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Integrated remote sensing for multi-temporal analysis of anthropic activities in the south-east of Mt. Vesuvius National Park

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ABSTRACT

This work shows a downscaling approach for environmental changes study using multi- and hyper-spectral remote sensing data. The study area, located in the south-east of Mt. Vesuvius National Park, has been affected by two main activities during the last decades: mining and consecutive municipal solid waste dumping. These activities had an environmental impact in the neighbouring areas releasing dust and gaseous pollutants in the atmosphere and leachate into the ground. The approach integrated remote sensing data at different spectral and spatial resolutions. Landsat TM images were adopted to study the changes that occurred in the area using environmental indices at a wider temporal scale. In order to identify these indices in the study area, two high spatial and spectral resolution MIVIS aerial images were adopted. The first image, acquired in July 2004, describes the environmental situation after the anthropic activities of extraction and dumping in some sites, while the second image acquired in 2010 reflects the situation after the construction of new landfill in an old quarry. The spectral response of soil and vegetation was applied to interpret stress conditions and other environmental anomalies in the study areas. Some Warning Zones were defined by “core” and “neighbouring” of the anthropic area. Different classification methods were adopted in order to characterize the study area: Spectral Angle Mapper (SAM) classification provided local covers, while Linear Spectral Unmixing Analysis (LSMA) identified main fractions changes of vegetation, substrate and dark surfaces. The change detection of spectral indices, supported by thermal anomalies, highlighted potential stressed areas.

1. Introduction

Territorial analysis requires attention in effective decision making for planning and monitoring anthropic activities. The management of anthropic areas and their surroundings is possible through the knowledge of specific thematic datasets, which are fundamental to evaluate the environmental sustainability. The synoptic perspective of remote imaging can be useful for detection and remediation of wastes and their environmental effects (Slonecker et al., 2010; Jensen et al., 2009). The United States Environment Protection Agency (US EPA) adopted topographic mapping and aerial photographs to monitor the location, area and historical changes to hazardous waste sites (Brilis et al., 2000). Many researchers explored remote sensing technologies to support environmental monitoring, particularly on the landfill detection (Silvestri and Omri, 2008), the monitoring of biogas emission (Slonecker, 2007) and leachate migration (Jones and Elgy, 1994).

The use of aerial photography with sufficient spatial resolution and available historical archives improved the solid-waste planning and management, detecting changes in land cover in and around the waste sites (Slonecker et al., 2010; Garofalo, 2003), for instance visual interpretation was applied to perform inventories of solid waste disposal in the Suffolk county (United States) (Barnaba et al., 1991).

Spaceborne and airborne sensors extended the analysis in waste sites beyond the visible and near-infrared wavelengths up to infrared and microwave, providing more data to retrieve land use/cover information and descriptive spectral indices of superficial characteristics (Slonecker et al., 2010; Ottavianelli et al., 2005). These tools have proved their efficiency in many current environmental issues even if the application for waste management is still limited to specific objectives (Beaumont et al., 2014). Several researchers have successfully used multispectral imagery for landfill site mapping and for the identification of new locations as decision

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tool. Some authors applied spatial filtering of Landsat TM data to enhance the identification of despoiled land to generate map of industrial and hazardous wastes (Foody and Embashi, 1995), to identify fugitive dust generation and deposition (Stefanov et al., 2003) or the effect due to hydrocarbon alteration (Zhang et al., 2009; Van der Meer et al., 2002). Remote sensing has been used successfully, considering phenomena connected to the consequences of soil contamination and pollution, such as thermal anomalies either due to organic biogas emission (Zilioli et al., 1992), or soil bleaching indices (Almeida-Filho et al., 1999), or vegetation stress (Kumar et al., 2001; Cenedese et al., 2003).

In the last decades, the reflectance spectroscopy approach has been extensively used to investigate and to monitor the vegetation condition (Silleos et al., 2006) and biophysical and biochemical vegetation variables (Smith et al., 2004; Beeri et al., 2007; Kochubey and Kazantsev, 2007; Mutanga and Skidmore, 2007; Darvishzadeh et al., 2008; Manzo et al., 2013; Noomen et al., 2015). According to the results of these studies, stressed vegetation is influenced by several factors. Therefore, the analysis of the effect of waste deposits requires the development of site-depending techniques.

Zarco-Tejada et al., 2002 and Splayt et al., 2003 observed good correlations between the concentration of many biochemicals within vegetation canopies and their hyperspectral reflectances at landfill sites. Some authors showed the improvement of the site mapping at landscape-scale, when sensor with fine spatial and spectral resolution are used - such as Advanced Visible InfraRed Imaging Spectrometer (AVIRIS) (Roper, 2001) and Multispectral Infrared and Visible Imaging Spectrometer (MIVIS) (Gomarasca and Strobelt, 1995; Gianinetto and Lechi, 2004). Airborne hyperspectral data was adopted to monitor soil contamination, particularly around landfill sites (Folkard and Cummins, 1998) and for monitoring bioremediation (Noomen et al., 2015). In conclusion, airborne remote sensing is a valid technique to collect information at high spectral and spatial resolution. However, the cost of these types of images is expensive; moreover, the number of multiple overpass in the same area at different date is often reduced: consequently, it is hard to find multi-temporal analysis performed with a hyperspectral device.

Thermal Infrared (TIR) data has been adopted in landfills for characterization of possible leakage or presence of biogas in the ground (Mazzoni et al., 1993; Lewis et al., 2003). Chiarantini et al. (1995) described a TIR imaging system and biogas model, and suggested that monitoring of waste disposal sites using a TIR system is possible, with measurements at ground and from airborne systems. TIR airborne acquisition, with high spatial and spectral resolution, defines more accurate superficial thermal anomalies. The limits of this type of data are to be found respectively in the cost (Beaumont et al., 2014), the availability of data which led to use single images (Hedges et al., 1996; Diot et al., 2000) and the satellite low spatial resolution data (Yan et al., 2014).

Recently the integration of multi-source remote sensing tools improved the analysis of these environments. Silvestri and Omri (2008) adopted aerial photographs (recent and historical) and Ikonos data to recognize different types of surfaces and vegetation cover, identifying uncontrolled landfills at regional scale. Ishihara et al. (2002) used medium resolution sensors (Landsat-TM, ASTER) to monitor illegal solid waste dumping by assessment of NDVI (Normalized Difference Vegetation Index) and VSW (Vegetation-Soil-Water) spectral indexes. A combined use of Synthetic Aperture Radar (SAR) data and satellite optical data was applied to identify potential illegal landfill sites (Cadau et al., 2013), to measure capped area and open cell of controlled landfill and their changes (Ottavianelli, 2007). Still recently, aerial differential thermal imaging has been proposed to characterize the ground temperature distribution of two solid waste landfills (Merla et al., 2014).

In Italy, the application of remote sensing in polluted areas had an increase in the interest rate, in particular towards integrating optical and radar systems for landfill monitoring (Cadau et al., 2013). Geographical Information System (GIS) maps can be useful to narrow down suspicious locations of uncontrolled landfill sites (Biotto et al., 2009).

In this paper, a downscaling approach for temporal analysis by multi-source remote sensing data is proposed. Landsat and MIVIS, aerial photos and thematic maps are fused in a GIS for environmental analysis. The training area is located in the South East of Mt. Vesuvius, which is particularly affected by land transformations due to anthropic activities (quarries and landfills) and to the establishment of the national park.

2. Study area

The study area is located in the southern part of Mt. Vesuvius national park, at about 20 km from Naples, Italy (Fig. 1). In the last decades, this site hosted several anthropic activities due to lava extraction. The national park was established in 1995 (Italian law D.P.R. 5/6/95), and hosts diversified natural and geologic landscapes. The strong anthropic pressure is due to the high level of urbanization of the metropolitan area of Naples in its surroundings. Mt. Vesuvius is a stratovolcano which has been active for 25,000 years. It is part of the Campanian Comagmatic Province that belongs to the potassium-rich Italian belt. It reaches a height of 1281 m a.s.l. Its structure comprises the older volcano, the Mt. Somma, whose summit collapsed, creating a caldera, and the younger volcano, Vesuvius, which since then has re-grown inside this caldera and has formed a new cone. This volcano is one of the most studied because, although in a dormant phase at present, it is an extremely active volcano with persistent periods characterized by phreato-magmatic Plinian eruptions, producing large pyroclastic flows and lava effusions and Strombolian activity. The current shape of the volcano is the result of the alternation between explosive and effusive type eruptions.

In the study area volcanic activity products of last 400 years lay, in particular phono-tephrite lava flows of 1906, 1839 and 1754 (Belkin et al., 1993), while the main fall out products refer to the eruption of 1944. After the 1944 eruption, Mt. Vesuvius started a quiescent phase that induced several local populations to build and to establish activities, from farming to lava blocks extraction. These quarries are located all around the volcano (Santacroce and Sbrana, 2003) and in some cases they were used also as landfill after being abandoned. Most of the quarry activities have been closed since 1999. The study area holds one of the widest extraction zones with 4 landfills and minor quarries within a few kilometres. Cava Sari is a quarry that was recently converted to landfill, not far from centre of Terzigno municipality (Fig. 1). The area is a lava open-pit mine site with a depth of 47–62 m, it has a volume of 800,000 m^3, and its top area reach 35,000 m^2. It was adopted as landfill sites for the disposal of waste, and it was expected it would host more than 740,000 tons of municipal solid waste (MSW) (OPCM 289 31/12/2009). Its activity ended in 2012.

From a botanical point of view, Mt. Vesuvius has a typical Mediterranean–type vegetation (Di Gennaro, 2002), with pioneering vegetated species on the lava. In addition the volcanic soil allowed the establishment of specialized agriculture activities as fruit trees and wineyards.

3. Data and materials

In order to collect information on the study area, we adopted MIVIS (Multispectral Infrared and Visible Imaging Spectrometer)