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Assessing soil erosion and control factors by radiometric technique in the source region of the Yellow River, Tibetan Plateau

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ABSTRACT

Measurements of ^{137}Cs concentration in soils were made in a representative catchment to quantify erosion rates and identify the main factors involved in the erosion in the source region of the Yellow River in the Tibetan Plateau. In order to estimate erosion rates in terms of the main factors affecting soil loss, samples were collected taking into account the slope and vegetation cover along six selected transects within the Dari County catchment. The reference inventory for the area was established at a stable, well-preserved, site of small thickness (value of 2324 $Bq \cdot m^{-2}$). All the sampling sites had been eroded and ^{137}Cs inventories varied widely in the topsoil (14.87–25.56 $Bq \cdot kg^{-1}$). The effective soil loss values were also highly variable (11.03–28.35 $t \cdot km^{-1} \cdot yr^{-1}$) in line with the vegetation cover change. The radiometric approach was useful in quantifying soil erosion rates and examining patterns of soil movement.

Introduction

Soil erosion is a complicated process that depends on many parameters, which in most cases interact and operate under significant temporal and spatial variabilities (Theocharopoulos et al., 2000). It is a major environmental problem in many parts of the world (Mitra et al., 1998). Assessment and forecasting of soil erosion are core issues in land management and are influenced by numerous factors, including climate, topography, soil attributes, land cover, and human activity.

As the global climate warms, glaciers and frozen soils in some sensitive regions can be significantly altered, thereby accelerating the degradation of alpine grassland ecosystems (Jorgenson et al., 2001). Permafrost ecosystems are particularly sensitive to climate change (Bubier et al., 1999; McGuire, 2002). As a result, terrestrial ecosystems in cold regions may strongly influence the water cycle and heat balance of the regional land–atmosphere system.

At present, the degradation of grassland in the source region of the Yellow River is an ongoing problem. Degradation of grassland refers to the deterioration of the vegetation–soil system (Chen and Wang, 2000), which can cause erosion of frozen soil. Accelerated erosion can cause degradation of the ecosystem, resulting in desertification (United Nations, 1977). According to Ma et al. (1999), the degraded grassland has reached an area of approximately 0.45×10^8 km^2, which is one-third of the total area of the Qinghai–Tibet Plateau. The most seriously degraded area is the secondary bare land ("black beach") that accounts for 16.5% of the total area of degraded grassland. Grassland degradation has threatened the local ecosystem, biodiversity conservation, and the economic development of local communities whose livelihood depends heavily on livestock (Li and Zhou, 1998a; Zhou et al., 2003).

Soil erosion caused by water, wind and freeze–thaw occurs extensively across the source region of the Yellow River, whereas gravity-induced erosion from rock falls, landslides, and debris flows are more localized. The process of coarsening of the texture of the surface soil (as a result of the loss of fine-textured materials), depletion of soil organic matter, and degeneration of vegetation occurs widely. The threat is more serious for the soils of the paramos (moors) that are highly susceptible to erosion and other degradational processes. In view of the significant effects the Tibet Plateau has on China's ecosystems, and even on global climatic change (An et al., 2001; Rea et al., 1998), soil erosion has become the region's most serious eco-environmental problem and one that must be controlled.

Radionuclide tracers have been used for investigation of the ecological processes related to the degradation of natural resources such as soil, water, plants, and animals (Prandle, 1994; Dahlgaard, 1994; Florou and Chalalou, 1997). For example, ^{137}Cs reaching the land surface as fallout from the atmosphere is rapidly adsorbed by clay minerals and organic matter in the surface soil. Its subsequent redistribution, both within the soil profile and across the land surface, is controlled by its interaction with tillage and related land-use practices, soil erosion, and sediment transport processes including the migration of soil particles (Ritchie and McHenry, 1990; Sutherland and Jong, 1990). The ^{137}Cs tracer method is seen as an efficient way to determine long-term

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soil redistribution rates under particular topographic, climatic, and pedagogical conditions (Schuller et al., 2000). It is based on the comparison between the ^{137}Cs inventories measured in the suspected eroded or deposited sites in the landscape, and a reference ^{137}Cs inventory normally established at a long-term undisturbed site.

The specific aim of this study was to use the ^{137}Cs tracer technique to gather reliable data on erosion and sedimentation rates in order to assess soil erosion and the long-term erosive landscape dynamics in the source region of the Yellow River.

Description of the study area

The study area is located in Dari County (33°45 N, 99°39 E) (Fig. 1) in the headwaters of the Yellow River. The average altitude is 4000 m asl, and it is an area subject to seasonal frost with an annual average temperature of −0.22°C, a mean annual rainfall of 547 mm and a mean annual evaporation of 1219 mm. The county-wide average temperature ranges from −0.1 to −3.5°C, with a high temperature maximum of 20.1°C and a minimum low temperature of −27.6°C (Dari Local Chronicles Compilation Committee, 1987). This area has an alpine semi-humid climate throughout the year, with only two seasons (cold and warm). Due to the complex topography, rock properties, slopes, and vegetation, the degradation of grassland in the source area of the Yellow River leads to soil erosion, revealing the exposed black top soils that warm up more rapidly and thus result in deepening the permafrost table.

Soil types within the study area were classified according to Chinese soil taxonomy (NSSO, 1998), using available soil survey data. Soils beneath the range of vegetated land area types were classified as alpine meadow soils (or closely packed fine soil, comparable to the FAO-UNESCO's cambisols) and alpine steppe soils (or frigid calcic soil, also comparable to the FAO-UNESCO's cambisols). Soils in the study area have formed in weathered Tertiary sandstone with a sandy loam texture (13% clay, 41% silt, and 52% sand), which contains 25.12 g $kg^{-1}$of organic matter and has a pH value of 7.9. There are three major alpine vegetation types in the study area: shrub meadow, *Kobresia* meadow, and grassland. Alpine meadow and grassland are the dominant vegetation types, with patchy vegetation and sparse vegetation on debris distributed in local high-altitude zones. The dominant plant species in the study area include *Kobresia pygmaea*, *K. humilis*, *K. capillifolia*, *K. tibetica*, *Stipaaliena*, *Potentilla multicaulis*, and *Leontopodium*. The livestock grazing in the study area has a long history.

Materials and methods

Materials

In order to evaluate soil erosion intensity and control factors, four sampling transects (S1, S2, S3, S4) were used to assemble information on soil redistribution rates from representatives of each of the degraded alpine meadow sites in the source area of the Yellow River. The soil sampling scheme was established to select representative sites of the degraded grassland soil characteristics, slopes, and vegetation coverage in the study area (Fig. 1). The soil samples were collected along the four transects following the slope direction, the sampling sites being 150 m apart. All four transects were located in seasonally frozen ground, their average slopes being 5% (S1), 20% (S2), 10% (S3) and 15% (S4).

At each sampling site, repeated cores were taken at each corner of an equilateral triangle with sides 1.0 m long. Soil samples were collected to a depth of 0.3 or 0.4 m, using a 90-mm-diameter core. With regard to upslope samples, the 0–0.10 m, 0.10–0.20 m and 0.20–0.30 m layers were isolated and analyzed separately, whereas cores at down-slope sites, where deposition might be expected, were split into 0.10 m layers. The three individual corner sub-samples at a specific depth increment were mixed to provide a composite sample of about 2.0 kg dry weight (d.w.) for that and every other increment. The samples served to determine both the depth distribution and the total amount of ^{137}Cs in the soil.

Three sets of remote data, including 1967 aerial photographs as well as 2000 satellite TM images of the study area, supported by a remote-sensing interpretation marker database established on the basis of transect surveys, were processed using ERDAS IMAGE and ARC/INFO software (with ArcView 3.1, ESRI Ltd.). Based on a 1:100,000-scale topographic base map, raw data were run through a series of treatments, including TM[ETM] radiation calibration, geometric rectification, UTM geographical coordinate image rectification, and topographic map (1:100,000) rectification. A remote-sensing interpretation database consisting of 246 marker points of eleven types was established on the basis of transect surveys so as to ensure an accuracy of RMS <1 pixel.

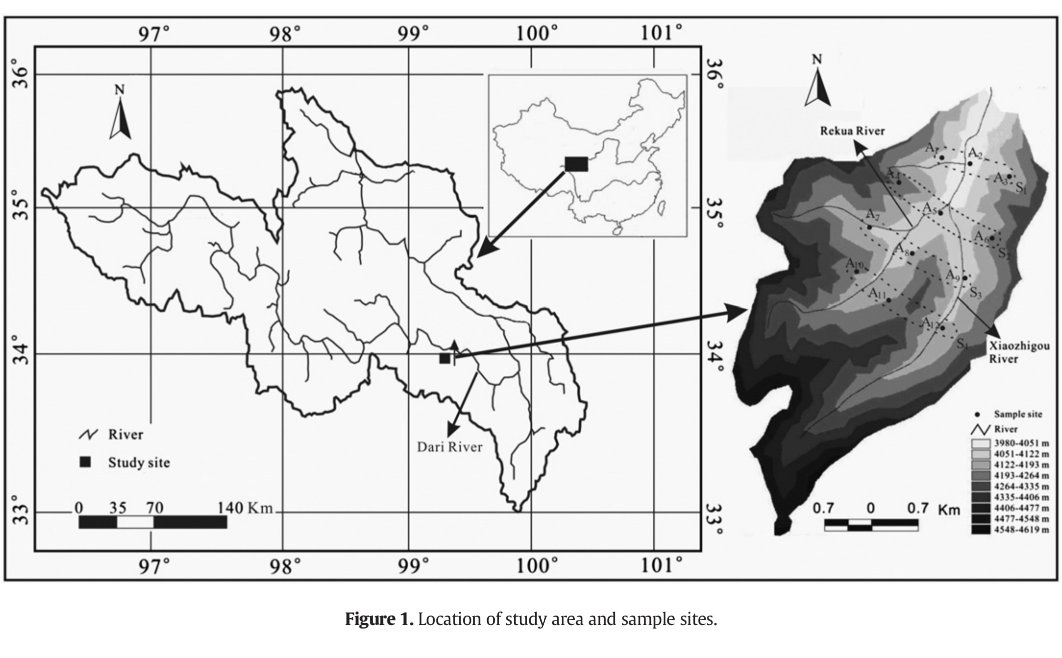

Figure 1. Location of study area and sample sites.