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Integrated hierarchical geo-environmental survey strategy applied to the detection and investigation of an illegal landfill: A case study in the Campania Region (Southern Italy)

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ABSTRACT

This paper describes an approach to detect and investigate the main characteristics of a solid waste landfill through the integration of geological, geographical and geophysical methods. In particular, a multi-temporal analysis of the landfill morphological evolution was carried out using aerial and satellite photos, since there were no geological and geophysical data referring to the study area. Subsequently, a surface geophysical prospection was performed through geoelectric and geomagnetic methods. In particular, the combination of electrical resistivity, induced polarization and magnetic measurements removed some of the uncertainties, generally associated with a separate utilization of these techniques. This approach was successfully tested to support the Prosecutor Office of Salerno (S Italy) during a specific investigation about an illegal landfill. All the collected field data supported the reconstruction of the site-specific history, while the real quarry geometry and site geology were defined. Key elements of novelty of this method are the combination and the integration of different methodological approaches, as the parallel and combined use of satellite, aerial and in-situ collected data, that were validated in a real investigation and that revealed the effectiveness of this strategy.

1. Introduction

Government bodies and law enforcement agencies, that monitor and evaluate the risks or the damages associated to waste disposal, can benefit from new survey strategies (both methods and technologies). These can support the detection and identification of parameter anomalies related to a landfill site, especially if connected to its mismanagement or to alleged illegal activities. The environmental characterization of these "risk" areas is rather a popular issue in Italy. In fact, the Campania Region (Southern Italy) has one of the worst records of illegal waste dumping practices. This partly depends on the fact that, since 1980, waste management in this area has been characterized by a perduring crisis [1,2].

Investigation methods, that allow both the identification and the characterization of areas, which constitute a potential source of risk, are always important with respect to the protection of natural resources and for an appropriate spatial planning. Three different goals, which are consequential to each other, are defined for characterizing a landfill site: (1) The detection and identification of the real waste "body", being the main source of contamination; (2) The geometrical characterization of the source of contamination, in terms of lateral extent, depth of excavation and presence of contaminants leaking (plumes of contamination); (3) The characterization of the type of waste, with recognition of waste with a strong metallic component (e.g. tanks, blast-furnace slag), hypersaline fluids (e.g. leachate pockets), resistive waste materials, etc.

The present article describes a methodological approach to the detection, identification and characterization of a landfill site, characterized by lack of previously well-defined administrative references. Consequently, the site geometry must be defined, in terms of lateral extension and depth, on the basis of geophysical

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survey findings, combined together with the indications derived from a pure surface geology approach.

In the landfill areas, the use of direct and well-known methods of investigation, such as geognostic surveys, exploratory wells, etc., is not always applicable. This is essentially due to the many complications, that arise during the execution phases, such as possible damages to the geomembrane. At the same time, the realization of direct investigation involves high costs and time-scales, that are not always compatible with the concerned problems. Therefore, the application of indirect geophysical methods could be a viable alternative to the "traditional" intervention strategies, thanks to the possibility of obtaining three-dimensional models for the landfill body with reduced technology and operational costs and the absence of risks related to further damage to existing structures.

The presence of waste, as a type of "foreign body" in the subsoil, determines important variations of some chemical-physical parameters, which are detectable by geophysical methods. Among them, the most important ones are the electrical conductivity and the magnetic susceptibility. In general, a multiscale approach is of paramount importance to obtain appreciable results in terms of both the geometry of the landfill body and its own typical materials characterization. In this approach, remote sensing tools play a key role, representing the first step of such a process. Indeed, where the main potential sources of pollutants are remotely identified, the in-situ investigation can target the area of concern. There are several remote sensing techniques, already used in the environmental monitoring, which can be applied for our purpose. These include the fusion of optical and Synthetic Aperture Radar (SAR) data [3] as well as multispectral imagery, both used to monitor surface contamination of soil and water [4,5] and to detect illegal landfill dumping and other illegal activities [6–11]. The different outputs can be combined with other data layers in a GIS environment both to define the exposure of cultural sites and to predict environmental violations [12–15]. On the other side, also geophysical prospecting techniques were tested for forensic purposes [16–18].

The main objectives of this investigation were to accurately define the edges of the landfill, to assist in the planning of the site recovery and to provide information relating to landfill depth. Secondary objectives included the identification of potential pollution pathways from the landfill, associated with the lack of any engineered barrier, and the characterization of site geology.

The chosen study area (Fig. 1) is located in the municipality of Giffoni Valle Piana, Province of Salerno, in the Campania Region (Southern Italy). In particular, the study sub-triangular area has a base length of about 175 m and a width of about 70 m, while the total area is approximately 6000 m^2. This zone was selected considering the fact that, in recent years, the Rio Secco riverbed became an open-air garbage disposal. Consequently, local authorities were interested in verifying the existence of anomalies associable to possible dangerous pollutant releases. During the summer months, when the river is dry, all kinds of waste (e.g. tires, drums asbestos, construction/demolition materials, solid waste) are discarded there. On the other side, during the peak of the rain season, the waste materials are transported towards the valley, while contaminated materials pollute both the river and the ground water, increasing the risks connected to illegal landfill activities.

2. Materials, methods and case study area

2.1. Materials and methods

First, before the geophysical surveys, a multi-temporal analysis of the landfill was carried out. This analysis allows to deduce the main changes caused by the exploitation of the area used as a quarry. On the other side, it enables the comparison and calibration of the electrical and magnetic survey results.

Following, the in-situ measurement activity was performed, using two different approaches: (1) Electrical resistivity; (2) Magnetometry. 2D Electrical resistivity tomography (ERT) is the most applied non-invasive geophysical technique for monitoring abandoned landfills, to determine the risk of soil and ground water contamination and to generate information on leachate migration patterns [19–25]. Moreover, the combined use of direct current resistivity and time domain induced polarization has been successfully applied to landfill mapping and characterization, as it usually depicts the waste layer with a relatively high chargeable unit [26,27]. Magnetic surveys were mainly used by geologists either to locate lithological characteristics (depending on such ore bodies, fault contacts, igneous-intrusive rocks, . . .) or to determine the probable depth to basement beneath sedimentary rocks. Magnetometric technique is already applied for forensic purposes in search of buried magnetic material. In particular, it is

Fig. 1. Orthophoto image of the study area; the dotted lines delimit the landfill area.