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Caesium-137 in Southeast Asia: Is there enough left for soil erosion and sediment redistribution studies?

Takahisa Furuichi [a,*], Robert J. Wasson [b]

[a] Center for Southeast Asian Studies, Kyoto University, 46 Shimoadachi-cho, Yoshida, Sakyo-ku, Kyoto 606-8501, Japan
[b] Asia Research Institute, National University of Singapore, Bukit Timah Campus, 468A Tower Block, #10-01, Bukit Timah Road, Singapore 259770, Singapore

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ABSTRACT

Low reference inventories of the fallout radionuclide ^{137}Cs in low latitudes may limit its present and future application for studies of soil erosion and sediment redistribution in Southeast Asia. ^{137}Cs reference inventories and concentrations in surface materials measured in nine and five areas, respectively, across Southeast Asia are here reported and reviewed. The compiled reference inventories decrease from north to south. Three global estimates of ^{137}Cs total fallout are also reviewed and compared to the measured data while taking into account factors that affect the fallout estimates and the reference inventory. The results are presented as a schematic regional distribution map of ^{137}Cs reference inventories for the year 2012. A relationship between a reference inventory and topsoil concentration is also provided. The measured ^{137}Cs concentrations suggest that a minimum detectable activity (MDA) less than 0.5 Bq/kg is required for detection of ^{137}Cs activity in topsoils in the lowest reference inventory areas. This sensitivity should allow, at present, ^{137}Cs to be a useful tool for analysis of soil erosion in Southeast Asia, should also be a useful chronometer, and will be a useful tracer at least where the reference inventory is more than 500–600 Bq/m^2. This level of MDA has been demonstrated in previous studies to be achievable by gamma-ray spectrometry using non-destructive sample treatment. As the nuclide decays, sufficient will remain to be useful until the middle of this century in most areas in Peninsular Malaysia and southern maritime Southeast Asia, and a few decades more in the rest of the region.

1. Introduction

Radioactive ^{137}C has been widely used as a tracer and chronometer in studies of soil erosion and sediment redistribution, particularly in middle latitude regions. The key characteristics of the nuclide for these studies are as follows. First, its origin is known and is solely anthropogenic, a result of atmospheric nuclear testing mostly during the 1950s and 1960s, providing a necessary condition for a chronometer in the analysis of sedimentation (Pennington et al., 1973; Ritchie and McHenry, 1990; Leslie and Hancock, 2008). Second, after fallout onto Earth's surface, the radionuclide is adsorbed especially on clays and colloids within the soil and accumulates in topsoils, making it a tracer of topsoil redistribution (Burch et al., 1988; Wallbrink and Murray, 1993). Comparison of nuclide concentrations in catchment soils and river sediments allows estimates of the proportionate contributions of topsoil to river suspended loads (Walling and Woodward, 1992; Collins et al., 1997). Third, the total amount of ^{137}Cs deposited in an area (hereinafter referred to as a 'reference inventory') can be quantified and a deficit or excess of the nuclide relative to a reference inventory allows estimates of net soil erosion and deposition, respectively (Kachanoski and De Jong, 1984; Loughran, 1989).

The radionuclide in low latitude regions may have significant potential for examination of soil erosion and sediment redistribution, which are contemporary environmental concerns (e.g. Walling, 2011). However, ^{137}Cs distribution is not uniform on Earth (Walling, 1998) and low deposition in low latitude regions compared to middle latitude regions may limit its use. IAEA-Garcia Agudo (1998) presented estimates for 1996 of the global distribution of ^{137}Cs deposition based on global deposition of ^{90}Sr (UNSCEAR, 1969) and concluded that some areas located near the equator, including Southeast Asia, should have enough ^{137}Cs in the soil for erosion studies. Walling and He (2000) depicted the global pattern of ^{137}Cs deposition using updated data and analysis provided by Larsen (1985) for ^{90}Sr and Cambray et al. (1989) for ^{137}Cs, although the potential for application to soil erosion and sediment redistribution studies based on the pattern was not indicated. Aoyama et al. (2006) estimated ^{137}Cs fallout in 10° × 10° cells from global measurements of ^{137}Cs in rain, seawater and soil; however, the feasibility of the use of the nuclide was not in the scope of the study. A key test of the idea that low deposition in low latitude regions

* Corresponding author. Present address: Department of Science, IT, Innovation and Arts, 41 Boggo Road, Dutton Park, QLD 4102, Australia. Tel.: +61 7 3170 5692; fax: +61 7 3170 5801.
E-mail address: Taka.Furuichi@science.dsitia.qld.gov.au (T. Furuichi).

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limits use is to evaluate concentrations of the nuclide in surface materials (i.e. hillslope topsoils and river sediments) and see if the quantity is sufficient for analysis of soil erosion and sediment redistribution. For this, the method of nuclide measurement must be considered.

In this study, ^{137}Cs reference inventories and concentrations in surface materials in several areas in Southeast Asia are measured and synthesized with additions from published data, and these results are compared with global estimates of fallout patterns. Based on the measured and estimated data, a schematic regional distribution of ^{137}Cs reference inventories is presented. Also, relationships between a reference inventory and concentration in topsoils are assessed. Then, the required detection level of activity and its technical feasibility are evaluated, and finally the potential of the nuclide for studies of soil erosion and sediment redistribution in Southeast Asia is discussed.

2. Methods

2.1. Data

Four sources of ^{137}Cs data have been used: (1) unpublished measurements produced by the authors (except east Java) of the radionuclide in soils and sediments (a reference inventory with the unit of Bq/m^2 and concentration in surface materials with the unit of Bq/kg) at five areas in Southeast Asia, and referred to hereafter as 'the unpublished measured data'; (2) published data of ^{137}Cs reference inventory in Southeast Asia, which are reported in previous studies and referred to hereafter as 'the published measured data'; (3) an estimate of latitudinal global fallout of the radionuclide based on ^{90}Sr fallout reported by UNSCEAR (2000); and (4) global estimates of the nuclide fallout with geographical (i.e. latitude and longitude) patterns presented in three previous studies. Locations of the unpublished and published measured data are shown in Fig. 1.

2.2. Sample collection

We measured ^{137}Cs reference inventories and concentrations in surface materials in Shan State (Taunggyi), Myanmar, located 97°E, 20.5°N with an annual rainfall of ca. 1500 mm, and Sarawak (Belaga), Malaysia, located 113.5°E, 2.5°N with an annual rainfall of >4000 mm. Sampling sites for the reference inventory measurement were on gently sloping (0–2°) mountain ridges under secondary forests. Nuclide concentrations in surface materials were also measured in west Java (the Cimanuk River catchment), Indonesia, located approximately 107.5–108.5°E, 6.5–7.5°S with 2200 mm annual rainfall, and Timor Leste (the Laclo River catchments), located approximately 125.5–126.0°E, 8.5–9.0°S with an annual rainfall ranging from <1000 mm on the north coast to >2500 mm in the high mountains. Samples for the reference inventory measurement were collected to 30 cm depth using a sampling ring. For collection of hillslope topsoils, one sample from a site consisted of typically six to ten sub-samples of ~50 g each from the top centimeter of soil, collected from an area of 2000 to 5000 m^2 using a plastic shovel and a sampling ring. For river sediments a sample consists of 20–50 sub-samples (20–50 g/sub-sample) of fine surface sediment veneers on channel beds and banks, collected using a plastic shovel in reaches up to five times the channel width to enhance representativeness. The numbers of samples collected are: in Shan State, one set of samples from eight different depths of a soil profile for the reference inventory, eleven from hillslope forest topsoils, eleven from hillslope cropland topsoils, 48 from river sediments; in Sarawak, one set of samples from eight different depths of a soil profile for the reference inventory, 14 from river sediments; in west Java: two from hillslope sediments and four from river sediments; and in Timor Leste, 20 from hillslope topsoils and 20 from river sediments.

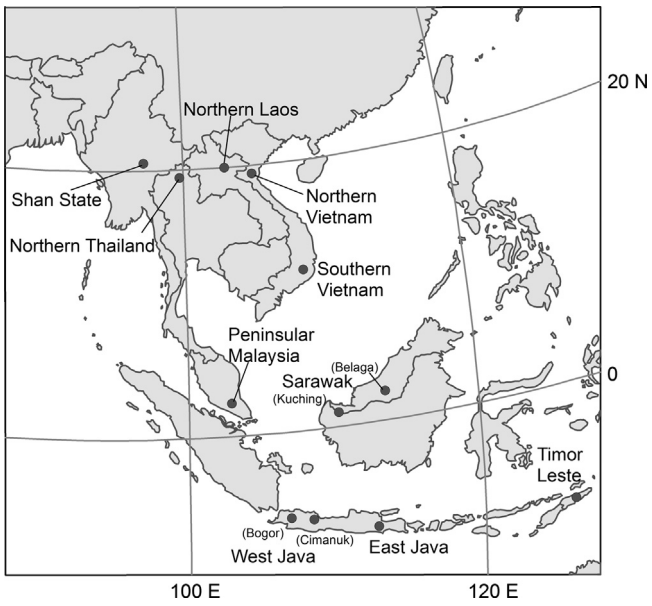

Fig. 1. Locations of the unpublished and published measured data of ^{137}Cs total inventory in soil profiles and ^{137}Cs concentration in surface materials.

2.3. Gamma-ray spectrometry

We used gamma-ray spectrometry using non-destructive (i.e. bulk or sieved) samples that have a significant advantage in simple processing in the laboratory. Although, for instance, a chemical preparation to remove ^{40}K from the AMP/Cs compound using chloroplatinic that reduces the background from ^{40}K has been applied for measurement of low level ^{137}Cs concentrations in sea water (Aoyama and Hirose, 2008), application of the method to soil and sediment samples has not been fully explored as sufficient mass of a sample can normally be collected and prepared. Also, for this reason, gas-flow proportional counting of beta particles (e.g. Wang et al., 1998) has seldom been employed in studies of soil erosion and sediment redistribution.

For quantifying the reference inventory in Shan State and Sarawak, bulk materials were used. For hillslope topsoils and river sediments, fine fractions extracted by wet-sieving were used, unless stated otherwise. Fine fractions are <63 μm for Shan State and Sarawak samples, <10 μm for west Jawa samples and <20 μm for Timor Leste samples. The choice of different size fractions is the result of separate research objectives in each area. The bulk or wet-sieved samples were dried at 50 °C for 72 h, then milled to disaggregate them. After that, the samples were dried again at 105 °C for 24 h and subsequently ashed at 450 °C for 48 h. The samples were pressed and sealed in plastic containers of a suitable size according to the sample mass.

Nuclide activity was determined by high resolution gamma-ray spectrometry at four laboratories: CSIRO Land and Water, Canberra, Australia (CSIRO-LW) for Shan State and west Java samples, the Department of Integrative Environmental Science, University of Tsukuba, Japan (DIES-UT) for Sarawak samples, the Low Level Radioactivity Laboratory, Kanazawa University, Nomi, Japan, (LLRL-KU) for Sarawak samples, and Environmental Research Institute of Supervising Scientist, Australian Government Department of Sustainability, Environment, Water, Population and Communities, Darwin, Australia (ERISS-DSEWPaC) for Timor Leste samples. The specifications of the gamma-ray detectors are summarized in