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The national census for soil erosion and dynamic analysis in China

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Abstract

The fourth national census for soil erosion was conducted in China during the period of 2010 – 2012. This census accomplished much: it determined the area of soil loss, both wind and water in China; the total number of erosion gullies; and the area benefitting from soil and water conservation measures in China. This paper presents census methodology, organization and the extent of soil and water conservation measures. Results show that the total soil erosion area is 2.95×10^6 km^2, in which 1.29×10^6 km^2 is water erosion located mainly in regions of high population density, and 1.66×10^6 km^2 is wind erosion mainly in Northwest China. Compared with data from the second remote sensing survey, the areas of water erosion and wind erosion have been reduced by 3.556×10^5 km^2 and 2.508×10^5 km^2 respectively. There were 666,719 erosion gullies counted in the Loess Plateau of Northwest China and 295,663 counted in the black soil region of Northeast China. There were 9.916×10^5 km^2 of land area that benefited from soil and water conservation measures, including 2.003×10^5 km^2 with engineering measures, 7.785×10^5 km^2 with biological measures, and 1.28×10^4 km^2 with other measures. This census will improve the current soil erosion database and will play a key role in future soil loss treatment.

Key Words: China, Soil erosion, Census, Dynamic changes

1 Introduction

The National Land and Water Resources Census helps in understanding the national status and changes in land and water resources in China. It also provides a quantitative basis for making decisions for sustainable economic development, for resource management and for resource use.

Americans began the National Erosion Reconnaissance Survey in 1934 (Nusser and Goebel, 1997; Goebel, 1998; Harlow, 1994). Shortly after that, the Soil Conservation Service was formed in the Department of Agriculture (Harlow, 1994). The sampling survey with a sample unit density 1% to 8% of soil erosion was started in 1956. The survey targets include soil type, land-use and area. The surveys have continued to the present, with the methodology continuously improved (Harlow, 1994; Nusser and Gobel, 1997; Gobel, 1998).

Europeans carried out a soil erosion risk assessment using the Universal Soil Loss Equation (USLE) model to evaluate the potential erosion risk and the actual erosion risk in 2002. Australia also launched a National Land and Water Resources Audit using a grid calculation method and based on the USLE model in 2000 (Yu and Rosewell, 1996; Yu, 1998).

China has conducted three remote sensing survey of soil erosion. Using the mid-1980s Landsat Multi-Spectral Scanning satellite images as the main information source, the first soil erosion survey was conducted using remote sensing. Soil erosion included water, wind, and freeze-thaw erosion.

The second survey began in 1999, using the mid-1990s Landsat Thematic Mapping (TM) image as the main information source. Geographic information system technology was applied to interpret the images, and then field verification was conducted. All of the works lasted 10 months, and a national 1 : 100,000 soil erosion classification and grading spatial database was established.

The third survey was in 2000 – 2001. The results of these surveys were very useful for providing a reliable and

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authoritative basis for developing "national ecological construction planning" and "national ecological protection planning", and for clarifying the key controlling areas in the Yangtze, Yellow and Pearl Rivers.

During the past decade during China's rapid economic and social development, the investment in soil and water conservation has increased, causing great changes in the soil erosion environment. Soil and water conservation research careers developed rapidly. Chinese scholars established and applied soil erosion models for the different erosion environments throughout the country. To obtain the latest information on soil erosion to better provide for improved soil and water conservation planning and governance, it was determined that it was necessary to conduct the fourth survey of soil erosion.

Law on Soil and Water Conversation required China to conduct its first national water census, which was also the fourth national census for soil and water conservation. The 3-year census accomplished much, particularly ascertained the condition of soil loss caused by water and wind, and the condition of soil and water conservation measures. This census provides the scientific basis for national strategies of ecological construction and soil and water conservation, and is very important for modernization of soil and water conservation. The scope of the last three Censuses included only the area, distribution, and intensity of soil erosion, while this census expanded its scope to the type, quantity, and distribution of water and soil conservation measures as well as the quantity, distribution, and area of erosion gullies in the Loess Plateau of Northwest China and in the black soil region of Northeast China.

2 Methodology

2.1 *Soil erosion census*

2.1.1 Model descriptions

The Universal Soil Loss Equation (USLE) is a widely-used equation for estimating soil erosion. It is used in many different countries, in many cases with modifications for local conditions. For several decades, Chinese scholars have used the USLE to conduct research on various types of eroded areas nationwide (Cai et al., 1996; Fu et al., 2001; Li and Liu, 1987; Liu, 2001; Zhang et al., 1992), and have studied the methods of computing USLE factors based on the characteristics of each type of eroded areas (Jia, 1986; Zhang, 1992; Zhang, et al., 2002). Based on these studies, a Chinese Soil Loss Equation (CSLE) (Liu et al., 2002) was developed including 7 factors of rainfall erosivity, soil erodibility, slope length, slope steepness, biological control practice and vegetation cover, engineering control practice and tillage control practice.

There are 2 major differences between the CSLE and the USLE. One is that soil conservation practice factors of cover and management used in the USLE were replaced by 3 factors of biological, engineering and tillage control according to Chinese soil conservation classifications. The other is that a steeper slope steepness factor equation was used based on measured data in the Loess Plateau (Liu et al., 1994).

This is the first time that the national census has used the CSLE and its various factors (e.g. weather, soil, topography, vegetation, land use, soil and water conservation measures) to compute the soil erosion rate, distribution and the area affected by soil erosion. The methodology of the census includes the collection of fundamental data, field survey, remote sensing, and model calculation.

Based on the different types of land use, three models were applied to calculate wind erosion on farmland, grassland, and sandy land respectively, which also is the Chinese characteristic model and has been applied to the wind erosion areas in China (Gao et al., 2012). The wind erosion model of farmland includes a wind factor, a soil moisture factor, and a terrain roughness factor; that of grassland and sandy land includes a wind factor, a soil moisture factor, and a vegetation coverage factor (Gao et al., 2012; Liu et al., 1998; Shi et al., 2005, 2006; Shi et al., 2008; Dobson et al., 1985; Zhang, 2002).

2.1.2 Primary sampling unit

In the soil erosion census, 33, 966 Primary Sampling Units (PSUs) were identified nationwide to collect factors of water erosion and wind erosion, with 32, 364 PSUs for water erosion and 2, 928 for wind erosion. Based on stratified sampling, those PSUs were distributed in various soil erosion areas with different densities in accordance with characteristics of soil erosion, and the densities of PSUs in different areas were determined in line with the following principles: in water erosion zones, PSUs were distributed with a density of 1%, but it decreased to 0.25% in plains, cities, and in counties whose number of PSUs was greater than 50, and the density was also 0.25% in the watershed of the Yarlung Zangbo River and its two tributaries in Tibet and Xinjiang Uygur Autonomous Regions; in wind erosion zones, the density of PUSs turned to be 0.25%, and it was the same in wind-water erosion zones.

The quality control techniques assured the accuracy of the design and data collection of PSUs. Based on the accuracy of the data, not only reliable estimates of the soil erosion rates of the sampling areas were acquired, but the accuracy of the soil erosion census was also improved.

2.2 *Gully census*

The Gully census was only carried out in the Loess Plateau of Northwest China and in the black soil region of Northeast China.

Based on past experience, a gully with a length longer than 500 m in the Loess Plateau was defined as a gully. In the black soil region, the length of a gully would be between 100 m and 5,000 m, and its watershed area should be less than 50 km^2.

Gullies were identified based on 2.5 m resolution remote sensing images and 1 : 50,000 digital line graph (DLG). Verification for identified gullies was accomplished by field visits, and by image and data analysis (Hu et al., 2004; Wu et al., 2008).

2.3 *Soil and water conservation measures census*

The numbers of conservation measures in every county of 31 provincial-level divisions (excluding Hong Kong, Macao and Taiwan) all over the country were collected by an analysis of the hydraulic, forestry, and agricultural annual statistical data and by review of statistical reports, engineering design and inspection data.

2.4 *Data collection*

2.4.1 Data for soil erosion census

In this census, the latest scientific achievements and data regarding water erosion and wind erosion were collected to compute erosion factors. The data included: 1) daily rainfall greater than 12 mm (erosive daily rainfall) for three decades, 1980 – 2009 or 1981 – 2010, from 2002 hydrologic stations and 959 weather stations as well as 6-hour interval wind speed and direction data from January to May and from October to the following March for two decades (1991 – 2010); 2) soil maps of the second national soil survey on a scale of 1 : 500,000 and 16,493 soil profiles that also included soil physical and chemical properties of 1,065 latest sampling points; 3) topographic maps nationwide on a scale of 1 : 50,000, topographic maps of PSUs on a scale of 1 : 10,000, and a national land use map on a scale of 1 : 100,000 in 2010; 4) remote sensing images with various spatial and spectrum resolutions, which include national 2.5 m high-resolution remote sensing images, 30 m resolution surface albedo from the HJ-1A/1B satellite, 1,000 m resolution MODIS data from 2005 to 2010, bright temperatures from Aqua/AMSR-E in 2010, AMSR-E trajectory data, a TRMM 3B42 data set from 1998 to 2010, APHRO_MA V1003R1 data from 1951 to 2007.

2.4.2 Data for gully census

2.5 m resolution remote sensing images and 1 : 50,000 digital line graphs (DLG) were used in the process of gully census.

2.4.3 Data for soil and water conservation measures census

Hydraulic, forestry, agricultural annual statistical data, annual statistical reports, engineering design and inspection data were used during the soil and water conservation measures census.

2.5 *Organization and quality control*

2.5.1 Census organization

In accordance with the unified deployment of the State Council Leading Group of the the First National Census for Water, census offices were established in all basins, cities, counties, provincial-level divisions and Xinjiang Production and Construction Corps (excluding Hong Kong, Macao and Taiwan). Technical teams were provided with the required equipment. Each census office at each level built a team for the soil and water conservation census. The soil and water census team of the Ministry of Water Resources defined the census directions, stages and methodology.

2.5.2 Technical team

This soil and water conservation census was the most difficult and technical in the history of the China soil and water conservation censuses. Many institutes and universities provided technical support to each census team at each level. Beijing Normal University, Institute of Soil and Water Conservation of Chinese Academy of Sciences (CAS) and Ministry of Water Resources (MWR), Institute of Soil Science of CAS, Institute of Mountain Hazard and Environment of CAS, were responsible for the calculation and analysis of soil erosion factors, rates, and intensities as well as map making. They provided 24 training courses for more than 3,000 technical staffs nationwide.

The census organization at each province and county also acquired technical support and training from local colleges.

2.5.3 Quality control

Quality control measures and defined process quality measurements for each phase throughout the whole census process were implemented. Once a quality audit of a phase was completed, audit comments were submitted.

After the census, observed data of almost a hundred plots for years as well as research findings of more than 200 papers were used to evaluate the census results to insure the reliability of the results.

3 Result and discussion

3.1 *Distribution, area, and intensity of soil erosion*

The total area of soil erosion is 2.949×10^6 km^2, covering 31.1% of the total census area, of which water erosion accounts for 1.293×10^6 km^2 and wind erosion makes up 1.656×10^6 km^2 as shown in Table 1. Compared to the soil erosion area of 3.556×10^6 km^2 in the second national remote sensing survey in 2002, that of this census is reduced by 17.1%, or 6.064×10^5 km^2.

Table 1 Area and percentage of soil erosion for water and wind erosion

Degree of erosion		Soil erosion type		Total erosion
		Water erosion	Wind erosion	
Slight	Area($\times10^4$ km^2)	66.7	71.6	138.4
	Percentage(%)	51.6	43.2	46.9
Moderate	Area($\times10^4$ km^2)	35.1	21.7	56.9
	Percentage(%)	27.8	13.1	19.3
High	Area($\times10^4$ km^2)	16.9	21.8	38.7
	Percentage(%)	13.0	13.2	13.1
Severe	Area($\times10^4$ km^2)	7.6	22.0	29.7
	Percentage(%)	5.9	29.7	10.1
Extreme	Area($\times10^4$ km^2)	2.9	28.4	31.3
	Percentage(%)	2.3	17.2	10.6
	Total eroded area ($\times10^4$ km^2)	129.3	165.6	294.9

1) Compared to the water eroded area of 1.649×10^6 km^2 in the second national remote sensing survey, the water eroded area for this census is reduced by 21.7%, 3.556×10^5 km^2. Slight and moderate erosion area is reduced by 19.6% and 36.7% respectively, while high eroded area was reduced by 5.38%. However, the severe and extreme eroded areas increased slightly because of steep slopes without conservation measures, land development and construction projects, and bare soil with no cover.

The provincial-level divisions where eroded area makes up more than 25% of its land area include Shanxi, Chongqing, Shaanxi, Guizhou, Liaoning, Yunnan, and Ningxia.

2) Compared to the wind eroded area of the second remote sensing survey of 1.907×10^6 km^2, that of this census is reduced by 13.15%, or 2.508×10^5 km^2. Slight, moderate, high, severe, and extreme erosion area is reduced by 9.2%, 13.5%, 12.0%, 18.4%, and 18.7% respectively.

The top four provincial-level divisions with the largest wind eroded area are Xinjiang, Inner Mongolia, Qinghai, and Gansu, the proportions of whose wind eroded area to the national total are 48.2%, 31.8%, 7.6%, and 7.6% respectively.

Since the mid 1980s, the Chinese government has identified the Loess Plateau and the upper reaches of the Yangtze River as key controlling areas, and invested considerable resources for comprehensive treatment. The census results demonstrate that the water eroded areas in Shaanxi, Ningxia, Shanxi, and Gansu in the Loess Plateau have decreased significantly. The proportion of the water eroded areas in those provinces decreased from 29.5% – 59.3% to 17.9% – 44.95%. The water eroded areas in Chongqing, Guizhou, Sichuan, and Yunnan in the upper reaches of the Yangtze River have reduced from 37.2% – 63.2% to 23.5% – 38.1%.

3.2 *Quantity, area, and distribution of gullies*

Some data on the gullies in the Loess Plateau of Northwest China and in the black soil region of Northeast China are shown in Tables 2 and 3. The province with the largest number of gullies in the Loess Plateau of Northwest China is Gansu Province which has 40.3% of the total gullies, followed by Shaanxi Province which accounts for 21.1% of the total gullies. Gullied areas in Gansu and Shaanxi provinces make up 28.9% and 24.0% respectively of the total gullied area in the Loess Plateau. In the black soil region, Heilongjiang Province has the largest number of gullies, accounting for 39.1% of the regional total; Inner Mongolia Autonomous Region has the largest gullied area, which accounts for 58.9% of the regional total.

Table 2 Gullies in the Loess Plateau of Northwest China

Region	Number of gullies	Area(ha)	Length(km)
Hilly and gully region	556,425	15671,937	470,978.8
Gully region of loess plateau	110,294	3049,520	92,299.4
Total	666,719	18,721,456	563,278.2

Table 3 Gullies in the black soil region of Northeast China

Type	Number of gullies	Area(ha)	Length(km)
Developing gullies	262,177	303,606	168,382.4
Stable gullies	33,486	61,236	27,130.3
Total	295,663	364,842	195,512.6

3.3 *Area, quantity, and distribution of the soil and water conservation measures*

3.3.1 Soil and water conservation measures

The total area benefitting from soil and water conservation measures is 9.916×10^5 km^2, among which 2.003×10^5 km^2 benefits from engineering measures, 7.785×10^5 km^2 benefits from biological measures, and 1.28×10^4 km^2 benefits from others. Areas benefitting from soil and water conservation measures are mainly distributed in the 11 provincial-level divisions of Hebei, Shanxi, Inner Mongolia, Liaoning, Jiangxi, Hubei, Sichuan, Guizhou, Yunnan, and Gansu, which make up 67.9% of the national total. The areas with the measures in each province are greater than 4.0×10^4 km^2, whereas that of Inner Mongolia, Sichuan, Yunnan, Shaanxi, and Gansu is greater than 6.0×10^4 km^2.

The current area with soil and water conservation measures is about 1.08×10^5 km^2 less than that reported in the 2011 China Statistical Yearbook. This is due to damage to soil and water conservation measures caused by natural hazards (droughts, floods, etc.) and damage caused by construction projects. In recent years, the proportion of the retained measures is relatively high due to protection by law and enhanced awareness of soil and water conservation in society.

3.3.2 Silt retention dams

A total of 58,446 silt retention dams have been built, with a silted land area of 927.57 km^2. Among them, there are 5,655 backbone silt retention dams with a storage capacity from 5.0×10^5 m^3 to 5×10^6 m^3 giving a total storage capacity of 5.701×10^9 m^3. Shaanxi and Shanxi Provinces have 51,259 silt retention dams and 3,654 backbone gully-control structures, which are 87.7% and 64.6% respectively of the national total.

4 Conclusion

4.1 *Census results and future erosion control*

The census results demonstrate that strong efforts can decrease water erosion in regions with high population. Furthermore, the distribution of soil and water loss areas demonstrates that the upper and middle reaches of the Yangtze River, the upper and middle reaches of the Yellow River, the black soil region in Northeast China, and the soil and stone mountain area in Southwest China are still suffering from severe erosion. These are key areas in the future for soil and water loss treatment. There is a need to continue implementing the ecological engineering plans in these areas, while promoting their economic development based on their distinctive industries.

The census results demonstrate that wind eroded areas are mainly distributed in the river sources in Northwest

China. Ecological self-restoration is an effective method that can quickly and economically achieve the goal of soil and water conservation in areas with low population density. Keeping the enclosure protection policy, and promoting plant recovery with ecological self-restoration in wide areas through active human intervention in relatively small areas has also been proven effective.

4.2 *Census result show locations of high risk erosion areas*

The census results show that severe water eroded areas are mainly distributed in regions with high population density and with increased hillslope farmland and gullies, the main source of river sand. It is necessary to speed up the control and management in these areas of hillslope farmland by implementing slope-to-terrace and related plans, in order to effectively slow runoff, reduce water and soil loss, and protect soil resources. In the Loess Plateau of Northwest China and in the black soil region of Northeast China, gully-control by combining biological and engineering measures in order should be enhanced immediately to reduce sediment load.

4.3 *Control man-made soil and water loss to improve the ecological environment*

According to the yield sampling survey, extreme erosion areas are distributed in mining areas where there are large quantities of production wastes that lead to severe man-made water and soil loss. In these areas, there is a need to comply with the policy of prevention and protection in the Soil and Water Conversation Act, to clarify mining companies' responsibilities for water and soil conservation, and to strictly execute the regulation of simultaneous design, execution, and inspection of soil and water conservation and main projects. If soil and water loss takes place, it is the mining company's responsibility to actively reduce these losses.

The census results show that in Eastern China where the economy is relatively advanced and people require high water quality and a good ecosystem, soil and water loss is slight. The goal of soil and water conservation is to improve people's living quality by building ecological and clean small watersheds to improve the circumstances and achieve a good ecological quality civilization.

In the future, the census results would be used to improve the fundamental database of soil and water conservation. This database will be used to analyze the conditions of water and soil loss in various areas, and to emphasize the important problems needing attention. This will guide implementation of soil and water conservation measures in needed areas based on scientific plans with definite goals, and provide a means for evaluation of progress in soil and water conservation in China.

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