Intensity of soil erosion and sedimentation inferred from spatial distribution of radionuclide ^{137}Cs in hillslope catchments, South Korea

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Abstract Erosion, transport and sedimentation of soil particles are considered for different bedrock catchments, underlain by granite, gneiss and sedimentary rocks, in South Korea. The spatial patterns of diffusion of the radionuclide ^{137}Cs, and the inventory within soil profiles, particularly its loss from upper horizons and translocation intensity towards lower horizons, were measured with a germanium detector. The intensity of soil erosion, estimated by the spatial variability of the ^{137}Cs inventory loss in these catchments, differs depending on bedrock, soil properties and runoff generation. Results indicate significantly higher rates of soil erosion and sedimentation in the granite and gneiss catchments than in the sedimentary rock catchment.

Key words radionuclide ^{137}Cs; soil erosion; sedimentation; South Korea

INTRODUCTION

Radionuclide ^{137}Cs has been extensively applied as an environmental tracer to estimate rates of soil erosion during the past few decades (Ritchie & McHenry, 1973). ^{137}Cs deposits as fallout on soil surface, and is redistributed by movement of soil particles (Rogowski & Tamura, 1970; Ritchie & McHenry, 1975), hence good relationships between ^{137}Cs loss and soil loss have been established (Ritchie & McHenry, 1975; Elliott *et al.*, 1990; Loughran & Campbell, 1995). The investigation of ^{137}Cs has also contributed to the development of geomorphologic research methods, particularly the assessment of soil erosion on upslopes, sediment redeposition on downslopes, and the associated rates of sediment distribution within catchments using spatially-distributed diffusion models for ^{137}Cs (Kachanoski & DeJong, 1984; Lance *et al.*, 1986; Walling & He, 1999). The underlying purpose of the present study is to develop an understanding of the intensity and rates of soil erosion from the spatial variability of ^{137}Cs, which was strongly absorbed onto fine particles on ground surfaces worldwide due to testing of thermonuclear weapons from the early 1950s, in different bedrock catchments underlain by granite, gneiss and sedimentary rocks in South Korea. The present study differed as an assessment based on radionuclide ^{137}Cs inventory for intensity of soil erosion occurring through surface and subsurface flows in different bedrock catchments from previous research of soil erosion by water in Korea, which focused on cropped and cultivated fields.

METHODS AND MATERIALS

For estimating the intensity of the soil erosion and sediment deposition within the catchments, bulk and core samples were taken from undisturbed soils for reference sites for each catchment where ^{137}Cs was absorbed in the 1950s, and remained on the surface soil. Bulk samples were oven-dried at 105°C for 24 hours and sieved through 2 mm mesh, and core samples were sliced at 2 cm intervals. ^{137}Cs inventory was analysed using Marinneli beakers, counting the gamma emission for 7200 seconds at the photo peak of 662 keV (net area from 657.7 to 665.5keV) with Gamma-Ray Spectrometry, HPGe detector, Ortec 919E at the KAERI (Korean Atomic Energy Research Institute). The rates of the soil erosion and sediment deposition were determined by comparing ^{137}Cs inventories at the study catchments with the baseline ^{137}Cs inventories in the uneroded soils at the reference sites in each catchment.

RESULTS AND DISCUSSION

Since 1990, several studies have indicated the average concentration of radionuclide ^{137}Cs within Korean soil (Table 1). However, to date, no estimates of soil erosion have been related to the spatial distribution of the radionuclide ^{137}Cs. The spatial dispersions of the radionuclide ^{137}Cs indicated that the average areal activities of the baseline ^{137}Cs inventories for uneroded soils were 2100 Bq/m^2 in the granite catchment, 2840 Bq/m^2 in the gneiss catchment, and 3366 Bq/m^2 in the sedimentary catchment (Table 1).

The results indicated that organic matter and clay content played the most important role in the lateral distribution of the radionuclide ^{137}Cs in the soils. ^{137}Cs inventory also displays a positive relationship with organic matter in vertical distributions. Surface elevation slightly influenced the lateral distribution of the ^{137}Cs inventory, i.e. it was greatly distributed on lowlands as a consequence of the greater adsorption capacity and the increased surface area (Fig. 1). Other factors such as soil permeability and slope gradient showed a poor correlation with distribution of the ^{137}Cs inventory in the soil.

The results from the vertical distribution of the radionuclide ^{137}Cs showed that the ^{137}Cs inventory in the granite catchment was about two times lower than the ^{137}Cs inventories in the gneiss and sedimentary catchments. This variation of the ^{137}Cs inventory indicates the more intensive erosion in the granite catchment than in the gneiss and sedimentary catchments. At most

Table 1 Baseline inventories of ^{137}Cs within soils in South Korea.

Location areas	Baselines	Authors	Years
Granite	48.1 Bq/g	Cho *et al*	1994
Tuff	773.0 Bq/g	Cho *et al*	1994
Daejeon	14.37 Bq/kg	Lee *et al*	1995
Forest	2501 Bq/m^2	Lee *et al*	1998
Hills	1058 Bq/m^2	Lee *et al*	1998
Paddy field	17.7 Bq/kg	Choi *et al*	1999
Upland field	27.8 Bq/kg	Choi *et al*	1999
Granite catchment	2100 Bq/m^2	Orkhonselenge *et al*	2005
Gneiss catchment	2840 Bq/m^2	Orkhonselenge *et al*	2005
Sedimentary catchment	3366 Bq/m^2	Orkhonselenge *et al*	2005

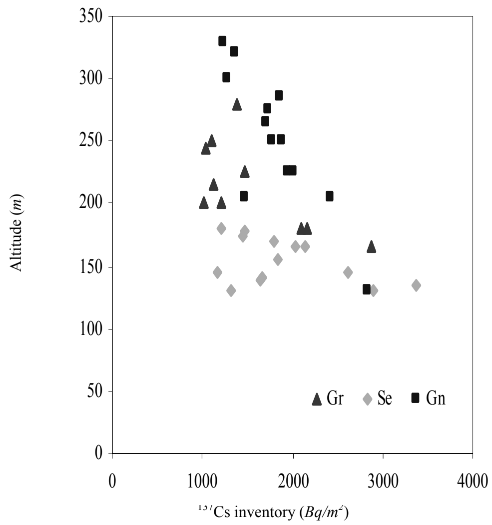

Fig. 1 Relationship between the radionuclide ^{137}Cs inventory and altitude in the catchments.

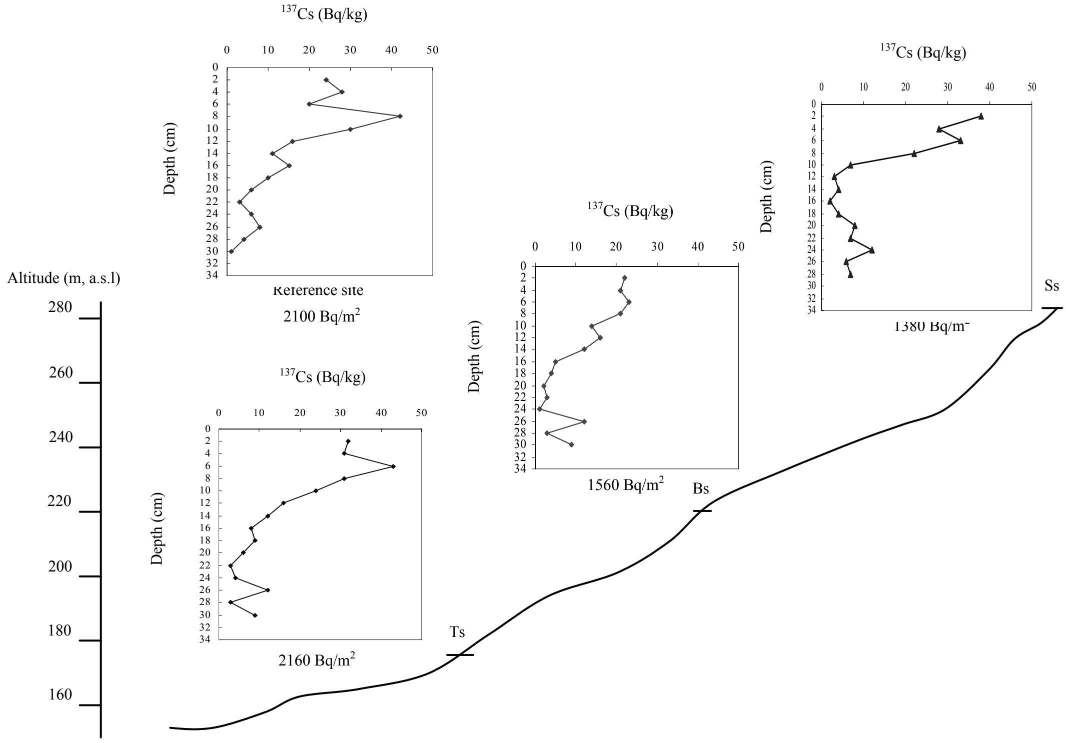

Fig. 2 Vertical distribution of the ^{137}Cs inventory along the hillslope in the granite catchment.

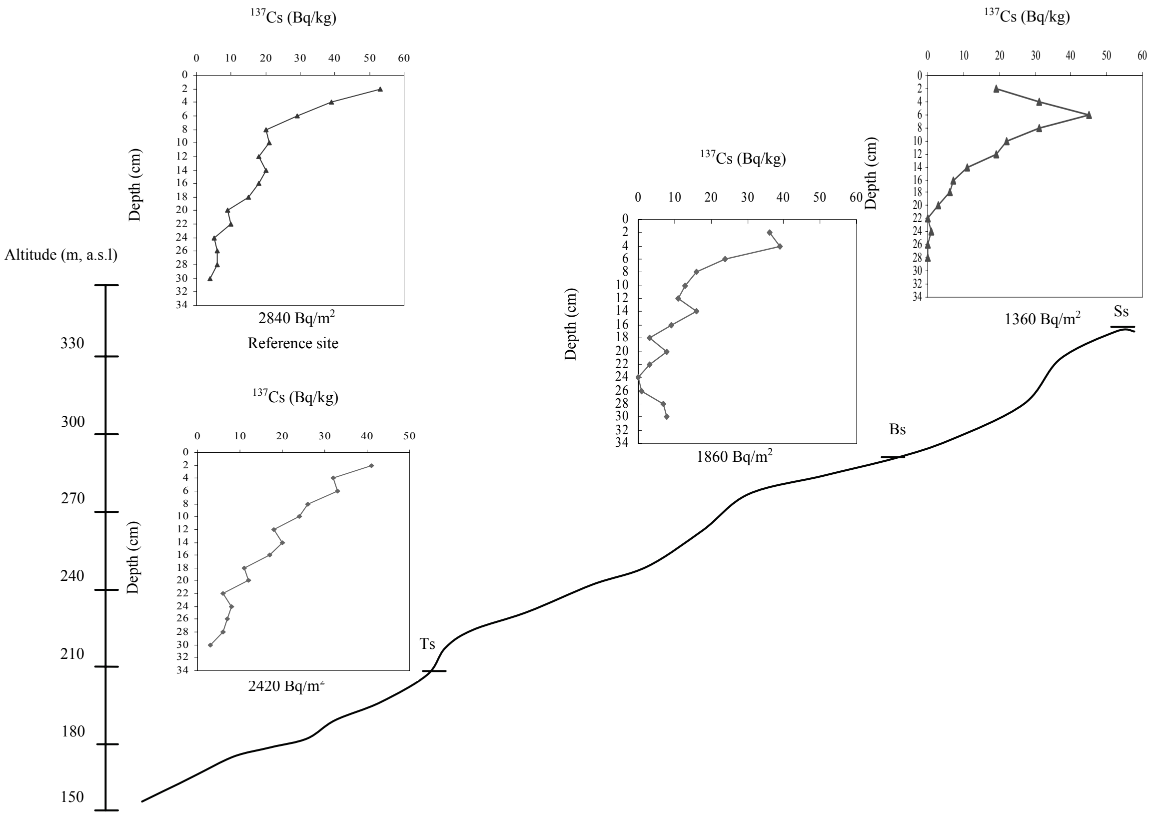

Fig. 3 Vertical distribution of the ^{137}Cs inventory along the hillslopes in the gneiss catchment.

sampling points, the vertical variability of the ^{137}Cs inventory within soil profiles showed an exponential curve with soil depths, having the highest inventories in the surface horizons, i.e. the vertical distribution of the ^{137}Cs inventory within soil tended to decrease in deep soil horizons, regardless of the different bedrock in these catchments (Figs 2–4).

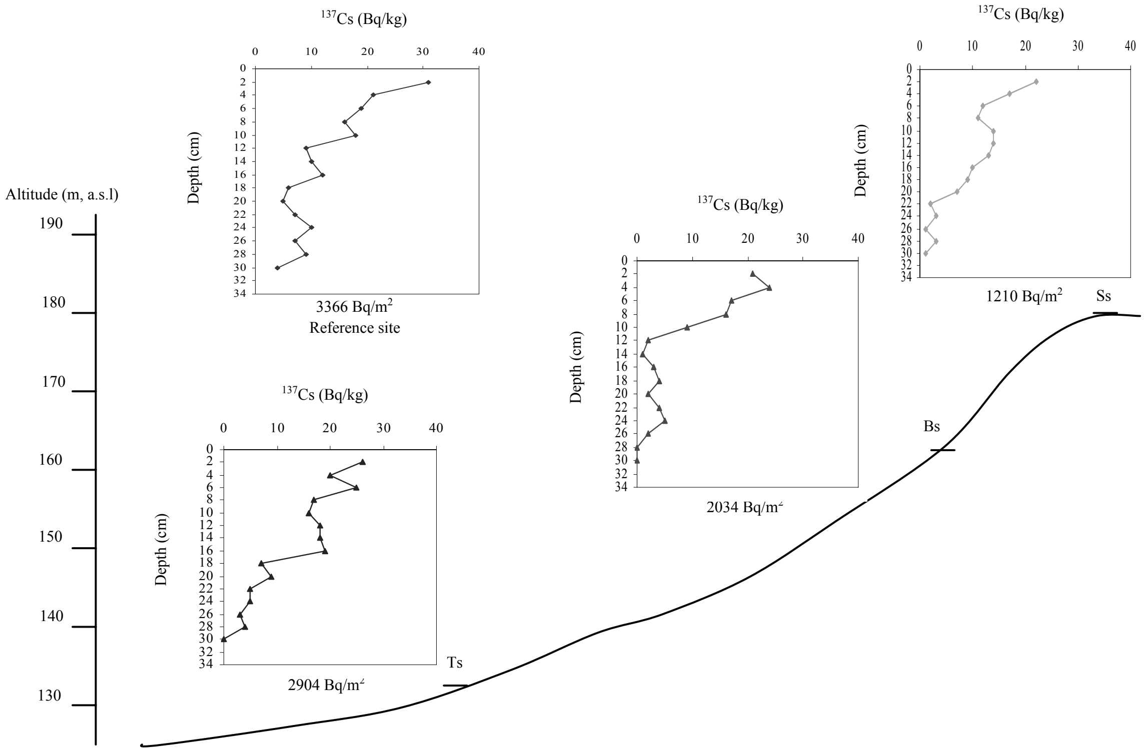

Fig. 4 Vertical distribution of the ^{137}Cs inventory along the hillslopes in the sedimentary catchment.

On toe slopes (Ts), the higher ^{137}Cs inventories at 2-cm depth indicated that ^{137}Cs was recently redistributed by eroded sediments from shoulder (Ss) and back (Bs) slopes. Soils developed on the shoulder slope and the straight part of the back slope in the granite catchment, were intensely eroded by overland flow (Fig. 2). In the gneiss catchment, soils were less vulnerable to erosion by surface flow, hence rates of soil erosion were not as high in terms of the lateral and vertical distributionsof the ^{137}Cs inventory along the hillslopes (Fig. 3). In the sedimentary catchment, the vertical distribution of the ^{137}Cs inventory indicated that the rates of soil erosion and sedimentation were relatively lower (Fig. 4). The average rates of the soil erosion were 40.71 t/ha/year, 26.56 t/ha/year and 22.27 t/ha/year in the granite, gneiss and sedimentary catchments, respectively. In general, the straight parts of back slopes and shoulder slopes are more sensitive to erosion processes compared to crest flats and toe and foot slopes in these catchments.

CONCLUSION

The intensities of soil erosion and sedimentation, estimated from the spatial variability of the radionuclide ^{137}Cs within the soil profiles, differ depending on the varying bedrock, soil properties, and hydrological processes. In particular, the vertical distribution of the ^{137}Cs inventory in the granite catchment indicates more significant intensive erosion and sedimentation than in the gneiss and sedimentary rock catchments. The radionuclide ^{137}Cs input in the soil and its loss in the catchments confirm the relative significance of the relationship between ^{137}Cs loss and soil loss, and the relationship between the spatial distribution of ^{137}Cs and organic matter in soils. The intensive erosion of soils by water in Korea could be a crucial environmental problem, and needs to be effectively managed in order to provide sustainable land uses for future generations. The present study has indicated the radionuclide ^{137}Cs as a useful indicator for retrospective assessment of soil erosion and sedimentation rates. For future geomorphologic studies, this study has also provided some valuable information of the soil erosion and sedimentation rates in the different bedrock catchments in South Korea. This is a modest contribution to the ongoing developments in the study of soil erosion for erosion control, measurement and prediction in Korea.

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