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Upscaling the use of fallout radionuclides in soil erosion and sediment budget investigations: Addressing the challenge

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Abstract

The application of fallout radionuclides in soil erosion investigations and related sediment budget studies has provided a widely used tool for improving understanding of soil erosion and sediment transfer processes. However, most studies using fallout radionuclides undertaken to date have focussed on small areas. This focus on small areas reflects both the issues addressed and practical constraints associated with sample collection and analysis. Increasing acceptance of the important role of fine sediment in degrading aquatic habitats and in the transfer and fate of nutrients and contaminants within terrestrial and fluvial systems has emphasised the need to consider larger areas and the catchment or regional scale. The need to upscale existing approaches to the use of fallout radionuclides to larger areas represents an important challenge. This contribution provides a brief review of existing and potential approaches to upscaling the use of fallout radionuclides and presents two examples where such approaches have been successfully applied. These involve a national scale assessment of soil erosion rates in England and Wales based on ^{137}Cs measurements and an investigation of the sediment budgets of three small/intermediate-size catchments in southern Italy.

Key Words: Fallout radionuclides, Caesium-137, Soil erosion, Soil redistribution, Upscaling, Catchment-scale, National scale, Sediment budget

1 Introduction

The potential for using fallout radionuclides to provide information on rates and patterns of soil loss and soil redistribution has now been clearly demonstrated by a wide range of investigations undertaken in many different areas of the world (e.g. IAEA, 2011, 2014; Zapata and Nguyen, 2010; Matisoff and Whiting, 2012; Walling, 2012). The key principle involved is that the fallout reaching the soil surface is rapidly and strongly adsorbed by the surface soil and its subsequent redistribution by erosion processes directly reflects the intensity and spatial distribution of those processes. Most work has focussed on the use of caesium-137 (^{137}Cs), a man-made fallout radionuclide associated with the testing of atomic weapons in the 1950s and early 1960s (see Walling, 1998; Zapata, 2002). Since most of the ^{137}Cs fallout occurred during the period extending from the late 1950s to the early 1970s, this radionuclide now affords a valuable means of documenting soil redistribution over the past ca. 50 years. Particular advantages of the approach include, firstly, the ability to obtain retrospective data on the basis of a single site visit and without the need to install permanent monitoring equipment and structures; secondly, the ability to integrate the impact of all processes resulting in soil redistribution; thirdly, the spatially distributed nature of the data; and fourthly, provision of time-integrated average rates of soil redistribution (see Walling and Quine, 1995; Mabit et al., 2008). The ability to generate spatially distributed data has coincided with a need for such data for validating physically-based distributed soil erosion models (e.g. de Roo and Walling, 1994; He and Walling, 2003; Norouzi Banis et al., 2004). An additional input of Chernobyl-derived ^{137}Cs fallout

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in some areas of Europe and adjacent regions provided further opportunities to exploit the approach for the period since 1986 (e.g. Golosov, 2002). Ongoing developments in using and interpreting ^{137}Cs measurements have also made it possible to document the impact of changing landuse, such as a shift from conventional to minimum-till management practices, on soil redistribution rates (see Schuller et al., 2007). Porto et al. (2014) have also demonstrated the potential for using repeat ^{137}Cs measurements to obtain information on two or more periods of time within the overall time window covered by ^{137}Cs measurements.

Attention has also been directed to the use of other fallout radionuclides. Some of these, including Plutonium-239 and 240 ($^{239\text{-}240}$Pu) (e.g. Tims et al., 2010; Alewell et al., 2014), are also the product of the same bomb tests that caused the fallout of ^{137}Cs, but others are natural geogenic or cosmogenic fallout radionuclies, including excess lead-210 (^{210}Pb$_{ex}$) and beryllium-7 (^{7}Be) (see Mabit et al., 2008). Plutonium-239 and 240 have much longer half-lives than ^{137}Cs, which means that it will be possible to use them further into the future, particularly in regions such as Australia where the global pattern of bomb fallout resulted in low fallout inputs. Use of the natural fallout radionuclides ^{210}Pb$_{ex}$ and ^{7}Be makes it possible to derive information relating to time windows different from than that associated with ^{137}Cs. Excess lead-210 provides the potential to extend the length of the period considered to ca. 100 years (Walling and He, 1999a; Mabit et al., 2014), whereas ^{7}Be can be used to document soil redistribution associated with individual events or short periods of heavy rainfall and therefore timescales of days to weeks (see Mabit et al., 2008; Walling et al., 2009; Walling, 2013). Conjunctive use of several fallout radionuclides in a single study can potentially provide information on the erosional history of a site, by providing information for different time windows (e.g. Benmansour et al., 2012).

There has recently been some questioning of the reliability of soil redistribution rates derived from fallout radionuclide measurements (Parsons and Foster, 2011), but this would appear to ignore the rapidly growing number of studies that have provided empirical validation of the approach (e.g. Porto et al., 2003a; Belyaev et al., 2008). Furthermore, Mabit et al. (2013) have provided a response to many of the specific criticisms. It is also important to recognise that all other techniques employed to document soil redistribution possess important inherent limitations (Loughran, 1990) and that fallout radionuclides can offer important and essentially unique advantages over other techniques.

To date, most work in applying fallout radionuclides in soil erosion investigations has focussed on relatively small areas, such as individual fields, although there have been some attempts to investigate larger areas (e.g. Loughran et al., 1996; Mabit et al., 2007). In these small-scale studies, relatively large numbers of samples are collected from a field, commonly using a grid or transect sampling strategy, and the resulting point estimates of soil redistribution rate are used to establish the gross and net erosion rate for the field or study area. This focus on small areas has been largely a response to practical constraints associated with collecting and analysing large numbers of samples. Sampling commonly involves collection of one or more bulk cores from individual sampling points and this can prove labour intensive. However, the processing and radiometric analysis of the resulting cores for radionuclide activity by gamma spectrometry can represent an even greater constraint in terms of both the cost and time involved when dealing with large numbers of samples. Count times for an individual sample are generally of the order of 12-24 hours and this will be directly reflected by sample throughput and the cost of analyses. The resulting emphasis on individual fields or small areas can be seen as appropriate for addressing concerns related to on-site impacts of soil loss and soil redistribution and associated issue of soil degradation and reduced productivity, since it provides site-specific data. However, this small scale focus can be seen as less appropriate for addressing other issues.

The need to also consider the offsite impacts of soil erosion linked to the important role of the mobilised sediment in degrading aquatic ecosystems and in the transfer and fate of nutrients and contaminants in terrestrial and fluvial systems is being increasingly recognised (Waters, 1995; Wood and Armitage, 1997; Warren et al., 2003; Owens et al., 2005; Kemp et al., 2011). This necessarily directs attention to net, rather than gross soil loss, to the transfer of sediment from individual fields to streams, and to the wider landscape rather than the field. As emphasised by Walling and Collins (2008) and Gellis and Walling (2001), the catchment sediment budget is increasingly seen as a key tool for providing the understanding of the behaviour and fate of sediment across larger areas required for the design of effective sediment control strategies. It directs attention to the mobilisation transfer and storage of sediment within the catchment and the relationship between the sediment output and internal sources and sinks. Fallout radionuclides can provide an invaluable and essentially unique source of information on rates of soil loss associated with sheet and rill erosion and the subsequent redistribution and

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