Heavy Metal Soil Contamination Detection Using Geochemistry and Field Spectroradiometry

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Definition

Technological advances in hyperspectral remote sensing have been widely applied in heavy metal soil contamination studies, as they are able to provide assessments in a rapid and cost-effective way. The present work investigates the potential role of combining field and laboratory spectroradiometry with geochemical data of lead (Pb), zinc (Zn), copper (Cu) and cadmium (Cd) in quantifying and modelling heavy metal soil contamination (HMSC) for a floodplain site located in Wales, United Kingdom. The study objectives were to: (i) collect field- and lab-based spectra from contaminated soils by using ASD FieldSpec® 3, where the spectrum varies between 350 and 2500 nm; (ii) build field- and lab-based spectral libraries; (iii) conduct geochemical analyses of Pb, Zn, Cu and Cd using atomic absorption spectrometer; (iv) identify the specific spectral regions associated to the modelling of HMSC; and (v) develop and validate heavy metal prediction models (HMPM) for the aforementioned contaminants, by considering their spectral features and concentrations in the soil. Herein, the field- and lab-based spectral features derived from 85 soil samples were used successfully to develop two spectral libraries, which along with the concentrations of Pb, Zn, Cu and Cd were combined to build eight HMPMs using stepwise multiple linear regression. The results showed, for the first time, the feasibility to predict HMSC in a highly contaminated floodplain site by combining soil geochemistry analyses and field spectroradiometry. The generated models help for mapping heavy metal concentrations over a huge area by using space-borne hyperspectral sensors. The results further demonstrated the feasibility of combining geochemistry analyses with filed spectroradiometric data to generate models that can predict heavy metal concentrations.

1. Introduction

The United Kingdom (UK) Environment Agency has listed over 1300 former mining sites responsible for heavy metal contamination of both land and water [1][2]. River systems can become contaminated by metals, for example lead (Pb), zinc (Zn), cadmium (Cd) and copper (Cu) if their drain catchments are underlain by mineralised geologies. In the UK, peak base-metal mining activity occurred in the 18th and the 19th centuries, when there was little or no environmental legislation preventing the release of contaminated water and sediments into the water courses. Floods are involved directly as serious agents of contaminant dispersion [3][4][5], resulting in sedimentation on agricultural and residential lands, where contaminants may remain for 10s or 100s of years until they are remobilised via surface or river bank erosion. Contaminated floodplain soils and sediments pose a potential danger to human health, safety of agricultural products and may adversely affect the environment [2][6]. Considering the paramount importance of soil for food security and the increasing size of urbanisation, it is important to identify and manage metal contaminated sites [7][8][9]. Therefore, an understanding of the contamination risk is required, as well as the development of quick, feasible and affordable estimation methods [10][11][12][13]. Traditional techniques for evaluating metals contamination in the environment typically involve field-based soil/sediment sampling, wet chemical digestion and subsequent laboratory analysis, followed by interpolating outputs to create spatial risk maps [14][15][16]. However, such approaches are time-consuming and often very expensive [2][17][18][19]. Advances in hyperspectral remote sensing are increasingly being applied in metal soil contamination studies, providing a more rapid, cost-effective and spatially extensive way to map contamination [20][21][22][23][24]. The utility of hyperspectral imaging to map the distribution of heavy metals in mining regions has previously been demonstrated by several studies [25][26][27][28][29][30]. Soil properties and concentration of minerals can be determined using hyperspectral imaging techniques since these are able to provide spectrally-rich and spatially-continuous information that can be extended for mapping and monitoring of soil contamination. Reflectance spectroradiometry is relatively more cost-effective than traditional measurements based on chemistry [17][31][32][33][34]. Spectral signatures obtained from soil constituents are distinguished based on their reflectance in specific bands of the electromagnetic spectrum [35][36][37]. Visible (VIS, 350–800 nm), near infrared (NIR, 800–1350 nm) and shortwave infrared (SWIR, 1350–2500 nm) spectroradiometers are used largely in soil science, since they can be handled easily in the field.

After correct calibration, they can be used to estimate several soil properties such as total carbon and nitrogen, sand and clay contents, cation exchange capacity and pH (e.g., [38][39]). Schwartz et al. [40] summarises the application of VNIR reflectance for estimating the soil contamination, and Shi et al. [41] review the role of VNIR soil spectra for predicting concentration of heavy metals. This study aims at investigating the potential added value of field spectroradiometry when combined with geochemical analyses of Pb, Zn, Cu and Cd, to quantify and model heavy metal soil contamination (HMSC). The specific objectives are to: (i) collect field- and lab-based spectra from contaminated soils and build associated spectral libraries; (ii) identify the specific spectral intervals associated with the modelling of HMSC by performing statistical discrimination analyses; (iii) collect and geochemically analyse the soil samples; and (iv) develop and validate a heavy metal prediction model (HMPM) using soil metal concentration and spectral reflectance data. The study explores, for the first time, the potential of spectrally discriminating contaminant metals in floodplain soils, which has significant implications for the mapping and management of contaminated soils in mining-affected river catchments. The main research hypotheses were that: (i) soil spectra exhibit differences in specific wavelengths, which support their spectral discrimination; (ii) heavy metal concentrations can be retrieved from the spectra at high accuracy; and (iii) the samples with the highest heavy metal concentrations (high concentration of heavy metals means the colour of soil will be darker) would have the lowest reflectance (or the highest absorbance) and that reflectance would increase proportionally as heavy metal concentrations decreased.

2. Widespread Dispersal and Hazards of Heavy Metals in the UK

Even though metal mining activity ceased almost a century ago, many west-draining rivers influenced by the flooding of June 2012 registered high concentrations of heavy metals in flood sediments that exceeded national and European standards [2]. Macklin et al. [4], Dennis et al. [42] and Brewer et al. [43] pointed out that at the catchments where historical metal mining took place, massive floods can cause dispersion, overbank sedimentation of highly contaminated constituents. In particular, deposition of fine-grained metal contaminated sediment on floodplains can pose a serious potential risk to the vigour, organisation and resilience of ecosystem services. Previous studies in the Ystwyth valley brought to light that sheep has the capacity to ingest high concentrations of heavy metals per day (1685 mg of Pb, 486 mg of Zn and 60 mg Cu), especially from the green vegetation during the winter [44][45][46]. The extraction of Pb, Zn and Cu from Wales has a long history, linked back to the Roman period or the Bronze Age in some regions. Generally, Pb and Zn mining peaked in the mid-19th century, with most mining operations closed by the beginning of the 20th century [22][47][48][49][50]. Many European researches have reported that offal can hold an elevated concentration of metals. Rodríguez-Estival, Barasona, and Mateo [51] unexpectedly discovered that 91.4% of cattle and 13.5% of sheep had high blood Pb concentrations related to a subclinical vulnerability, and two cattle had blood Pb concentrations expressive of clinical poisoning. The previous studies are related directly with results from West Wales and presented the detailed risks of floodplain contamination from bovine species, which are found to be very vulnerable to Pb poisoning, especially young animals [52][53]. Furthermore, when the produced meat of the poisoned animals reaches the food chain, human health will be in danger. The problem of soil contamination by heavy metals in , and of course many other areas of the UK, will increase as a result of floods that happened in the past century. Therefore, innovative monitoring techniques, such as hyperspectral remote sensing, are highly recommended to characterise qualitatively and quantitatively the heavy metal contamination and investigate the short-term solutions, to protect the ecosystem services at large and human health specifically [2][28].

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Keywords

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