation, freezing, bioturbation, and compaction [22].

The permeability of the soil can now be determined using ‘pressure differential’, that is, the difference between atmospheric and borehole pressures [15, 24], which can be obtained with the aid of the Gasclam in-borehole monitor. Pressure differential occurs when the soil permeability does not change in consonance with the cycle of changes in the atmospheric pressure; therefore, the pressure differential is helpful to evaluate the permeability of diverse soils. With the knowledge of soil permeability, soil gas availability can be determined from the amount of gas detected. Information about soil permeability and gas availability is then required for an accelerated understanding of the relationships between gas concentration and temperature.

Since atmospheric pressure has been investigated and found not to be the dominant driver of changes in ground-gas concentration in this site, this work intends to verify if the temperature is the dominant influencing factor on the release of and changes in landfill CH_4/CO_2 concentrations.

Materials and Methods

The Gasclam (In-borehole monitor)

A ground-gas measuring device, Gasclam [15] was deployed in-situ to acquire the datasets analysed in this work. This instrument can continuously monitor various ground-gases at the same time with their controls every 60 minutes without human intervention for about three months [15]. Gasclam logs the various gases using the sensors integrated into it. It has an adjustable sampling rate that can vary from two minutes to once daily. The logged data can be transferred to a processor for analyses using an alternative GPRS telemetry system.

Data Sampling

The device was set up in a 50 mm well to continuously monitor the ground-gases and their controls on an hourly basis for a period of six weeks. The time-series data were thereafter downloaded and analysed graphically specifically to ascertain the magnitude of control temperature has on the changes in and release of CH_4/CO_2 concentrations.

Site Information

This is the same landfill site investigated by Nwachukwu and Anonye [15] to quantify the level of control barometric pressure has on CH_4/CO_2 emissions. The site has formally pronounced a landfill during the 1940s with the reception of mainly domestic, commercial, and industrial waste materials. Due to the quest for housing and change in government policies, houses were erected on the site during the 1970s; however, the dumping of waste on it stopped five years later. Many years later, LFG was established to be escaping into a number of properties. To stop gas escaping into the houses, a 'venting trench' was constructed. However, this did not solve the problem fully as the inhabitants still perceived the odour of the gases. Consequent site study revealed the presence of hazardous wastes in the site and that some of the houses are standing right on tipped materials.

It was felt necessary to determine the concentration of the LFG when the inhabitants of the houses built on the site complained of bizarre smells from their houses. There was also the panic of potential explosions due to CH_4, suffocation from CO_2, and toxicity arising from Volatile Organic Compound (VOC).

Results and Discussion

The time series data obtained with the aid of the gas monitor were utilized to study CH_4/CO_2 concentrations and temperature with respect to time. This was to determine whether temperature controls the concentration of these gases and if it does, the magnitude of that control. The effect of hysteresis on the variations in gas concentrations was also examined. However, the effect of soil permeability was adopted from the previous work of Nwachukwu and Anonye [15].

The strength of the correlation between ground-gas concentration and temperature was established using linear regression analysis. This was done by splitting the dataset into different phases of increasing and decreasing temperature (Fig. 1a) and then determining the R^2 values (Table 1a-b) for the specific phases. In Fig. 1a, sections 1–5, CH_4 and CO_2 tend to increase without recourse to temperature. Nevertheless, sections 6, 7, and 8 display clearer proof of relationships. However, it was not thought enough to look at the graph and conclude whether or not there is a correlation, which is why linear regression analysis was done.

The dataset gathered on an hourly basis over a month in the borehole at the studied site shows variations in CH_4/CO_2 concentrations (Fig. 1a, b). This obviously supports the guidance condition for repeated sampling [22]. Variability also exists in the relationship between gas concentration and temperature when analysed in terms of continuous sampling periods of rising length. However, this variability mismatches the sampling rate of the gases. The variation in the relationship of the gas concentration and atmospheric temperature occurs over days and not hours; therefore, the hourly sampling setting should be changed to match the frequency of the above change (Fig. 1a).

The obvious loops produced by linking data points in time series imply that landfill gas concentration is influenced by hysteresis (Fig. 1a, c). A clearer evidence of the loops can be observed in sections 1–4 of Fig. 1a.

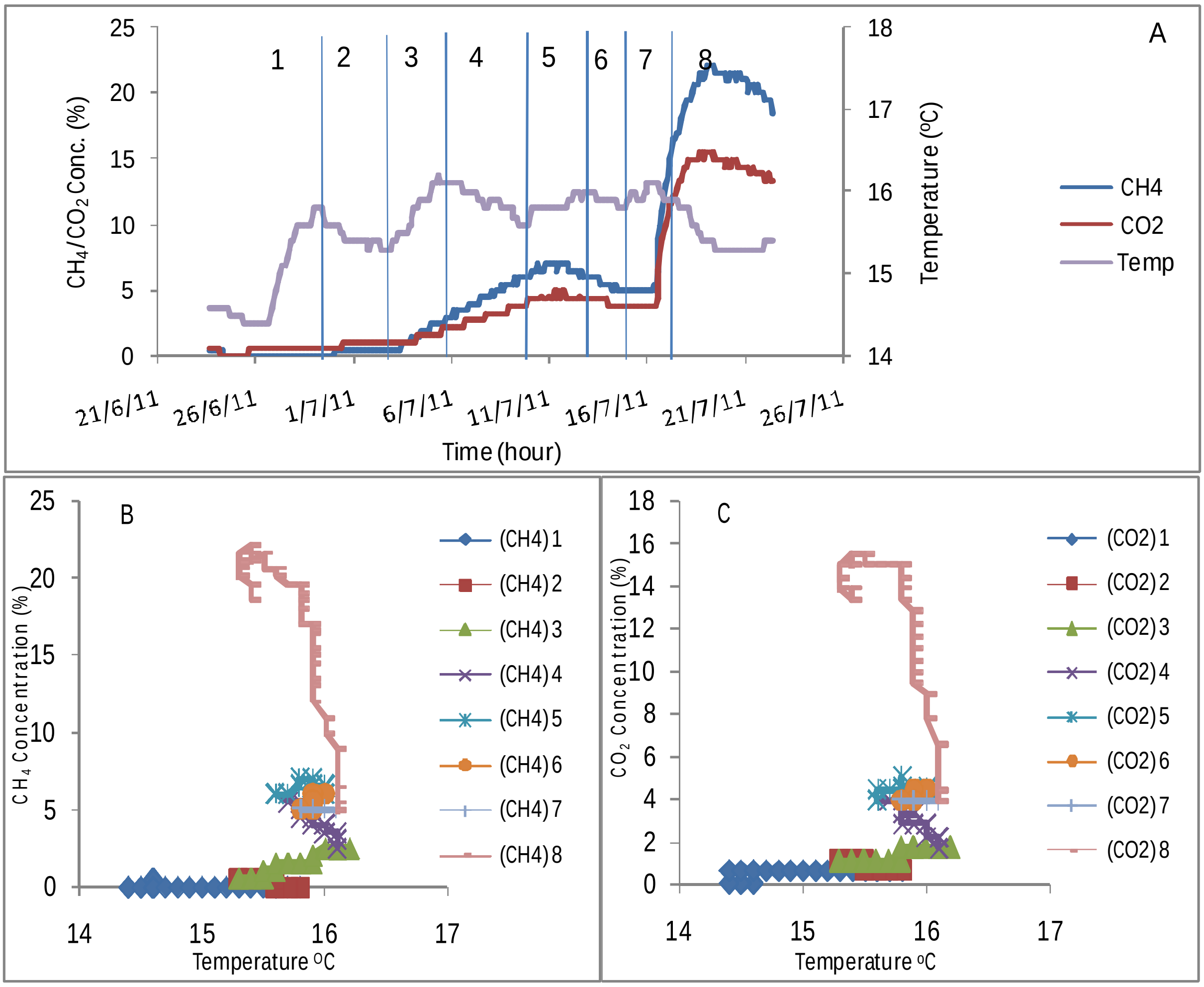

Figure 1. A-C: **CH_4, CO_2 concentration (%) and temperature (degrees) vs time (hour). The time-series data is divided into sections 1–8. Series split is established on periods of varying temperature, B, C. The analysis is for the entire dataset. However, different sections of fluctuations in concentration with temperature are designated in various colours**

Numerous decreasing and increasing temperature periods displayed a weak negative R^2 with CH_4 and CO_2 concentrations (Fig. 1b). This negative R^2 backs the guidance condition for sampling sequel to decreasing temperature so as to increase the probability of detecting the worst case. In spite of slightly improving the R^2 by considering concentrations of CH_4/CO_2 over specific periods of increasing and declining pressure as specified in sections 1 and 2 combined, 3 and 4 combined, 5 and 6 combined, 7 and 8 combined (Table 1a); and also in view of different periods of increasing and different periods of decreasing temperature (Table 1b), the R^2 stayed insignificant at 95% confidence level. This implies that temperature is not the dominant control.

Nwachukwu and Anonye [15] have already established that the atmospheric and borehole pressures did not always overlap in this site (Fig. 2a) and resulted in a pressure gap. This obviously, is an indication of instability in soil permeability. The apparent loops created by the link of data points in the time sequence indicate that soil permeability is affected by hysteresis (Fig. 2b). A lot of these loops were observed in sections 1–4, which validates our previous observation.

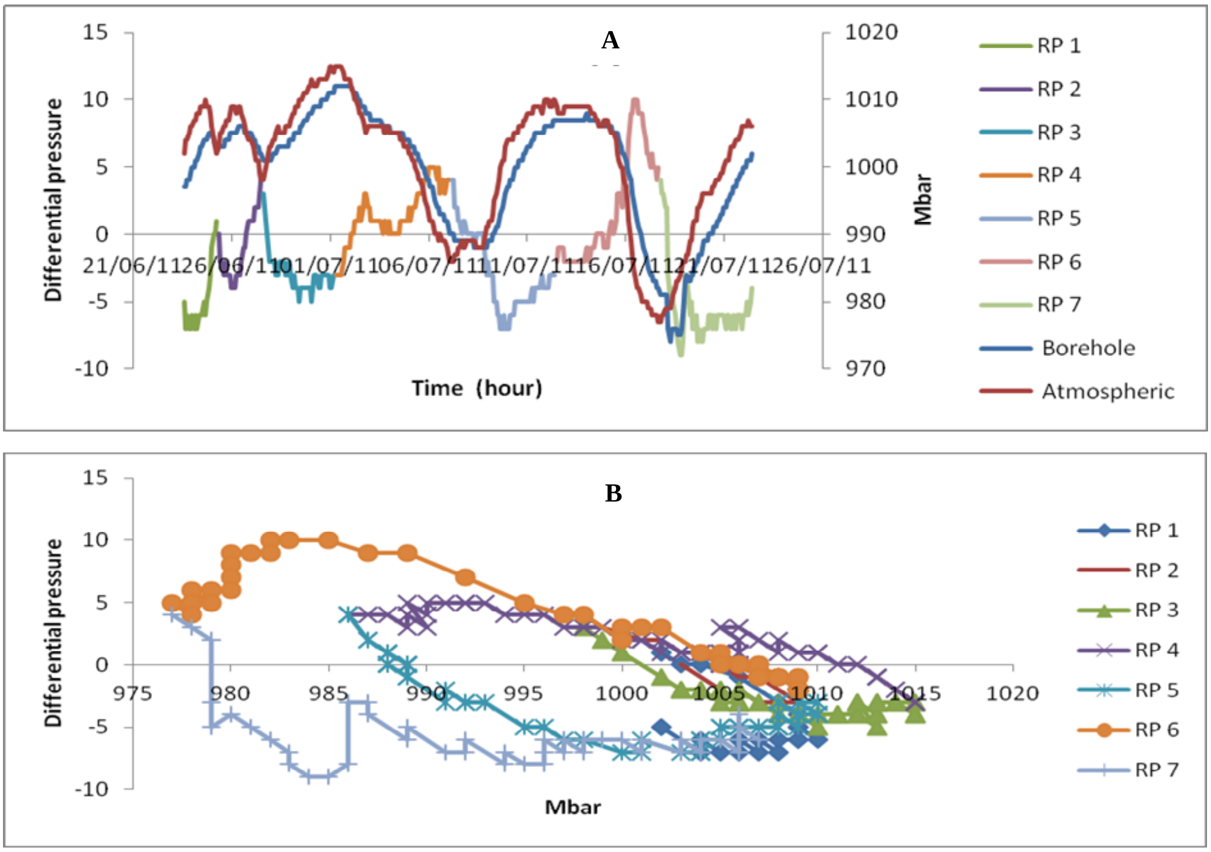

Figure 2 (A-B). **The relationship between atmospheric pressure, borehole pressure and differential pressure as time series of increasing duration (A). B displays the differential pressure as a function of atmospheric pressure (Nwachukwu and Anonye, 2012)**

Table 1a. **Gas correlations (R^2) over single periods of rising and falling atmospheric temperature.**

Gas	Sections 1 and 2	Sections 3 and 4	Sections 5 and 6	Sections 7 and 8
CH_4	0.060	0.204	-0.033	- 0.719
CO_2	0.298	0.125	0.034	- 0.643

Table 1b. **Gas concentrations over single periods of rising atmospheric Pressure and single periods of falling atmospheric temperature.**

Gas	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8
CH_4	-0.033	-0.668	0.940	- 0.857	0.528	0.423	n/a	-0.753
CO_2	0.175	- 0.792	0.755	-0.846	0.114	0.178	-9E-13	-0.626

Conclusion

The time series data obtained from the Gasclam visibly demonstrated the presence of a positive relationship between CH_4/CO_2 concentrations and barometric temperature over the entire monitoring period. This result was unexpected as it did not agree with the negative correlation (although very low) between the concentrations of CH_4/CO_2 and atmospheric pressure using the same dataset by Nwachukwu and Anonye [15]. Ideally, there was supposed to be a negative correlation between the gas concentrations and atmospheric temperature, just as atmospheric pressure since the temperature is known to increase with pressure. Despite slightly improving the R^2 by considering their concentration during single phases of upward and downward temperature, single phases of upward temperature and single phases of downward temperature, the correlation remains insignificant at 95% confidence level. The visible loop produced by the link of the data points in time-series is a pointer that the concentration of the gases is largely influenced by hysteresis. Splitting of the data sequence into specific phases of decreasing and increasing pressure makes a remarkable improvement in the strength of the relationship. For example, the R^2 values of the relationship over the second increasing and decreasing limb of the barometric temperature are 0.125 and 0.204 for CO_2 and CH_4 respectively; this was improved by dividing the time-series data into specific increasing and decreasing temperature limbs during which CO_2 and CH_4 had positive R^2 values of 0.755 and 0.940 respectively for increasing limb temperature, and negative R^2 of 0.846 and 0.857 for decreasing limb. This implies that while the temperature is the main driver during the decreasing limb temperature, it was not during the increasing limb temperature. Therefore, a positive correlation of gas concentration with any environmental control over any monitoring period does not automatically mean that such parameter does not exercise control on the variability/ emission of the gas. It may suggest only that it is not a major control. Also, even a very low positive correlation during the whole monitoring time could suggest the presence of control as in the present case.

Fluctuation in the soil permeability is among the established causes of the identified changes in the concentrations CH_4/CO_2. This can be observed in the data loops and caused by inconsistency in the relationship between atmospheric pressure and barometric pressure. Extra sampling time is needed for gaining an understanding of the rate of production of subsurface gas and the amount of influence it has on variability in and emission of gas concentration. Changes in the landfill water depth and the geology of the monitoring wells are other potential controls.

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Conflict of Interest

Note that there is no conflict of interest whatsoever.

References

1. F. A. Osra, H. K. Ozcan, J. S. Alzahrani and M. S. Alsoufi, *Sustainability*, 13 (2021) 1462. https://doi.org/10.3390/su13031462
2. L. Lombardia, A. Cortib, E. Carnevalea, R. Baciocchic and D. Zingarettic, *Energy Procedia*, 4 (2011) 465. https://doi.org/10.1016/j.egypro.2011.01.076
3. M. D. Vaverková, *Geosciences*, 9 (2019) 431. https://doi.org/10.3390/geosciences9100431
4. P. O. Njoku, J. O. Odiyo, O. S. Durowoju and J. N. Edokpayi, *Open Environ. Sci.*, 10 (2018) 15. https://doi.org/10.2174/1876325101810010001
5. M. S. Korai, R. B. Mahar and M. A. Uqaili, *Proceedings of the 14th International Conference on Environmental Science and Technology Rhodes, Greece*, (2015).

https://cest2015.gnest.org/papers/cest2015_00321_poster_paper.pdf

6. J. Bogner, A. M. Abdelrafie, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti and T. Zhang, Waste management. In Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. & Meyer, L.A. (eds): Climate Change: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, (2007) 34. https://archive.ipcc.ch/publications_and_data/ar4/wg3/en/ch10.html
7. EEA (European Environment Agency), *Annual European Community Greenhouse Gas Inventory 1990–2018 and Inventory Report 2020*. Submission to the UNFCCC Secretariat. EEA Technical Report No. 6, (2019). https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2019
8. T. Hou, Y. Wang, F. Guo, Q. Jia, X. Wu, E. Wang and J. Hong, *Sustainability*,13 (2021) 4780. https:// doi.org/10.3390/su13094780
9. R. B. Jackson, K. Lajtha, S. E. Crow, G. Hugelius, M. G. Kramer and G. Piñeiro, *Annual Review of Ecology, Evolution, and Systematics*, 48 (2017) 419. https://doi.org/10.1146/annurev-ecolsys-112414-054234
10. A. T. Sosulski, M. Szymanska, E. Szara and P. Sulewski, *Agronomy*, 11 (2021) 21. https://dx.doi.org/10.3390/agronomy11010021
11. O. Boucher, P. Friedlingstein, B. Collins and K. P. Shine, *Environ. Res. Lett.*, 4 (2009) 044007. https://doi.org/10.1088/1748-9326/4/4/044007
12. P. Forster, V. Ramaswamy, P. Artaxo, T. Berntsen, D. W. Fahey, et al. (2007): Changes in atmospheric constituents and in radiative forcing. In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (eds.): Climate Change 2007*:* The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA. http://www.cgd.ucar.edu/events/20130729/files/Forster-Ramaswamy-etal-2007.pdf
13. IPCC, Climate Change: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Geneva, Switzerland (2014) 151. https://www.ipcc.ch/report/ar5/syr/
14. K. A. Adegoke, M. Iqbal, H. Louis, S. U. Jan, A. Mateen and O. S. Bello, *Pak. J. Anal. Environ. Chem.*, 19 (2018) 1. doi:10.21743/pjaec/2018.06.01
15. A. N. Nwachukwu and D. Anonye, *Environ. Monit. Assess.*, 185 (2013) 5729. https://doi.org/10.1007/s10661-012-2979-0
16. Landfill Gas Monitoring Guidance, North Carolina Department of Environment and Natural Resources, Division of Waste Management Solid Waste Section (2010). https://files.nc.gov/ncdeq/Waste%20Management/DWM/SW/Field%20Operations/Environmental%20Monitoring/LandfillGasMonitoringGuidanceDocument.pdf
17. Health and Safety Executive, Review of landfill gas: Incidents and guidance, DINTD5/030, Health and Safety Executive, London, (2003).

http://www.environment-agency.gov.uk/

18. N. Aitkenhead and G. M. Williams, *Q. J. Eng. Geol. Hydrogeol.*, 24 (1991) 191. https://doi.org/10.1144/GSL.QJEG.1991.024.02.03
19. US EPA, Air emissions from municipal solid waste landfills—background information for proposed standards and guidelines, U.S Environmental Protection Agency, Office of Air Quality Planning and Standards: Research Triangle Park, NC. https://catalogue.nla.gov.au/Record/4030627
20. New York Times, Ohio homes condemned by gas bring a fight over compensation, New York US, (1984). https://www.nytimes.com/1984/11/11/us/methane-condemns-11-suburban-akron-homes.html
21. N. J. O'. Riordan and C. J. Milloy, Risk assessment for methane and other gases from the ground, *CIRIA Report* 152, CIRIA London, UK (1995). https://www.thenbs.com/PublicationIndex/documents/details?Pub=CIRIA&DocID=200618
22. S. Wilson, S. Oliver, H. Mallett, H. Hutchings and G. Card, Assessing risks posed by hazardous ground gases in buildings, CIRIA Report 665, London UK, (2007). https://www.ciria.org/ProductExcerpts/C665.aspx
23. A. N. Nwachukwu, B. E. Ephraim, N. V. Nwachukwu and C. U. Uwa, *Catrina: The Int. J. Environ. Sci.*, 21 (2020) 83. https://cat.journals.ekb.eg/article_97575.html
24. S. Boult, P. Morris and S. Talbot, Contaminated land application in real environment (*CL:AIRE)* B*ulletin*, RB 13, (2011). https://www.claire.co.uk/component/phocadownload/category/11-research-bulletins?d