Soil Erosion Analysis in the Eastern Junggar Region Based on the MCM Model and 137Cs: Postprint

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Abstract

The China CRI correction model (MCM) was applied to estimate the 137Cs background values at 27 sampling sites in the Zhundong region of Xinjiang, calculate soil erosion amounts for sand land, bare land, cultivated land, forest land, and grassland, validate these calculations, and explore the application potential of the MCM model in the study area. The results showed that: (1) The total 137Cs at each sampling site ranged from 130.10 to 2671.54 Bq · m-2, with an average value of 1076.31 Bq · m-2. Soils in the central and northern parts of the study area were predominantly in an erosion state, while soils in the southern part were predominantly in a deposition state; (2) The 137Cs background values estimated by the MCM model ranged from 979.87 to 1249.60 Bq · m-2, with an average value of 1140.20 Bq · m-2, which are relatively reasonable results; (3) The soil erosion moduli for cultivated land, grassland, and unused land in the desert-plain area located in the central part of the study area were 24.66, 34.30 t · hm-2 · a-1, and 77.84 t · hm-2 · a-1, respectively, indicating that the soil erosion moduli calculated based on the MCM model can effectively reflect the soil erosion conditions in the study area; (4) Significant differences existed in soil erosion moduli among different land types, with the order being sand land > bare land > grassland > cultivated land > forest land, and the average annual erosion modulus in the study area was 75.86 t · hm-2 · a-1. The soil erosion moduli calculated using the 137Cs background values estimated by the MCM model in this study area are relatively reasonable and have broad application prospects.

Full Text

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Abstract

This study employed the Modified CRI (MCM) model to estimate 137Cs background values at 27 sampling points in the Zhundong region of Xinjiang, and subsequently calculated and validated soil erosion rates for sandy land, bare land, cultivated land, forest land, and grassland. The results demonstrated that measured 137Cs inventories across all sampling points ranged from 130.10 to 2671.54 $\mathrm{Bq \cdot m^{-2}}$, with a mean value of 1076.31 $\mathrm{Bq \cdot m^{-2}}$. Soils in the central and northern portions of the study area were predominantly in an erosional state, whereas soils in the southern region were primarily depositional. The MCM model-estimated 137Cs background values fell between 979.87 and 1249.60 $\mathrm{Bq \cdot m^{-2}}$, averaging 1140.20 $\mathrm{Bq \cdot m^{-2}}$. Soil erosion moduli for cultivated land, grassland, and unused land in the central desert plain region were 24.66, 34.30, and 77.84 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$, respectively, indicating that the MCM model can effectively characterize soil erosion conditions in this region. Significant differences in erosion moduli were observed among land use types, following the order: sandy land > bare land > grassland > cultivated land > forest land. The average annual erosion modulus for the entire study area was 75.86 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$. These findings demonstrate that 137Cs background values derived from the MCM model yield reasonable soil erosion modulus estimates for this study area, suggesting broad application potential for this approach.

Keywords: 137Cs; MCM model; soil erosion; Zhundong region; Xinjiang

1. Introduction

The 137Cs tracing technique has been widely applied in soil erosion research and is recognized as an optimal method for investigating soil erosion processes, erosion modulus estimation, and regional case studies. Walling and others established the global 137Cs background value distribution model using 10°$×45°*gridcells,thoughsimulationresultsforChinaweregenerallylowerthanmeasuredvalues.Aoyamaetal.s* grids, yet simulation accuracy remained unsatisfactory. Zhang Wei et al. developed the Modified CRI model for mainland China, establishing a calculation software that predicts 137Cs background values based on the positive correlation between 137Cs deposition and annual precipitation. This model enables high-resolution, high-precision simulation of 137Cs reference inventories across mainland China through Kriging/Cokriging interpolation.

However, practical applications face challenges in reference site selection. Current 137Cs background data are primarily obtained by collecting soil samples from minimally disturbed sites without erosion or deposition, then interpolating results. In recent decades, intense human activity has made it increasingly difficult to locate ideal reference sites in many regions, compromising the reliability of 137Cs technology for soil erosion assessment. The Zhundong region, located in the eastern Junggar Basin, experiences chronic wind erosion, making the identification of suitable background value sites particularly challenging. Consequently, obtaining extensive measured background data for model validation is difficult. Nevertheless, comparing soil erosion rates derived from the MCM model with those from 137Cs tracing provides an effective validation method. The Zhundong region represents a typical desert area with extensive open-pit coal mining activities that significantly disturb the land surface, creating severe soil erosion problems. Applying 137Cs tracing technology to study soil erosion in this region is crucial for maintaining soil and water security in the eastern Junggar Basin.

1.1 Study Area Description

The Zhundong region comprises a narrow zone from Caina to Beitashan in the eastern Junggar Basin, with geographic coordinates of 88°10 -91°10 E and 43°30 -45°00 N, covering an area of approximately 2.23\$×10ˆ{4}\$ km^{2}. Elevations range from 2042.3 m to 1473 m. The region experiences an arid climate with annual precipitation of 183.5 mm and annual evaporation of 1303 mm. Strong winds prevail year-round, with a maximum of 88 windy days annually. The average wind speed is 3.7 $\text{m}\cdot\text{s}^{-1}$, reaching a maximum of 16 $\text{m}\cdot\text{s}^{-1}$ (Level 7), indicating intense wind erosion. Land use is dominated by sandy and bare land, with minor cultivated and grassland areas. Soils are primarily aeolian sandy soil and gray-brown desert soil with low vegetation coverage (<30%) and minimal organic matter accumulation.

1.2 Sample Collection and Measurement

Soil samples were collected during July–August 2016 and May 2017. Based on the topography, landforms, and land use conditions of the Zhundong region, 27 sample plots were selected (Fig. 1). Each plot measured 20 m × 30 m, with three sampling points arranged in a "品" pattern. Surface gravel and plant residues were removed before collecting samples at 0–20 cm depth using a ring knife. Samples from the same soil layer within each plot were mixed, air-dried, ground, and passed through a 2 mm sieve. 137Cs activity was measured at the Beijing Research Institute of Uranium Geology using a low-energy, low-background HPGe γ-spectrometer (20A-Plus detector). Samples (>400 g) were counted for $ $50,000 s, with measurement error <5% based on the 661.6 keV peak area.

1.3 Calculation Methods

1.3.1 MCM Model The MCM model, developed by Zhang Wei et al., evaluates existing research data and conducts model optimization to calculate 137Cs distribution patterns across China. The model first grids mainland China into 2.5°$×2.5°*cellsandcalculates*137*Csreferenceinventoryforeachcellusingprecipitationdata.Then,using*0.5°×0
*designatingeach*2.5°×2.5°*gridasRi,jandeach*0.5°×0.5°*gridasRm,n.ForanypointXwithcoordinates*($,) where ϕ ranges 13.75°-55.75°E and ranges 17.25°-53.25°N, the model calculates:

$$i = 1 + \text{round}\left(\frac{\phi - 13.75}{2.5}\right)$$

$$j = 17 - \text{round}\left(\frac{\theta - 17.25}{2.5}\right)$$

$$m = 6 - 5 \times \text{round}\left(\frac{\phi - 13.75}{2.5}\right) + \text{round}\left(\frac{\phi}{0.5}\right)$$

$$n = 90 - 5 \times \text{round}\left(\frac{\theta - 17.25}{2.5}\right) + \text{round}\left(\frac{\theta}{0.5}\right)$$

Finally, Kriging/Cokriging interpolation is applied to achieve high-resolution simulation of 137Cs reference inventories at any location in mainland China.

1.3.2 Cultivated Land Soil Erosion Rate Calculation The simplified mass balance model is widely used for cultivated land soil erosion assessment:

$$A = A_0(1 - \frac{h}{H})^N$$

where A and A_0 are the measured and reference 137Cs inventories ($\text{Bq} \cdot \text{m}^{-2}$), respectively; h is the average annual erosion thickness ($\text{mm} \cdot \text{a}^{-1}$); H is the plow layer thickness (cm); and N is the sampling year.

1.3.3 Non-Cultivated Land Soil Erosion Rate Calculation For non-cultivated soils, the vertical distribution of 137Cs differs significantly from cultivated soils. The erosion rate is calculated using:

$$R = 10 \times \frac{A_0 - A}{C \times \rho \times T}$$

where R is the soil erosion rate ($\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$); A is the measured 137Cs inventory ($\mathrm{Bq \cdot m^{-2}}$); A_0 is the reference inventory ($\mathrm{Bq \cdot m^{-2}}$); C is the 137Cs mass activity ($\mathrm{Bq \cdot kg^{-1}}$); ρ is the average soil bulk density ($\mathrm{g \cdot cm^{-3}}$); and T is the time since 137Cs deposition began (years).

2. Results

2.1 Distribution Characteristics of MCM-Modeled and Measured 137Cs

Measured 137Cs inventories in the study area ranged from 130.10 to 2671.54 $\mathrm{Bq \cdot m^{-2}}$, averaging 1076.31 $\mathrm{Bq \cdot m^{-2}}$. MCM-modeled 137Cs background values ranged from 979.87 to 1249.60 $\mathrm{Bq \cdot m^{-2}}$, averaging 1140.20 $\mathrm{Bq \cdot m^{-2}}$. This background range is substantially different from the decay-corrected value of 6211 $\mathrm{Bq \cdot m^{-2}}$ reported by Pu Lijie et al. in Korla, Xinjiang, but closely matches the simulated values of 1193 $\mathrm{Bq \cdot m^{-2}}$ for Aksu and Lop Nur regions by Qi Yongqing et al. Background values from similar regions—Bayannur (909 $\mathrm{Bq \cdot m^{-2}}$) and Luochuan, Shaanxi (1032 $\mathrm{Bq \cdot m^{-2}}$)—are also comparable, validating the reasonableness of our background range.

Cultivated land samples generally showed 137Cs contents significantly below background values, indicating severe erosion from long-term tillage and land consolidation. Sample point 8 showed 137Cs content notably higher than background due to its location at the outlet of the Baiyang River watershed, where deposition of mountain-derived organic matter occurs. Sample point 9, located downstream in the plain area, also exhibited 137Cs content above background from fluvial deposition.

Grassland sample point 7, with high vegetation coverage that effectively reduces erosion, showed 137Cs content significantly above background. Sample points 10-12 ranged from 130.10 to 722.52 $\mathrm{Bq \cdot m^{-2}}$, all below background, indicating erosion. Sample points 13-16 ranged from 983.90 to 2671.54 $\mathrm{Bq \cdot m^{-2}}$, all above background, indicating deposition. Overall, central and northern study areas were dominated by erosion sites, while southern areas were primarily depositional, except for sample point 18.

Forest land sample point 17 showed 137Cs content above background. Sample point 19, despite high vegetation coverage, was below background due to its location in a high groundwater table, highly salinized dry lake basin where seasonal river flushing removes 137Cs.

Among sandy land sites, only sample point 20 showed 137Cs content above background; all others were erosional. Sample points 20-22 were fixed sandy lands with vegetation coverage of 15-30%, supporting *Haloxylon ammodendron*, *Salsola* spp., and *Ephedra* spp., whose protective effects resulted in deposition at points 20 and 21.

Among bare land sites, points 23, 25, 26, and 27 experienced erosion, with point 23 showing the lowest 137Cs content (130.68 $\mathrm{Bq \cdot m^{-2}}$) due to chronic wind erosion and lack of vegetation. Sample points 24 and 28 showed 137Cs content above background, indicating deposition from protective gravel cover.

2.2 Soil Erosion Rate Estimation

Erosion rates varied significantly among sample points. Point 23 exhibited the lowest erosion rate at 20.56 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$ (1.82 $\mathrm{mm \cdot a^{-1}}$), while point 27 showed the highest at 625.68 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$ (48.94 $\mathrm{mm \cdot a^{-1}}$). Among depositional sites, point 16 (artificially enclosed perennial pasture) had the highest 137Cs activity and maximum annual deposition rate (22.74 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$, 2.48 $\mathrm{mm \cdot a^{-1}}$). Conversely, point 23 had the lowest 137Cs activity and minimum deposition rate (6.74 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$, 0.51 $\mathrm{mm \cdot a^{-1}}$).

Average soil erosion rates by land use type followed the order: sandy land (144.78 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$) > bare land (98.73 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$) > grassland (34.30 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$) > cultivated land (24.66 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$) > forest land (-22.74 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$). Sandy and bare lands, distributed mainly in the central and northern regions with low vegetation coverage, experienced intense wind erosion, particularly during April–May when average wind speeds reached 4.60 $\mathrm{m \cdot s^{-1}}$ and maximum speeds reached 17.80 $\mathrm{m \cdot s^{-1}}$. The presence of extensive semi-fixed sandy lands and mobile dunes further exacerbated wind erosion in these areas.

Cultivated land and grassland showed similar average erosion rates due to higher vegetation coverage that effectively mitigated erosion. However, grassland rates were slightly higher because extensive desert grasslands in the region suffer from water limitations and poor quality. Forest land, located primarily in the southern region with *Picea schrenkiana* and high canopy cover, showed net deposition.

Validation using grain size comparison methods from Cao Yue’ e et al. yielded wind erosion rates of 124.61 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$ for sandy land and 50.84 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$ for unused land (mainly bare and sandy land), consistent with our results. After excluding southern mountainous sites, our cultivated and grassland erosion rates (24.66 and 34.30 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$) aligned closely with these reference values, confirming the reliability of our method. The time-distance effect of wind erosion, where multi-year averages exceed single-year measurements due to depletion of erodible particles, explains some discrepancies. Excluding the unrepresentative bare land point 23, the unused land erosion rate of 77.84 $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$ closely matched measured data, validating our approach for sandy and bare land assessments.

3. Conclusions

1. Soils in the central and northern Zhundong region were predominantly erosional, while southern soils were primarily depositional. The MCM model-estimated 137Cs background values of 979.87-1249.60 $\mathrm{Bq \cdot m^{-2}}$ (mean: 1140.20 $\mathrm{Bq \cdot m^{-2}}$) were reasonable and consistent with values from similar regions.

2. Soil erosion moduli for cultivated land, grassland, and unused land in the central desert plain were 24.66, 34.30, and 77.84 $t \cdot hm^{-2} \cdot a^{-1}$, respectively, effectively reflecting actual erosion conditions.
3. Significant differences existed among land use types: sandy land > bare land > grassland > cultivated land > forest land. The region-wide average erosion modulus was 75.86 $t \cdot hm^{-2} \cdot a^{-1}$. The MCM model-derived 137Cs background values produced reasonable soil erosion estimates, demonstrating substantial application potential for this methodology in the Zhundong region.

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