Geoderma 241–242 (2015) 180–209

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Potential of integrated field spectroscopy and spatial analysis for enhanced assessment of soil contamination: A prospective review

A. Horta *, B. Malone, U. Stockmann, B. Minasny, T.F.A. Bishop, A.B. McBratney, R. Pallasser, L. Pozza

Department of Environmental Sciences, The University of Sydney, New South Wales 2006, Australia

ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form 20 November 2014
Accepted 25 November 2014
Available online 3 December 2014

Keywords:
Proximal sensing
Spatial statistics
Field spectroscopy
Soil contamination

ABSTRACT

There are tens of millions of contaminated soil sites in the world, and with an increasing population and associated risk there is a growing pressure to remediate them. A barrier to remediation is the lack of cost-effective approaches to assessment. Soil contaminants include a wide range of natural and synthetic metallic and organic compounds and minerals thus making analytical costs potentially very large. Further, soil contaminants show a large degree of spatial variation which increases the burden on sampling costs. This paper reviews potentially cost-effective methods for measurement, sampling design, and assessment. Current tiered investigation approaches and sampling strategies can be improved by using new technologies such as proximal sensing. Design of sampling can be aided by on-the-go proximal soil sensing; and expedited by subsequent adaptive spatially optimal sampling and prediction procedures enabled by field spectroscopic methods and advanced geostatistics. Field deployment of portable Visible & Near Infrared [wavelength 400–2500 nm] (Vis-NIR) and X-ray fluorescence (PXRF) spectroscopies will require special calibration approaches but show huge potential for synergistic use. The use of mid-infrared spectroscopy [wavelength 2500–25,000 nm, wavenumber 4000–400 cm^{-1}] (MIR) for field implementation requires further adaptive research. We propose an integrated field-deployable methodology as a basis for further developments.

Crown Copyright © 2014 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

Contents

1. Introduction . . . 181
2. Soil contamination assessment . . . 183
   2.1. Soil contaminants and sources of contamination . . . 183
   2.2. Contaminated site characterisation — current approach . . . 183
   2.3. Sampling for contamination assessment . . . 183
3. Infrared spectroscopy for measuring soil contaminants . . . 184
   3.1. Heavy metals . . . 185
      3.1.1. Studies on contaminated sites . . . 186
      3.1.2. Geochemical studies . . . 186
   3.2. Organic contaminants . . . 186
   3.3. Other applications . . . 190
4. PXRF for measuring soil contaminants . . . 191
5. Taking IR and PXRF to the field and the role of spectral libraries . . . 194
6. Spatial analysis for sampling, predicting and mapping contamination . . . 195
7. Prospective methodology for soil contamination assessment supported by field spectroscopy and advanced spatial analysis . . . 202
   7.1. The synergistic use of Vis-IR and PXRF — data fusion . . . 202
   7.2. In-field soil inference engine . . . 203
   7.3. Spatial analysis — adaptive sampling and mapping . . . 204

* Corresponding author at: Faculty of Agriculture and Environment, Biomedical Building, 1 Central Avenue, Australian Technology Park, Eveleigh, NSW 2015, Australia.
E-mail address: ana.seixashorta@sydney.edu.au (A. Horta).

http://dx.doi.org/10.1016/j.geoderma.2014.11.024
0016-7061/Crown Copyright © 2014 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

8. Conclusions . . . 205
Acknowledgments . . . 205
References . . . 205

1. Introduction

Mining, urbanisation, and agricultural and industrial processes have resulted in the contamination on the order of 10^7 sites[1] across the globe with contami'nants such as heavy metals and organics. The European Union has 342,000 contaminated and 2.5 million potentially contaminated sites (Panagos et al., 2013). One of the leading European countries for developing legislation for soil quality assessment and protection, The Netherlands, has 265,000 sites potentially contaminated; from those, 11,000 sites are actually in need of urgent remedial action (Ministry of Housing, Spatial Planning and the Environment, 2010). Typical soil contaminants in Europe include Total Petroleum Hydrocarbons (TPH) and heavy metals which contribute to 60% of soil contamination. About 160,000 contaminated sites potentially exist across Australia (State of the Environment Committee, 2011). Sites impacted by TPH represent a significant proportion of Australia's contaminated land (Clements et al., 2009). In the United States, 1200 sites are on the National Priority List (NPL) for the treatment of contaminated soils, indicating the extensiveness of this problem (Mulligan et al., 2001). Approximately 63% of the sites on the NPL include contamination from toxic heavy metals.

Given the pressure on soil for food security and growing urbanisation, the identification and remediation of contaminated sites is of increasing importance (Liu et al., 2013; Chen, 2007; Luo et al., 2012; Cai et al., 2008). Many of these contaminated sites are now becoming attractive as high value commercial and residential land but health and environmental risks are at stake. However, remediation rates are quite modest, e.g. in 33 European countries where 127,000 sites have been recognised as contaminated and 1.17 million are potentially contaminated, only 58,000 (5%) have undergone some kind of remediation (Panagos et al., 2013). In Australia, the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment estimates that Australian companies only clean up roughly 1000 sites each year, i.e. 0.5% per annum, which may be not much better than maintaining a steady-state situation in terms of overall numbers, i.e. cleaning up sites as fast as newly contaminated sites are created and/or identified. Estimated clean-up costs are of the order of $2 billion per year, with the total remediation cost being much larger (State of the Environment Committee, 2011). Additional sites continue to be identified, as contamination is often not apparent until a site is prepared for sale or redevelopment or the land use changes (NSW EPA, 2013).

Worldwide, national and other jurisdictional protocols have been devised for contaminated site assessment, establishing decision-support systems to evaluate the need for remediation. Most legal frameworks propose decision models based on risks to human health, the soil ecosystem and food safety. Risk evaluation is site-specific and dependent on future land management. Regardless of the soil protection target, decisions are supported by a tiered site characterisation whereby a site undergoes a preliminary investigation followed by more intensive investigations in stages. This approach allows data from each stage to be assessed and fed into planning the next stage of investigation. In each progressive tier, the assessment becomes less conservative, is based on more site-specific information and, hence, is more complex, time-consuming and often more expensive (Clements et al., 2009; Ministry of Housing, Spatial Planning and the Environment, 2010).

Remediation processes are expensive and rely on estimates of the amount of contaminated soil which needs be removed and the type of contaminant (Mulligan et al., 2001; Lewandowski et al., 2006; Schultz, 1997). Therefore, accurate estimates of the spatial distribution of contaminants are essential (Markus and McBratney, 2001; Motelay-Massei et al., 2004; Imperato et al., 2003). In practice, the evaluation of the extent and source of site contamination requires soil sampling and further laboratory analysis to gather information about the type and degree of contamination (Cattle et al., 2002). Sampling at an individual location along with associated laboratory analytical costs can be as much as 1000 AUD (depending on the type of contamination), and some replications of samples may be needed to define the contamination, and even then this may be not be entirely accurate. In Europe, costs for site investigations generally are between €5000 to €50,000 and costs for remediation projects usually fall in the range of €50000 to €500,000 (Van Liedekerke et al., 2014).

Legislation in The Netherlands, Australia and the United States advocates where possible the use of formal probabilistic sampling schemes (e.g. simple random, stratified random) for contaminated site assessments. These types of sampling design support an unbiased decision about whether contamination levels exceed a threshold of unacceptable risk which helps to identify the location of "hot spots" or plume delineation and to characterise the nature and extent of contamination at a site (US EPA, 2002). Often choosing the most resource-effective design is a trade-off between performance and cost that accounts for practical issues such as schedule and budget risks and health and safety risks. It is important that the necessary data are available to enable a statistical analysis to inform the decision of whether or not the site presents an unacceptable risk to human health or the environment, and is suitable for the intended future land use.

Contamination thresholds exist for a wide range of pollutants (heavy metals and organics) (Ferguson, 1999; Regan et al., 2002) and these determine whether the location from which it emanates requires remediation. This location can refer to an established volume of soil or a determined exposure area depending on the criteria defined in the decision model. Normally, decisions are made based on the mean or maximum concentration measured for a certain volume or area of contaminated soil. In the case of the mean, a 95% confidence interval is computed to determine if this concentration exceeds or is below the threshold. The more samples taken the more precise will be the estimates of the mean. These practical requirements make soil contamination assessments expensive, time-consuming and, as a result, often based on inadequate field data.

However, it is necessary to generalise the results to unsampled locations and to define homogeneous contamination zones (along with an estimate of the associated uncertainty) across the site being assessed (Gilbert, 1987; Bierkens, 1997). Geostatistical techniques can be used in a geographic information system (GIS) to provide information on the spatial distribution of contamination (Burrough, 2001).

In summary, there is room to optimise current decision-based models for soil contamination assessment namely by improving the quality and quantity of information provided in the preliminary investigation stages. The current situation with respect to measurement and delineation motivates a range of questions which will be addressed in this review.

There is a way forward; increasing advances in electronics, information technology, and spatial statistics can contribute significantly.

[1] An estimate may be obtained as follows: if we assume that developed economies have 0.005 contaminated and potentially contaminated sites per capita [Panagos et al., 2013 report 0.00502 sites per capita for the European Union] and a population of 1 billion, emerging economies have 0.0025 contaminated sites and potentially contaminated per capita and a population of 2 billion, developing economies have 0.001 contaminated sites and potentially contaminated per capita and a population of 4 billion, we get a total of 14 M. Given uncertainty this is probably between 10 M and 20 M.

Download English Version:

https://daneshyari.com/en/article/6408603

Download Persian Version:

https://daneshyari.com/article/6408603

Daneshyari.com