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Photogrammetry for environmental monitoring: The use of drones and hydrological models for detection of soil contaminated by copper

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HIGHLIGHTS

- Soil sampling and analysis to investigate copper concentration is very expensive.
- A method aimed to increase the effectiveness of investigation is proposed.
- The method involves photogrammetry, hydrology and wetlands prediction indices.
- High resolution DEM (30 mm) has been generated.
- Prediction indices are able to detect areas of Cu accumulation at plot scale.

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ABSTRACT

Campania Region of Southern Italy has a complex environmental situation, due to geogenic and anthropogenic soil pollution. Some of the pollutants such as copper are mobilized in the organic matter. It has been shown that wetlands provide physical as well as biogeochemical barriers against pollutants. Therefore, the objective of this study was to introduce and test an innovative approach able to predict copper accumulation points at plot scales, using a combination of aerial photos, taken by drones, micro-rill network modelling and wetland prediction indices usually used at catchment scales. Data were collected from an area measuring 4500 m^2 in Trentola Ducenta locality of Caserta Province of southern Italy. The photos processing with a fifth generation software for photogrammetry resulted in a high resolution Digital Elevation Model (DEM), used to study micro-rill processes. The DEM was also used to test the ability of Topographic Index (TI) and the Clima-Topographic Index (CTI) to predict copper sedimentation points at plot scale (0.1–10 ha) by comparing the map of the predicted and the actual copper distribution in the field. The DEM obtained with a resolution of 30 mm showed a high potential for the study of micro-rill processes and TI and CTI indices were able to predict zones of copper accumulation at a plot scale.

1. Introduction

Currently, Campania Region, in South Italy, is facing one of the most critical environmental problems due to agricultural soil pollution by accidental contamination. Unfortunately, the overall situation is heterogeneous and complex. Between the years 1998 and 2008, six of the 55 National Interest Priority Site (NIPS) gazetted in Italy were located in Campania Region (Vito et al., 2009). Of the six NIPS, Domitian Coast Flegreo and Agro Aversano were selected as most important in Campania Region (Law no. 426 of 1998). In addition, the National Institute of Health has included these NIPS areas among the 44 Italian regions with high levels of cancer risk, due to the different and numerous pollutants found in soil such as heavy metals.

High concentrations of heavy metals in Campania Region are a result of a combination of geogenic pollution caused by natural phenomena, and anthropogenic pollution due to voluntary or accidental activities (Cicchella et al., 2005). Geogenic pollution is essentially linked to the processes of parent rock genesis that are extremely rich of metallic elements, due to volcanic activities and related events, such as hot springs and fumaroles (De Vivo et al., 1995). Anthropogenic pollution is mainly related to industrial activities, which produce high concentrations of cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni), and zinc (Zn) (Filippelli et al., 2012). Motor vehicle traffic also results in high concentrations of Cd, Cr, Cu, Ni, Pb, selenium (Se) and Zn in the areas near driveways (Albanese and Cicchella, 2012). Use of inorganic pesticides and chemical fertilizers could result in soil

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pollution by Cu, Hg, manganesium (Mn), Pb and Zn (Swaine, 1962). Other causes of soil pollution include point sources like gasoline pumps and illegal dumping of household waste (Lima et al., 2012). Nowadays, the mapping of geogenic pollutants in Campania Region is known and predictable (Albanese et al., 2007). However, it is still very difficult to predict the diffusion and distribution of anthropogenic contaminants.

Among anthropogenic pollutants, the copper has a significant importance in agronomy since it is an essential element, although in high concentrations has a strong toxic effect on plants and animals. Belonging to group 11 elements of the periodic table, its electronic level is incomplete; therefore, it is a very versatile ion that can interact chemically with the organic and mineral soil components. Due to its ability, it is not very mobile in the soil and, therefore, tends to accumulate in the superficial soil layers (Kabata-Pendians and Pendias, 2001). Mobility of copper in soil is essentially related to chelation by organic matter and adsorption processes, which is highly dependent on the pH of the soil. It has been demonstrated that 1 g of humic acids has the ability to chelate from 48 to 60 mg of copper (Stevenson and Ficht, 1981). For this reason, copper accumulates in the superficial soil layers.

Because their diffusion is “patchy”, it is really difficult to predict the extent and the location of pollutants. Current methods for determining distribution of pollutants require carrying out a characterization procedure involving analysis of a large set of organic and inorganic substances in each unit of homogeneous soil. These procedures are rather laborious and expensive. Typically, the characterization is carried on a grid of 10×10 m, resulting in 100 samples per ha. It is therefore extremely difficult and expensive to sample and characterize soil from the entire region with a sufficiently dense mesh. Another technique involves the use of imaging spectroscopy. It is utilized to identify spatial mineral patterns and to monitor temporal changes in contaminated river sediments (Buzzi et al., 2014).

Some landscape structures can be considered as physical or biogeochemical barriers against contaminants, when they are set between the source of polluted water and the receiving water body (Muscutt et al., 1993). Wetlands play a fundamental role, due to their structural characteristics, they are classified as area buffers. Wetlands fulfil this role through absorption of the pollutants by plants and dilution in the absence of significant nitrogen concentration and by denitrification processes (Montreuil, 2011). Infascelli et al. (2013) tested the efficiency of different topographical and hydrological indices suited to predict wetland distribution at the catchment scale. It is likely that similar approaches may be transferred to plot scales (Capolupo et al., 2014).

In particular, Topographic Index (TI) has widely been used for estimating the spatial distribution of soil moisture and runoff source areas (Chirico et al., 2003). In particular, it has been applied for studying spatial scale effects on hydrological processes (Sivapalan and Wood, 1987; Beven et al., 1988; Sivapalan et al., 1990; Famiglietti and Wood, 1991), for identifying flow paths (Robson et al., 1992), for characterizing biological processes (White and running, 1994), vegetation patterns (Moore et al., 1993) and forest site quality (Holmgren, 1994) and for predicting wetland distribution (Merot et al., 2003). This index is usually calculated from elevation data (Sörensen et al., 2006). Indeed, the digital terrain analysis produces an intermediate dataset that includes the spatial discretization of the terrain in elemental units, the connectivity among these elements and, terrain attributes (Chirico et al., 2005). Results of digital terrain analysis must be used in consequently terrain-based hydrological application (Chirico et al., 2005).

At plot scales, the calculation of the indices to describe the spatial distribution of soil moisture must be based on an extremely accurate and precise Digital Elevation Model (DEM) (Chirico et al., 2005). Several devices can be used to generate high precision DEM. A common example involves use of laser scanners (Khorashahi et al., 1987; Huang et al., 1988; Bertuzzi et al., 1990; Romenkens et al., 1986). It allows for improved resolution and accuracy of the resulting DEM, though it requires considerable amount of time for data collection and processing. However, Rieke-Zapp et al. (2001) proposed photogrammetric techniques to generate DEM. The accuracy and the resolution of DEM produced by photogrammetric techniques were similar to those obtained with the laser scanner, while time required for data collection reduced significantly.

The introduction of important innovations such as drones and fifth generation software for photogrammetry may significantly improve the results. Drones could allow for reduced flight quotas and to reach difficult-to-access areas; therefore, resulting in a drastic decrease in the time and costs of data acquisition and of the entire operation of monitoring (Nex and Remondino, 2014). It also makes it possible to obtain high resolution aerial photos at plot scale. The fifth generation software can process hundreds of digital images at the same time and to obtain their automatic restitution leading to a significant reduction in photo/image processing time (Pierrot-Deseilligny et al., 2011).

Natural phenomena characteristics vary considerably in space and time (West and Shlesinger, 1990), because of many interacting factors, some of which operate over large distances, other over long time periods. This variability contains both trend and random factors. Random component is a structural, scale-dependent element, for which, at least within a specific radius of influence, the spatial differences between the properties of the soil can be expressed, rather than in absolute terms, as a function of the distance of separation between the sampling points (Castrignanò and Stelluti, 1997). It follows, then, that temporal and spatial variability is strongly influenced by scale and variables of observation. Therefore, it is necessary to define the methods suited to estimate the values of the natural phenomenon properties being studied, where measured data are not available. So, no deterministic model can describe spatial variability because it is based on the application of an algorithm defined a priori (Castrignanò et al., 2011). On the contrary, statistical models can assess and model spatial variation (Castrignanò et al., 2011). In particular, spatial relationships among data values can be quantified and processed by the modern statistical theory, based on the theory of regionalized variables (geostatistics) (Journel and Huijbregts, 1978; Goovaerts, 1987).

Areas with accumulated copper such as wetlands have been compared to sedimentation micro-basins. In the present study, the possibility of predicting the distribution of copper sedimentation/accumulation points at plot scale was explored. It is important to underline that the terms “accumulation” and “sedimentation” are used interchangeably to indicate the copper storage at a point, following a micro-runoff process. The method employed, considers different approaches, used in other context to determinate the distribution of wetlands at catchment scale. It involves application of drones, fifth generation software for photogrammetry, modelling of transport processes and geostatistics.

2. Study area

The study area is located in the municipality of Trentola Ducenta, in Caserta Province. It is at an altitude of 68 m above mean sea level and is one of 77 municipalities of the NIPS Litorale Domizio Flegreo and Agro Aversano. The experiment was conducted in an area measuring 4500 m^2 (Fig. 1), suspected of being contaminated with heavy metals and organic pollutants. Soil samples were taken from the site at regular mesh of 5×5 m, for a total of 170 points. For each point, the concentration of 15 elements was carried on all samples found to have traces of pollutants.

Analyses of soil samples were conducted by the Mass Spectrometry Laboratory of University of Naples Federico II, by applying the method EPA 6010C 2007. Each sample have been first reacted with nitric acid and has been made up to a final volume in a volumetric flask with a reagent water, and, then, analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES), that measures characteristic emission spectra using an optical spectrometry. Indeed, aerosol, resulting from a nebulisation process of the samples, is transported to the plasma torch, where a radio-frequency inductively coupled plasma produces a