

Quantitative assessment of soil erosion and deposition rates by ^{137}Cs measurements

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Scope

Quantifying soil erosion and soil deposition processes is often important in understanding their dimensions in semi-arid environments and in identifying land management methods to reduce their effects, for example, the siltation of small reservoirs. The ^{137}Cs method is an innovative means of measuring the amount of sediment eroded from fields, redistributed downstream, and accumulated in dam reservoirs. This radionuclide tracer technique provides information about mid-term erosion rates over approximately 40-50 years.

Target group

Soil scientists, environmental chemists, ecologists

Requirements for application

- Sampling equipment: undisturbed soil sampler, e.g. Split Tube Sampler from Eijkelkamp or a simple scraper plate, which can be produced locally at low-cost (for details see Loughran et al., 2002).
- Soil laboratory facilities to process samples for bulk density determination and analysis of radionuclide ^{137}Cs concentrations in the sediment (for the latter a specific Isotope-laboratory is needed).
- Computer facilities and software: Application of conversion models to convert ^{137}Cs inventories into soil redistribution rates.

Description and application of the tool

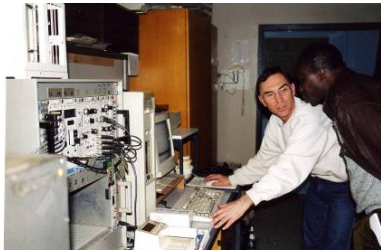
The isotope ^{137}Cs was produced by radio-nuclear weapon testing during the 60s, where ^{137}Cs was distributed globally with the stratosphere and deposited worldwide as radionuclide fallout. The element ^{137}Cs is not produced naturally and has a half life of 30.17 years, which indicates that today approximately 30-40% of the original radionuclide fallout still remains in the soil (Walling and Quine, 1993). By measuring the amount of ^{137}Cs in the soil, sediment redistribution patterns can be determined and soil erosion/deposition rates for specific fields, hillslopes or small reservoirs can be calculated. The method was found to be valid for Africa even though ^{137}Cs concentration in the soil is relatively low due to the distance from the source and the time elapsed since the last radionuclide fallout. A wide range of environmental studies have shown that the ^{137}Cs inventory in the soil is still significant and hence adequate to quantify sediment movement (Collins et al. 2001; Desta, 2005; Faleh et al., 2005; Rucker et al., 2008).

The first step in the ^{137}Cs approach is to select adequate, undisturbed reference sites near the study area where neither erosion nor sedimentation have taken place. Reference sites should be flat, should not have been cultivated during the last 50 years and preferably should be covered by grassland. From these reference sites, representative undisturbed ^{137}Cs samples are taken (Picture 1) at depth intervals (e.g. 5 cm increments) in order to establish a depth profile of the ^{137}Cs distribution in the soil. The ^{137}Cs inventory value is used as the reference value for the specific region to be sampled. The ^{137}Cs depth profile helps to define the depth at which ^{137}Cs continues to be found in the soil and, therefore, the required depth for soil samples taken for the purpose of capturing the total amount of ^{137}Cs (Figure 1).

The sampling strategy and the sampling design depend on the scope of the study (e.g. hillslope sampling, reservoir sampling or integrated catchment studies) and the environmental conditions (e.g. flat terrain, complex morphology, land use conditions) and should be adjusted to required needs (Pennock and Appleby, 2002).



Picture 1 Undisturbed soil sample



Picture 2 Processing of soil samples by a HPGe detector in the Isotope laboratory

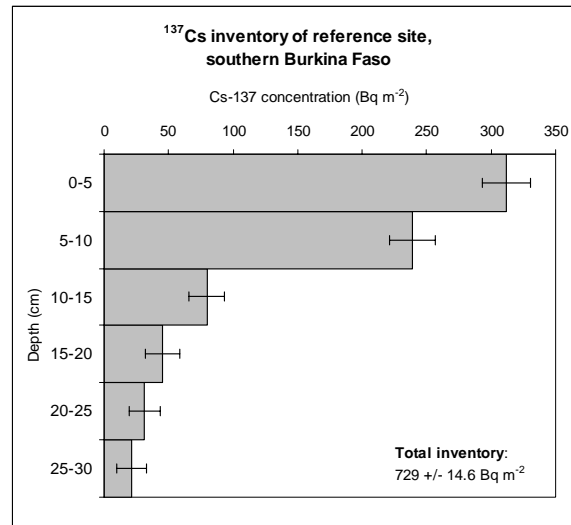


Figure 1 Depth profile of ^{137}Cs inventory

For laboratory analysis, all samples are oven dried at 105°C, sieved (2-mm mesh sieve) and weighed. Bulk density can be calculated as the ratio of dry mass to volume. The radioactivity of ^{137}Cs in the soil samples can be measured by a HPGe detector in an isotope laboratory (Picture 2). Dependent from the degree of ^{137}Cs concentration in the soil, the measuring time varies from 25.000 sec to 250.000 sec per sample until a measuring error below 10% is reached. In order to calculate the total amount of ^{137}Cs per unit area, the ^{137}Cs concentrations (Bq kg⁻¹) are converted into areal activity (Bq m⁻²) by using the equation of Sutherland (1994):

$$^{137}\text{Cs inventory} = \sum_{i=1}^n C_i \times BD_i \times DI_i \times 1000$$

where ^{137}Cs inventory = total area inventory (Bq m⁻²), i = sampling depth, n = maximum number of sample depth with detectable ^{137}Cs , C_i = activity concentration per unit mass (Bq

kg^{-1}) for depth i , BD_i = dry bulk density (Mg m^{-3}) for depth i , and D_i = depth increment (m) for sample i (Sutherland, 1994, p.61-62).

In order to convert ^{137}Cs inventories into soil redistribution rates (t ha^{-1}), conversion models such as the proportional models or the mass-balance models 1, 2 or 3 can be used (Walling and He, 2001; Walling et al., 2002). In a comparative approach it was found out that calculated results varied little between different conversion models and that even the proportional model showed reasonably accurate results. The proportional model requires information about the reference inventory, the ^{137}Cs concentration at individual sampling points, the year of sampling, the actual plough depth, the bulk density and the particle size correction factor. The particle size correction factor can be set to a constant value of 1.0. The calculation is a linear function indicating soil erosion when an individual sampling point has a lower ^{137}Cs concentration than the local reference ^{137}Cs inventory. If the ^{137}Cs concentration is higher than the local reference, sediment has accumulated. The equation can be expressed by:

$$Y = 10 \frac{BdX}{100TP}$$

where Y = mean annual soil loss ($\text{t ha}^{-1} \text{yr}^{-1}$), d = depth of plough or cultivation layer (m), B = bulk density of soil (kg m^{-3}), X = percentage reduction in total ^{137}Cs inventory (defined as $(A_{\text{ref}}-A)/A_{\text{ref}} \times 100$), T = time elapsed since initiation of ^{137}Cs accumulation (yr), A_{ref} = local ^{137}Cs reference inventory (Bq m^{-2}), A = measured total ^{137}Cs inventory at the sampling point (Bq m^{-2}), P = particle size correction factor (Walling and He, 2001, p. 6).

The calculated soil redistribution rates can be visualized by a map showing the spatial distribution of erosion and deposition rates over the last 50 years (Figure 2). Although the concentration of ^{137}Cs is comparatively low in West African environments, results clearly differentiate zones of sediment loss and gain. The redistribution map of a hillslope in southwestern Burkina Faso shows maximum erosion rates of $16 \text{ t ha}^{-1} \text{yr}^{-1}$ at the summit and shoulder position of the hillslope and maximum deposition rates of more than $20 \text{ t ha}^{-1} \text{yr}^{-1}$ at the footslope/valley position. These deposition rates can be used as an approximate value of expected sediment yield for valley locations and hence sedimentation rates of reservoirs.

It is also possible to apply this method to samples taken from bottom sediments of reservoirs. In this way, the amount of deposited material is calculated directly. Measurements follow the same procedure as described above and result in an approximate estimate of reservoir sedimentation rates over the last 50 years.

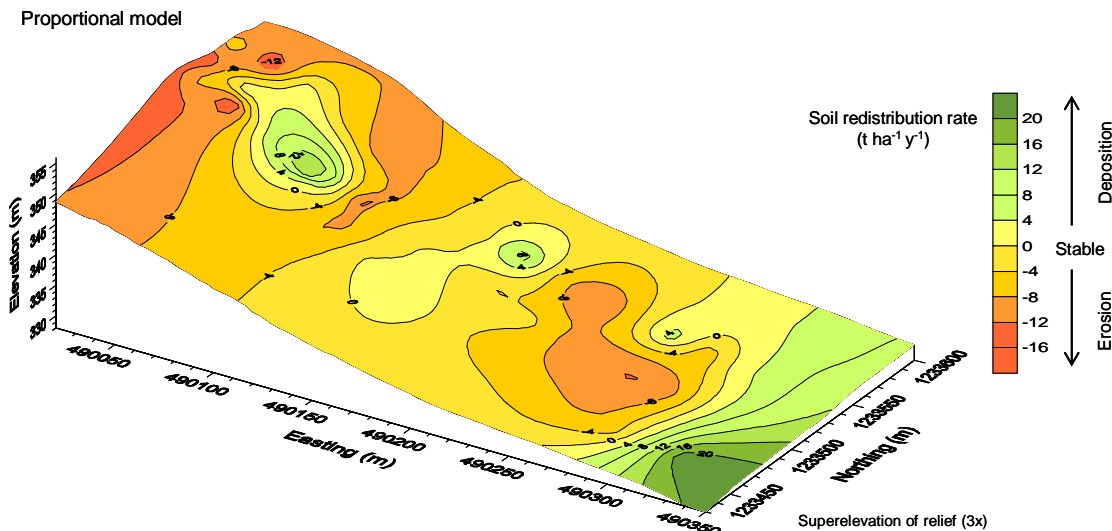


Figure 2 Spatial pattern of soil erosion and deposition at a hillslope in south-western Burkina Faso based on the proportional ^{137}Cs conversion model

Lessons learned and recommendations

An advantage of the ^{137}Cs technique is its independent retrospective assessment of medium-term erosion rates. The method allows the collection of soil samples during one intensive field visit without the need to monitor erosion and sedimentation processes over a long time period. A major limitation is the expense and time required for analysis by an isotope laboratory. Other constraints are limitations due to uncertainties of sampling errors, parameter uncertainties, environmental variability and unequally distributed rains at the time of radionuclide fallout. Furthermore, the ^{137}Cs approach neglects sediment transport and deposition by wind and should be used only in environments where water is the dominant agent for soil erosion (Chappell, 1999).

However, for the tested sites in Burkina Faso, the ^{137}Cs technique performed very well and provided an adequate quantification of soil erosion and sedimentation rates.

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