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Top-down approach from satellite to terrestrial rover application for environmental monitoring of landfills

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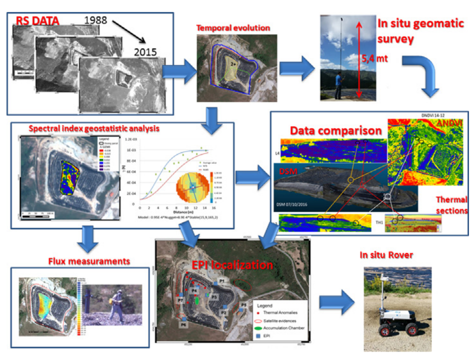
HIGHLIGHTS

- The spectral analysis was performed by satellite data
- Thermal and Photogrammetric survey produced in situ information
- The Environmental Points of interest (EPI) were localized
- Geostatistical analysis supported the measurements
- Chemical analysis confirmed the identification of EPI

GRAPHICAL ABSTRACT



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ABSTRACT

This paper describes a methodology to perform chemical analyses in landfill areas by integrating multisource geomatic data. We used a top-down approach to identify Environmental Point of Interest (EPI) based on very high-resolution satellite data (Pleiades and WorldView 2) and on in situ thermal and photogrammetric surveys. Change detection techniques and geostatistical analysis supported the chemical survey, undertaken using an accumulation chamber and an RIIA, an unmanned ground vehicle developed by CNR IIA, equipped with a multiparameter sensor platform for environmental monitoring. Such an approach improves site characterization, identifying the key environmental points of interest where it is necessary to perform detailed chemical analyses.

1. Introduction

An accurate analysis of landfills is fundamental to improve their planning and management and aid decision making strategies. Accordingly, European Directive 31/1999/CE and Italian law 36/2003 require long-term monitoring of different matrices (air, soil, water) from landfill opening until the post-closure care period. Thus, the optimization of novel matrix analysis techniques is a crucial issue since current investigation methods are expensive and time-consuming.

The application of remote sensing is a non-contact and cost effective technique, in support of traditional sampling methods (Slonecker et al.,

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2010), which improves the monitoring of different environmental matrices in terms information gathering and identification of proxy factors to identify phenomena occurring in the landfill area. The loss of fugitive biogas or leachate may produce effects at different spatial and temporal scales which require an accurate analysis to correctly interpret local environmental dynamics (Slonecker et al., 2010; Manzo, 2012). In landfill areas, changes include land degradation (Amiri et al., 2014; Biotto et al., 2009) in terms of land consumption, or loss of rural activities and 'natural' environment (Mei et al., 2016). Consequently it is fundamental to identify multiscale approaches for the analysis of such anthropogenic impacts and their effects at proper scales, identifying drivers and proxies.

Remote sensing provides numerous data products which describe the earth's surface. These data may be integrated in a Geographic Information System (GIS) with ancillary data such as chemical measurements, cadastral data and indicators of environmental state. Many researchers have explored the use of remote sensing techniques for environmental analysis, particularly landfill site detection have found that (Brilis et al., 2000; Sener et al., 2006; Wang et al., 2009), more effective results were obtained by using high resolution sensors (Silvestri and Omri, 2008; Caprioli and Scognamiglio, 2012). Other authors have adopted remote sensing to identify biogas emissions (Slonecker, 2007), leachate migration (Jones and Elgy, 1994) as well as fugitive dust generation and deposition (Stefanov et al., 2003).

The combination of remote sensing techniques with GIS permits the management of large quantities of spatially distributed data. Jensen et al. (2009) integrated the synoptic perspective of remote sensing by developing a GIS-based system for detection and remediation of wastes and their environmental effects. Recently (Errico et al., 2015) defined a workflow for the detection of environmental hazards developing a GIS-based processing methodology to merge optical and SAR data, using multi-temporal very high resolution sensors (VHR), Geoeye and Cosmo-SkyMed.

Optical and SAR data integration was adopted by Persechino et al. (2013) for the development of GIS-based tools to investigate legal and illegal dumping areas. Cadau et al. (2013, 2014) described a synergic approach based on optical and SAR data for detecting illegal landfills and monitoring existing and known waste disposal sites, combining also land surface temperature data with SAVI and entropy derived by texture analysis for the detection of anomalies. Previous studies have utilised reflectance spectroscopy to investigate environmental matrices in polluted areas by using vegetation indices as a proxy of stress conditions (Noomen et al., 2012, 2015; Manzo et al., 2013, 2016; Mahmood et al., 2016). Several modelling approaches have been utilised to extract information based on spectral mixture modelling (Tromp and Epema, 1998), principal component analysis (Chikhaoui et al., 2005) comparison of maps to quantify changes in degradation classes (Li et al., 2007), and also a semivariogram method of spatial autocorrelation for landfill surroundings analysis (Woodcock et al., 1988; Brivio et al., 1993; Manzo et al., 2016). The use of geostatistics for image analysis is a very powerful tool since variograms capture information concerning the overall image variance and provide input for ecological modelling (Van der Meer, 2012). The range, the distance where the geostatistical model first flattens out, is an indication of fragmentation regarding the landscape (Hyppanen, 1996). An assessment of spatial variability linked to pollution can be performed using directional variograms (Manzo et al., 2016).

Some authors have focused on the analysis of Thermal InfraRed (TIR) data to characterize leakage or the presence of biogas in the ground (Mazzoni et al., 1993; Lewis et al., 2003; Beaumont et al., 2014; Yan et al., 2014) Aerial thermal imaging supports the analysis of the differential ground temperature distribution of landfills, (Merla et al., 2014) and also phenomena connected to the consequences of soil pollution due to biogas emissions (Zilioli et al., 1992; Beaumont et al., 2014). Lega et al. (2012) and Lega and Persechino (2014b) introduced a method for the detection and tracking of environmental contamination using multiple manned and unmanned platforms, demonstrating that infrared thermography is an ideal tool for environmental contamination identification, and that multi-scale aerial platforms can be adopted for preliminary global and local analysis. Recently, the bio-thermal effect of landfills has been studied by integrating TIR with other data using thermal band time series and vegetation indices derived from Landsat 8 data (Mahmood et al., 2016).

Currently, the availability of large remote sensing datasets - both optical and radar (Lillesand et al., 2014; Campbell, 2011) applicable to landfill monitoring, is increasingly rapidly. The new generation of satellites such as Sentinel 2 and Landsat 8 (Drusch et al., 2012; Irons et al., 2012), have sensors with better temporal and spatial resolution, allowing time series to be performed with a higher frequency than in the past, thus providing new opportunities for applications in the study of landfills. The integration of satellite/airborne sensing with ground based spectral and chemical measurements is proving of interest for the detection and monitoring of waste disposal areas (Manzo et al., 2016; Alexakis et al., 2016).

Recently, the development of unmanned aerial vehicles (UAV) and unmanned ground vehicles (UGV) capable of carrying spectral and chemical sensors (Persechino et al., 2010; Gasperini et al., 2014; Roldán et al., 2015), has improved the in situ analysis to determine ground truths and improve field surveys. Such upcoming technologies provide numerous opportunities for novel applications both of optical and thermal analyses. Lega et al. (2014a, b) adopted a thermal pattern and tracking approach, integrating drone platforms and advanced sensors, in order to identify superficial anomalies over landfill areas and possible polluted sites. Gasperini et al. (2014) analysed the digital surface model derived using photogrammetric techniques for subsidence monitoring in municipal solid waste dumps.

Persechino et al. (2013) and Manzo et al. (2016) investigated the definition of a hierarchical protocol to monitor landfill areas by integrating different tools in top-down approaches. The top-down approach described here integrates multi-source data from Very High Resolution (VHR) satellite sensors, thermography, photogrammetry and in situ chemical analysis. The aim is the identification of Environmental Point of Interest (EPI) to be monitored by in situ-chemical analysis. This procedure, developed during the NO-GAS Project, funded in the framework of the Innovation hub "Renewable Energy and Energy Efficiency Technologies for the Sustainable Management of environmental resources" by the European Regional Development Fund (ERDF), focused on punctual and areal emissions from landfills. The project aimed to integrate different types of environmental, chemical and geomatic analyses to optimise the monitoring and biogas exploitation management in landfills.

2. Study area

The study area is located in the controlled landfill site in Vetrano locality of the municipality of San Giovanni in Fiore, in the Sila Massif, in Calabria, Southern Italy. From a geological point of view the area is characterized by grey-brown clays on middle-upper Miocene calcarenite formations, whose high erodibility cause local landslides in areas neighbouring the study area (a1 – Fig. 1).

This site hosted 345,000 tons of municipal solid waste (MSW) from 2000 to 2013 in 4 different parcels. The first parcel was active until 2007 (green line — Fig. 2a) and hosted 70,000 tons, parcels 1 and 2 were active until 2012 (red line) and hosted 224,000 tons. The final parcel (2+) on the top of the landfill was active until November 2013, with 129 tons. The base of the landfill is at 602 m a.s.l. and the top is 629 m a.s.l., the depth of the waste dumped is up to 27 m (CNR IIA, 2016).

The analysis was performed during the closing phase of the landfill activity during the laying of final capping over the last opened parcel, which was capped by ground cover until the end of June 2015. The final capping was applied by a high density 1-mm thick polyethylene (HDPE) between July and September 2015 (CNR IIA, 2016). The biogas extraction system had 20 active wells in the old parcel, while other wells were under construction during the period of analysis in parcel 2+. Consequently this parcel shows the highest land cover variation due to landfill activities.

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