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Application of Caesium-137 Technique on Wind Erosion in Gonghe Basin, Qinghai Province, China*

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Introduction

The worldwide fallout ^{137}Cs, associated with the atmospheric testing of nuclear weapons during 1950s and 1960s, has provided a valuable man-made tracer for studies of soil erosion and sediment delivery (Ritchie & MeHenry, 1990). Since its introduction in the 1970s, the ^{137}Cs technique has widely applied in water erosion leading to profound accomplishments (Ritchie & Ritchie, 1996). Until the 1990s a few attempts was made to estimate the wind erosion rate using ^{137}Cs technique, and it is still in an exploring stage (Chappell, 1999).

Here we report the results of ^{137}Cs sampling, measurements to investigate wind erosion in Gonghe Basin of Qinghai Province during 1998-1999. The objectives were to analysis ^{137}Cs distribution in the area and its depth profile of different soils, determine ^{137}Cs reference inventory of the area, and estimate wind erosion of sampling plots and the whole area, and discuss the input and output ways of aeolian sediment in the Basin.

Materials and Methods

Study area

The Gonghe Basin of Qinghai Province is located between the Qilian Mountains to Kunlun Mountains at the northeastern edge of the Qinghai-Tibet Plateau and the Qinling Mountains, at latitude 35°20′-36°51′N, longitude 98°24′-101°22′E, and elevation between 2 400-3 500 m above sea level. The basin has 210 km length, 30-90 km width and a total area 13 787 km^2. The climate of the area belongs to plateau temperate semiarid type, with a mean annual temperature 1.0-3.3°C. The mean annual precipitation 250-400 mm and annual evaporation is 1 528-1 937 mm. Prevailing wind are northwest wind and southeast, with mean annual wind velocity is 2.1-2.7 m/s and gales (>17.0 m/s) occur on a mean of 15.5-50.6 days/a. Dust storms (visibility < 1000 m) occur on a mean of 6.5-20.7 days/a. Due to dry and cold climate, frequent and strong wind, spare vegetation, plentiful surface sand material, and irrational economic activities in recent decades, the basin becomes one of the regions suffering from severe desertification in the steppe and

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desert steppe zones in China. The total desertified land area in the basin is 4 926.12 km^2, accounting for 35.73% of the total area (Dong *et al*., 1993).

^{137}Cs sampling and measurement

Total 380 ^{137}Cs samples were taken from seven general sampling sites (RS1-7) involving main land types of the area and four typical sampling plots (SAM1-4) represented most severe desertified land (SAM1), severe desertified land (SAM4), on-going desertified land (SAM2) and latent desertified land (SAM2) respectively. At the general sites, the sampling arranged at specific soil with random 2-3 repeatedly sampling points. At typical plots, according to topography, three sampling forms were adopted, i.e. grid (SAM1), parallel transects (SAM2 and SAM3) and vertical transects (SAM4) (Walling & Quine, 1993) .The SAM1 plot has 60×40 m, SAM2 and SAM3 100×100 m and SAM4 100×25 m, with a same 10 m spacing between sampling point. ^{137}Cs samples include bulk sample and incremental sample, collected respectively by spiral drill with 7.4 cm internal diameter and 15 cm depth, and scraper-plate with 20 cm length, 10 cm width and 2 cm depth (increment). Meanwhile, at some specific points, grain-size and bulk density samples were collected.

^{137}Cs samples were air-dried, ground to pass through a 1-mm mesh sieve. All samples weighting about 400 g each were test by γ-ray detector (EG&G ORTEC LOAX HPGe) connected to an ORTEC amplifier and multi-channel analyzer in the in the Nuclear Physics Laboratory of Sichuan Union University, Chengdu, China (Yan *et al*., 2001).

Computational methods

The ^{137}Cs point inventory, *CPR* (Bq/m^2) was calculated by Eq.(1) (Walling & Quine, 1993)

$$CPI=\sum_{i=1}^{n} 10^3 \cdot C_i \cdot Bd_i \cdot D_i \qquad (1)$$

where *i* is the sampling depth and *n* is total number of samples with detectable ^{137}Cs, C_i is ^{137}Cs activity for sample *i* (Bq/kg), Bd_i is the bulk density (t/m^3) for depth *i*, and D_i is the depth (m) for sample *i*.

And ^{137}Cs redistribution was calculated as (Walling & Quine, 1993):

$$CPR=(CPI-CRI)\cdot 100/CRI \qquad (2)$$

where *CPR* is ^{137}Cs percentage residual at a sampling point in the field relative to the native control area(%), *CPI* is ^{137}Cs point inventory (Bq/m^2) and *CRI* represents ^{137}Cs reference inventory (Bq/m^2).

Results and Discussion

^{137}Cs inventory and its depth distribution

The mean ^{137}Cs activity and the total ^{137}Cs inventory of the region were determined to be 4.84±0.34 Bq/kg and 1513.83±108.37 Bq/m^2 respectively. The ^{137}Cs activity of different land types was in the order: woodland > playa > cold grassland > dry farmland, steppe > fixed sand dune > desert steppe > shift sand dune > interdune (Table 1). The ^{137}Cs depth distribution can be divided into normal profile (NP), aggrading profile (AP), eroding profile (EP) and disturbed profile (DP). The playa RS3 is typical AP (Fig.1a), woodland RS2 DP-EP (Fig.1h), shift dune SAM1and SAM4 AP-EP (Fig.1b), fixed dune RS2 AP (Fig.1g), interdune SAM1 and SAM4 typical EP (Fig.1c), cold grassland RS7 and SAM3 typical NP (Fig.1d), steppe RS4, SAM2 and SAM4 EP-DP (Fig.1e), desert steppe RS5 and SAM1 EP (Fig.1i), dry farmland SAM2 and SAM3 typical DP (Fig.1f).

^{137}Cs reference inventory

The ^{137}Cs distribution of cold grassland was uniform over the region and its depth distribution approached a negative exponential curve. From the ^{137}Cs determination of samples collected at RS7 in cold grassland, the ^{137}Cs reference inventory of the Gonghe Basin was 2691.78±196.08 Bq/m^2 which is essentially equal to the

Table 1. ^{137}Cs activity and inventory of different land types in Gonghe Basin.

Land type	No. of sampling sites or plots	Number of samples Bulk	Number of samples Increment	Mean ^{137}Cs activity (Bq/kg)	Mean ^{137}Cs inventory (Bq/m^2)
Fixed sand	RS1	1×2	\	2.48±0.21	881.63± 72.04
Woodland	RS2	1×2	\	12.59±0.79	4733.05±293.99
Playa	RS3	1×3	1×10	10.57±0.67	3977.39±240.12
	RS6	2×2	1×10	1.88±0.16	671.25± 58.53
Shift sand dune	SAM1	22	1×10	1.75±0.15	2218.36±195.04
	SAM4	8	\	0.91±0.10	2337.05±228.61
Interdune	SAM1	28	1×10	0.51±0.05	148.88± 14.91
	SAM4	7	\	0.51±0.06	209.83± 22.69
Grassland	RS4	1×2	\	7.67±0.50	1796.54±117.12
	RS5	1×3	\	0.76±0.08	366.29± 39.91
	RS7	5×3	1×10	8.55±0.60	2691.78±196.08
	SAM1	30	\	3.43±0.27	1150.56± 90.01
	SAM2	36	1×10	5.64±0.39	1636.43±115.85
	SAM3	34	1×10	8.80±0.55	2156.25±135.48
	SAM4	2×2	\	3.92±0.26	1303.38± 87.26
Farmland	SAM2	45	1×10	4.69±0.33	1111.36± 78.42
	SAM3	45	1×10	6.30±0.43	1772.49±122.84
Total or mean		380		4.84±0.34	1513.53±108.37

mean ^{137}Cs reference inventory of the Northern Hemisphere. Regression analysis shows that the ^{137}Cs depth profile of RS7 can follow the function of peak distribution as following (Yang *et al.*, 1998):

Cs=98.576(1-(0.989-z/19.208)$^{3.689}$)(0.989-z/19.208)$^{2.689}$ (3)

Compared with the exponential distribution and typical peak distribution, it appears a downward shift of ^{137}Cs peak and flatting trend in the curve. This phenomenon which was frequently seen in reference materials may be ascribed to the steadily downward migration of ^{137}Cs in recent several decades (Yang *et al.*, 1998).

Wind erosion estimation by ^{137}Cs model

The model of ^{137}Cs profile distribution to estimate wind erosion rate of natural soil profiles (sand dune, interdune and grassland) was developed as Eq.(4) in accordance with ^{137}Cs reference inventory of the region.

E_R=-100·Bd·ln(1+0.9951CPR/100) /0.2658T (4)

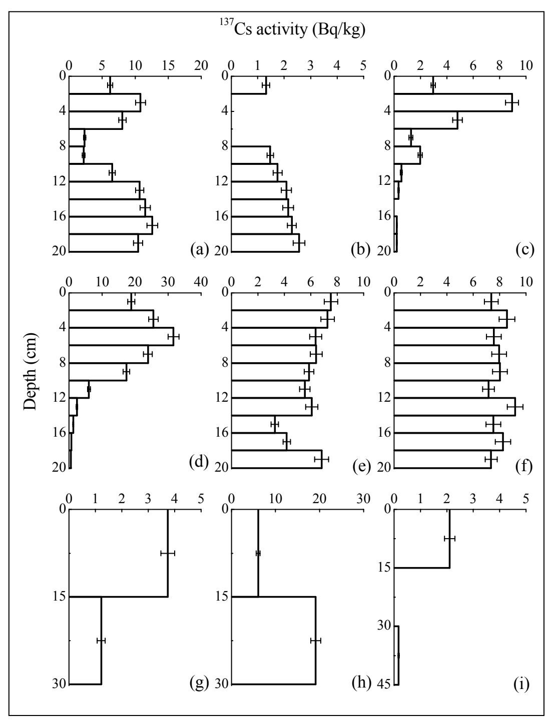

Figure 1. Depth distribution of ^{137}Cs in some sampling sites of Gonghe Basin: **a.** Playa (RS3); **b.** Shift dune (SAM1); **c.** Interdune (SAM1); **d.** Cold grassland (RS7); **e.** Steppe (SAM2); **f.** Dry farmland (SAM3); **g.** Fixed dune (RS1); **h.** Woodland (RS2); **i.** Desert steppe (RS5).

where E_R is the net wind erosion rate of the sample site (t/ha•a), *CPR* is the loss of ^{137}Cs (%), *Bd* refers to the bulk density of sampled soil (t/m^3), *T* is the time period between the year of maximum ^{137}Cs fallout (1963) and the sampling year, in this study, *T*=35 a. For the cultivated soil (farmland SAM2 and SAM3), the wind erosion rate was calculated using the ^{137}Cs proportional model (Sutherland *et al.*, 1991):

$$E_R=-10^4\cdot Bd\cdot Pd\cdot(CPR/100)\,/T \qquad (6)$$

where *Pd* is the plough depth (m), and *T* is cultivation time, for SAM2 *T*=9 a (1989-1998) and SAM3 *T*=20 a (1978-1998).

By these models, the wind erosion rate of four sampling plots was calculated to be 24.910±1.088 t/ha•a averagely, reaching the moderate to severe grade (Zachar, 1982). The sand dune plot SAM1 with the largest rate 43.679±1.491 t/ha·a was ones experienced severe wind erosion continuously; The farmland/grassland plots SAM2 and SAM3 were in degrees of moderate and slight of wind erosion, 14.901±0.974 t/ha·a and 7.484±0.533 t/ha·a, but land reclamation had such a great influence on wind erosion that the accelerated wind erosion came to 5.74-8.80 times than normal wind erosion. The dune plot SAM4 was in severe wind erosion, 33.576±1.353 t/ha·a, but it was relatively slighter than SAM1 plot because of counteraction by steady accumulation of aeolian sand.

Regional wind erosion assessment and erosion-deposition equilibrium

According to the desertified land classification (Dong *et al.*, 1993), the wind erosion rates of four plots were converted into the regional wind erosion assessment by erosion-deposition equilibrium model. The wind erosion rate of the Gonghe Basin was 12.556 t/ha•a which passed test of erosion-deposition equilibrium at a relatively small error less than 10%. Among the eroded sediments, more than 57% were preserved in the form of sand dunes, which was the main sand source of development of land desertification; 17% were transported into the Yellow River and its tributaries, which were the main sediment source of the upper reach of the Yellow River; 14% were deposited on the surface as dust; less than 1% of the sediments deposited in the inland lakes and rivers; and a very small portion was transported great distance as suspension dust.

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