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Fugitive Gaseous Emissions Characterization from Municipal Solid Waste Landfill by a New Integrated Approach: Field Surveys and Remote Sensing

Giuseppina Oliva[a,*], Domenico Giaquinto[a], Paolo Napodano[a], Marco Limongiello[b], Salvatore Barba[b], Alberto Vivarelli[c], Giorgio Cardona[c], Vincenzo Belgiorno[a], Tiziano Zarra[a], Vincenzo Naddeo[a]

[a]Sanitary Environmental Engineering Division (SEED), Department of Civil Engineering, University of Salerno, via Giovanni Paolo II 132, SA, Fisciano, 84084, Italy
[b]Surveying and Geo-Mapping for Environment and Cultural Heritage, Department of Civil Engineering, University of Salerno, via Giovanni Paolo II 132, SA, Fisciano, 84084, Italy
[c]Ind.Eco S.r.l., Sda Monfalcone, 23, 04100, Latina, Italy
goliva@unisa.it

Municipal solid waste (MSW) landfills release different gaseous compounds in ambient air, including greenhouse gases and VOCs, with relevant effects in terms of contribution to global warming and odour annoyance. The accurate characterization and monitoring of these emissions is thus of fundamental importance to avoid negative impacts and for identifying and evaluating the effectiveness of mitigation measures. Currently, different and no universally accepted and standardized methods have been validated for the measurement of these emissions from landfill (landfill gas, LFG). The most widely-used techniques for the identification of emission rates from areal sources are known as “hood methods”. However, these methods are not particularly accurate for sampling LFG. Moreover, conventional approaches for LFG sampling frequently neglect the evaluation of fugitive emissions from crucial points of biogas network (i.e.: wells, drains, pipeline), which can be also interested by leakages and can thus result in significant emission of LFG into the atmosphere. For the abovementioned reasons, the development of specific methods for the assessment of the LFG emissions is of great interest to overcome the related issues.

In the present work, an integrated and advanced approach for the monitoring and mapping of MSW landfill gas emissions has been presented and validated. The proposed procedure integrates multiple approaches to provide a complex and polyvalent survey of the landfill, also including the evaluation of the landfill terrain morphology and the presence of possible non-homogeneous areas. The experimental activities were carried out at a complex MSW landfill located in Central Italy (Lazio Region) and were organized into four steps: (i) identification and characterization of the fugitive emissions from landfill cover, by Flux Chamber device in different points of a geo-localized grid on landfill body; (ii) characterization of landfill terrain morphology and of possible fugitive emissions from biogas wells and other points considered relevant in the network, by using remote sensing with surveys implemented with drone equipped with RGB, multispectral and thermal cameras together with topographic measurements with GNSS receivers; (iii) integration of the geo-referenced results, including the Digital Terrain Model (DTM), the Normalized Difference Vegetation Index (NDVI), the thermographic mapping and the point monitoring results on landfill cover; (iv) elaboration of maps of the emissions levels for the different investigated compounds and the identification of critical points/areas.

The results were elaborated and discussed (i) for the evaluation of the emissions from the investigated landfill, (ii) for proving the accuracy of the proposed procedure with cross-validation approaches and (iii) for extending the proposed procedure to a wider application for different types of landfills.

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1. Introduction

Despite the fact that the odorous compounds account for less than 1 % (v/v) in the composition of landfill gas (LFG), the odour annoyance associated to their release can result in negative and significative impacts on the exposed population (Lim et al., 2018; Sakawi et al., 2011). The main odour sources of landfill plants are identified to be landfill working face (WF), leachate treatment area, LFG wells and waste transport vehicles (Wenjing et al., 2015; Ying et al., 2012). However, the uncontrolled release of LFG from landfill bodies, due to leaks from network or fugitive emissions from the surface, represents the main odour source of landfill in post-management phase (Du et al., 2023; Özkal, 2023). The assessment of odour impact can be implemented using dispersion models, numerical simulation which requires as input the emissions data of the odour source. The emission characterization of area sources of odours can be characterized in terms of surface odour emission rate (SOER). To calculate this parameter, static chamber (SC) and flux chamber (FC) are among the sampling tools usually adopted for area sources (Lucernoni et al., 2017; Zarra et al., 2016). However, these samplings techniques are related to possible over estimation or under estimation of odour emissions (Oliva et al., 2021). These tools are also not adequate for the exhaustive characterization of odour emissions from landfill, especially in post-management phase (Naddeo et al., 2016). In this condition, in fact, the emissions of odours are almost completely associated to fugitive emissions from crucial points of biogas network (i.e.: wells, drains, pipeline), which can be also interested by leakages and can thus result in significant emission of LFG into the atmosphere (Scheutz et al., 2008). Consequently, it is strongly needed a comprehensive approach for the characterization of odour impact from area and fugitive sources with effective and reliable tools (Oliva et al., 2024). The integration of different monitoring approach is the preferred solution to retrieve complex and exhaustive data for the monitoring of odour emissions from landfill in post-management phase (Senatore et al., 2021). Unmanned aerial vehicles (UAV) have become common instruments for obtaining important analytical data in many fields (Cuenca-García et al., 2020; Ronchi et al., 2023). In particular, UAV can be adopted in waste management application for collecting data also for landfills (Sliusar et al., 2022). In this study, it was proposed a novel approach for integrating characterization of the fugitive emissions from landfill cover by Flux Chamber device, in different points of a geo-localized grid on landfill body, with remote sensing characterization. In particular, the results were integrated with the characterization of landfill terrain morphology and of possible fugitive emissions from biogas wells and other points considered relevant in the network, by using remote sensing with surveys implemented with drone equipped with RGB, multispectral and thermal cameras together with topographic measurements with GNSS receivers and geo-referenced results, including the Digital Terrain Model (DTM), the Normalized Difference Vegetation Index (NDVI), the thermographic mapping and the point monitoring results on landfill cover. Results were discussed for the elaboration of maps of the emissions levels for the different investigated compounds and the identification of critical points/areas retrievable by the areal mapping with UAV.

2. Materials and methods

2.1 Site description

Research studies were conducted at a non-hazardous waste landfill, located in the municipality of Latina, Lazio Region (Italy). The landfill is approximately located at 11.5 km from the centre of the town. The Borgo Montello landfill site consists of 6 different basins, all closed, with n.19 regulation stations and n. 229 biogas extraction lines. The main activities of the post-management basins consist of (i) management and control of the drainage system and leachate collection, (ii) management and control of the collection system and biogas combustion (iii) management of human and technological resources available at the plant.

2.2 Characterization of fugitive emissions from landfill cover

The characterization of fugitive emissions from landfill cover was conducted according to “Enviromental Agency Guidance on monitoring landfill gas surface emissions, LFTGN07” (U.K. Environment Agency, 2010). A square mesh network of approximately 40 meters per side was defined on the surface of the landfill. The air samples to analyze were taken in the n. 40 points for basin identified as S7 and n. 42 points for basin identified as S8, corresponding to the vertices of the networks. The air was collected with a stainless-steel chamber (Scentroid, SF450, Chamber Sampler, Canada) operated as Static Chamber according to the standard used for the measurement. For each point, the coordinates of the point, the meteorological conditions at the time of sampling and the emission parameters detected with on-site analysis were reported. For each sampling point the following activities were conducted: (i) the chamber was positioned at the node of the mesh and the geographical coordinates of latitude and longitude were detected (WGS84, Time Zone 33); (ii) pressure was exerted on the chamber in order to prevent entering of air from the edges of the chamber; (iii) the sampling points at the head of the chamber were closed and the time necessary to fill the chamber with emissions coming only from the landfill body was waited, estimated at approximately 100 seconds; (iv) the values of the meteorological parameters were measured; (v) at the end of 100 seconds, the portable instruments were connected to the sampling points positioned at the head of the chamber and the values measured in terms of CH_4, CO_2, O_2, H_2S and TVOCs were acquired every 100 seconds for a further 500 seconds (at time 100, 200, 300, 400, 500, 600). The on-site analyses were conducted using a handheld multi-gas instrument (MRU, Optima 7 Biogas,) for the characterization of emissions in terms of CH_4, CO_2, O_2, H_2S, equipped with NDIR sensors and electrochemical sensors, and using portable GC-PID (IonScience,Tiger) for the characterization of emissions in terms of total volatile organic compounds (TVOCs). Isopleths were mapped with Surfer Software.

2.3 Characterization of fugitive emissions from biogas network with portable analytical systems

For all the investigated basins (S4, S5, S6, S7, S8), it was carried out a monitoring activity with specific instrumentation with the aim of verifying the presence of any biogas leaks in correspondence with the regulation stations, pipes and extraction wells. At the time of monitoring, some lines were undergoing maintenance, therefore it was taken into account that a total of 14 regulation stations could be inspected for a total of 156 biogas extraction lines. Specifically, 100% of the lines were subjected to visual inspection, while 44% of the lines were subjected to measurement. The on-site analyses were conducted using a handheld multi-gas instrument (MRU, Optima 7 Biogas) for the characterization of emissions in terms of CH_4, CO_2, O_2, H_2S, equipped with NDIR sensors and electrochemical sensors, and using portable GC-PID (IonScience,Tiger) for the characterization of emissions in terms of total volatile organic compounds (TVOCs).

2.4 Thermographic investigations from the ground and remote sensing with drone equipped with RGB

The Unmanned aerial vehicles, equipped with RGB sensors, were used in order to map the plant and have a georeferenced information base, combined and interpolated with measurements of specific thermal anomalies using a manual thermal camera with operator on the ground, both georeferenced using GNSS measurements. The combined use of aerial and ground-based passive optical instrumentation allowed to combining fast large-scale mapping. The aerial surveys were carried out with n. 3 different sensors: Sensefly Ebee X for the reconstruction the topography, the DJI Mavic 3T for the reconstruction of the thermography and DJI Mavic 3M or the reconstruction of Normalized Difference Vegetation Index (NDVI). The surveys were conducted in the first hours of the day and the acquisition required 4 hours. Thermographic investigations from the ground were carried out with a FLIR I3 hand-held thermal camera. This thermal camera is capable of measuring temperatures radiometrically, with a resolution of 60 x 60 pixels, and thus each pixel corresponded to a temperature value. Soil thermography can provide important information about the criticality of pipeline, gas leaks from a well or valve insulation. GNSS Emlid Reach RX was used to take the coordinates of the points where each photo was made with the thermal camera in order to implement geolocation of anomalies found with manual thermal camera and operations from the ground. With the same instrument, the photogrammetric targets necessary for georeferencing the RGB flight and subsequent topographical processing were measured, validating a metric precision of approximately 2 cm in planimetry and 3 cm in altimetry.

3. Results and discussion

3.1 Characterization of fugitive emissions from landfill cover

In Figure 1 the maps for S8 basin, with a temporarily capped zone, were reported to summarize the results of the field investigation, from which emerged that the methane concentrations of the emissions deriving from the coverage of the landfill were lower than the experimental detection limit (0.01%) for almost the entire surface of the basin. In the North-West area of the basin, at the time of sampling, maintenance works were underway. Consequently, the highest concentrations of the investigated compounds were detected in the aforementioned area. However, the maximum concentrations detected from emissions from the S8 basin surface were of the order of 0.2 mg m^{-3} in terms of TVOCs and 0.08% in terms of methane. The concentrations of hydrogen sulphide were lower than the instrumental detection limit (1 ppm) for all the points investigated. From the analysis of the main results of the field investigation in S7 basin, it emerged that the methane concentrations of the emissions deriving from the landfill coverage were lower than the instrumental detection limit (0.01%) for almost the entire surface. Higher concentrations, but still less than 0.10% of methane, were found in the southern area of the same basin. In basin S7, the concentrations of hydrogen sulphide were lower than the instrumental detection limit (1 ppm) for all the points investigated.

For calculating rates of emissions, it was measured the gradient of the graph of methane concentration versus time. No significant positive variations of methane concentrations were observed over the time, confirming the low emissions rate of the investigated basins with temporarily and permanent capped zones, which resulted lower than 0.1 mg of methane per square meter per second.

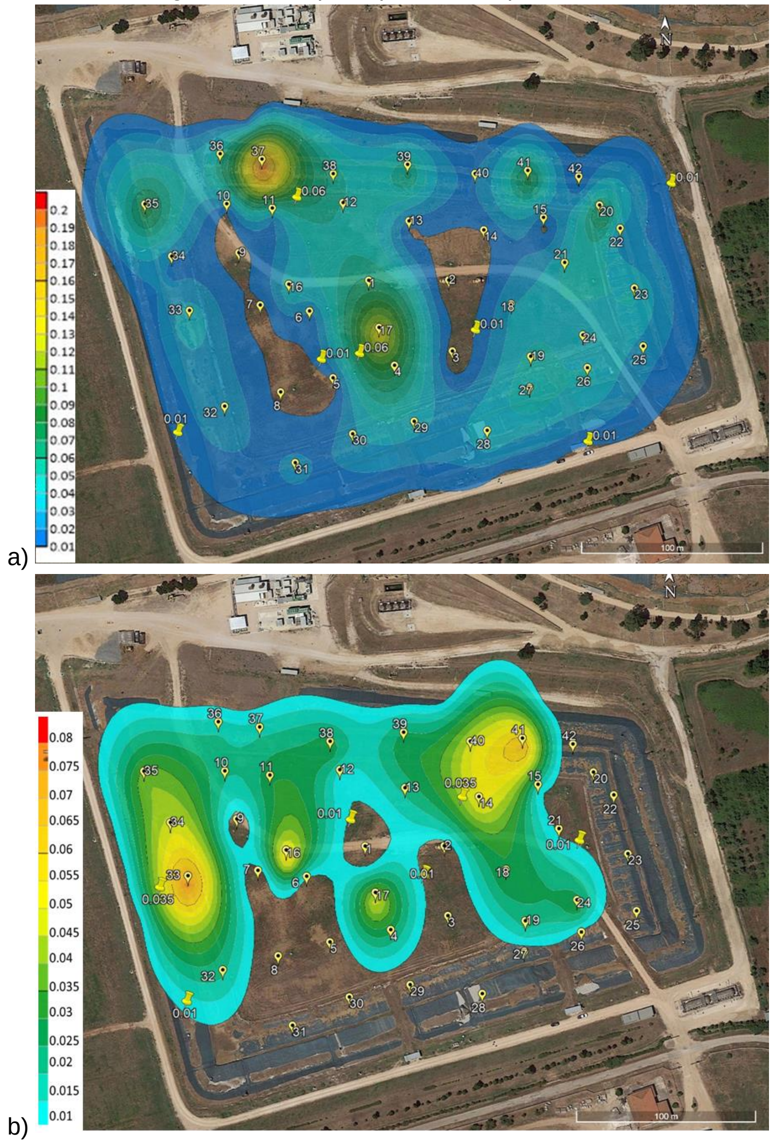

Figure 1 - a) Map of S8 basin reporting isoconcentration curves of total volatile organic compounds (TVOCs), expressed in mg m^{-3}; b) Map with visualization of methane isoconcentration curves, expressed in percentage.

3.2 Characterization of fugitive emissions from biogas network with portable analytical systems

The instrumental survey conducted along the lines and for all the wells did not detect any biogas leaks. However, values different from the average were found in the S7 Basin, in particular for the P12 extraction well.
In fact, this well reported a CH_4 concentration of 1.7%, while along the lines and in the other wells of the same basin they are close to the detection limit. Furthermore, the CO_2 concentration was also equal to 3008 ppm, differently from the other points where the values ranged between 200 and 300 ppm.

3.3 Remote sensing with surveys implemented with drone equipped with RGB

The check of the condition of the insulating material covering the pipes was implemented with thermal camera from the ground in order to verify the presence of any breakage or to prevent its occurrence. Indeed, according to the investigations carried out, heat losses due to poor insulation appear clearly on the thermal image, thus offering the possibility of quickly checking and repairing damaged insulation in order to avoid significant or major damages, energy losses and emissions of greenhouse gases into the atmosphere. In the case, it is important

to emphasize how to obtain reliable thermographic results, it is essential to operate in the absence of too intense solar radiation. The topographic and thermographic surveys carried out along the lines and for the wells did not highlight any anomalies with respect to the surrounding environment attributable to possible biogas losses. However, some anomalies were found at the same point where, during the instrumental survey on the ground, values different from the average were detected (Basin S7, extraction well P12) as reported in Figure 2.
The well mentioned above have different shades of colours compared to the other wells in which there was a greater homogeneity. The highest heterogenicity of the colours can therefore be correlated to a wider range of temperature (Sliusar et al., 2022). These results are useful to confirm as the integration of different tools allowed to validate field data.

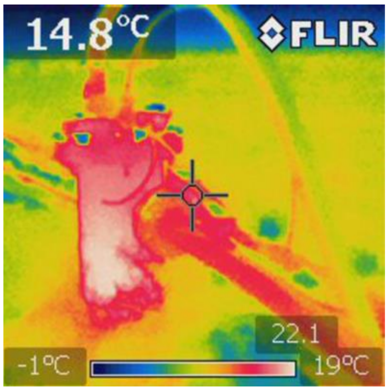

Figure 2: Thermographic surveys on well P12

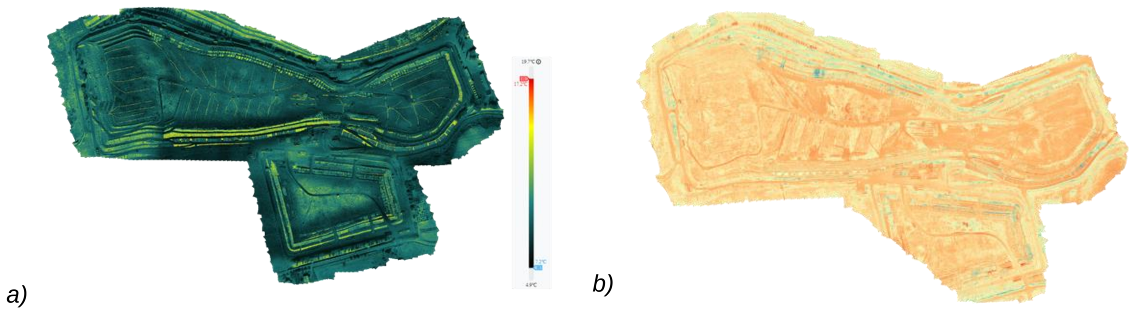

Figure 3 - a) Thermographic radiometric orthophoto of the landfill; b) Multispectral map of the landfill

From the processing of the images obtained from the thermographic survey with a drone, the DTM (Digital Terrain Model) was produced with the level curves at 1 m intervals of the entire system and the dimensioned plan. In Figure 3a, it is possible to observe the thermographic radiometric orthophoto. From the images taken by the thermographic flight plan, the thermal mapping with a ground resolution of 5 cm was carried out for the entire complex. The analysis of the mapping revealed that no critical issues are present but it detected only some outliers, especially near wells and in some sections with tubulars. The procedure has therefore highlighted where attention can be paid from the inspection from the ground to verify whether the critical points identified are actual gas leaks at a different temperature from the external context or false positives (e.g. change of material and reflectivity). The analysis of the multispectral maps produced was reported in Figure 3b and it did not identify vegetative stress anomalies, essentially due to the absence of a type of vegetation that could be affected by any gas losses, both due to temperature effects and effects of substances that may affect plants.

4. Conclusions

The proposed methodology allowed to identify a new and optimized tool for the characterization of landfill odour emissions in post-management phase. The methodology, integrating ground level analyses with remote sensing approach, determined the possibility to detect anomalies with large scale and fast tools. Results demonstrated that the investigated landfill did not present any significant leakage of biogas from the landfill surface or biogas network. Analysis from multispectral maps produced did not reveal abnormalities from vegetative stress, confirming the absence of gas losses potentially affecting the vegetation. The activities carried out demonstrated how the integrated approach between UAV flights, topographic, thermographic and instrumental surveys from the ground was able to identify the presence of possible critical aspects. Results confirmed that the investigated basins in the different moments of the sampling activities were characterized by low emissions rate, typically found in with temporarily and permanent capped zone.

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