ORIGINAL ARTICLE

Risk assessment of water soil erosion in upper basin of Miyun Reservoir, Beijing, China

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Abstract This research selected water soil erosion indicators (land cover, vegetation cover, slope) to assess the risk of soil erosion, ARCMAP GIS ver.9.0 environments and ERDAS ver.9.0 were used to manage and process satellite images and thematic tabular data. Landsat TM images in 2003 were used to produce land/cover maps of the study area based on visual interpreting method and derived vegetation cover maps, and the relief map at the scale of 1:50,000 to calculate the slope gradient maps. The area of water soil erosion was classified into six grades by an integration of slope gradients, land cover types, and vegetation cover fraction. All the data were integrated into a cross-tabular format to carry out the grid-based analysis of soil erosion risk. Results showed that the upper basin of Miyun Reservoir, in general, is exposed to a moderate risk of soil erosion, there is 715,848 ha of land suffered from water soil erosion in 2003, occupied 46.62% of total area, and most of the soil erosion area is on the slight and moderate risk, occupied 45.60 and 47.58% of soil erosion area, respectively.

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Introduction

Miyun Reservoir is the main surface source of the drinking water for Beijing with the population of 14.93 million (Beijing Municipal Commission of Population and Family Planning 2005). Sediments and nutrients from agricultural, pastoral and forestry lands that enter the reservoir with water soil erosion make the main pollution sources, and have an impact on the safety of water supply for Beijing, and on the operation and life span of the reservoir by destruction of water conservancy facilities (Zhou and Wu 2005). The problem of water soil erosion in the areas has a long history, always involving an overlap between long-term changes in climate and irrational human activities. In order to protect the water quality, it is necessary to reduce the soil erosion and improve the environment within the upper stream of Miyun reservoir (Yang et al. 2005). From the beginning of the reservoir operation, a series of environmental measures, such as water protection, afforestation, conversion of farmland back to forests or grassland, and so on (Gao 1999; Yu et al. 2004), have been taken to restored the deteriorated land and they have many obvious effects. As there is still a lot of land that suffered from soil erosion, it is very crucial to survey the status of soil erosion, especially risk assessment, at regional-scale for the comprehensive management work on the soil and water conservation.

Although risk assessment of water soil erosion is very important, it limited by data availability and quality (Anton 2006). The process of soil erosion is governed by numerous natural and anthropogenic factors, so soil

erosion risk can be assessed by soil properties, climate characteristics, vegetation, terrain, and ground cover (Lal 2001). Remote sensing provides data over large regions with a capability to regular revisit the same land area, and can therefore greatly contribute to regional soil erosion risk assessment by quickly deriving pertinent indices (Siakeu and Oguchi 2000; Boggs et al. 2001; Awasthi et al. 2002; Fan et al. 2004; Anton 2006).The objective of this study is to develop an efficient and fast simple way to directly assess water soil erosion risk and to detect its eroded areas in the region by using remote sensing and geographical information system (GIS) technology.

Materials and methods

Study area

The Miyun reservoir, built in 1960, is located in the north area of Beijing (Fig. 1). Its maximum volume of water storage is 4.375 billion m^3. The northern part of the reservoir is shallow and the southern part is deep. The maximum depth is 63.5 m (Gu et al. 2006). The upper basin of the reservoir, covering an area of 1,535,400 ha, includes parts of Miyun, Huirou, and Yanqing Counties of Beijing and Guyuan, Chicheng, Zhongli, Luanping, Huilai, Fengning, Xinglong, Chengde and Zhangjiakou Counties or Cities in Hebei Province. The morphological types are moderate and lower mountains, hill and valley, and the altitude varies between 150 and 1,800 m above sea-level.

The study area locates in warm temperate zone, and is representative of continental monsoon climate with semi-humid or semi-arid climatic characteristics that the evaporation is greater than the rainfall in a year. And it is also classified into warm climate with dry winter according to Cohen classification of the climate. It is cold and arid in winter, and torrid and humid in summer. The annual mean temperature is about 8–10°C. The mean annual rainfall is 400–600 mm, and rainfall patterns are highly variable, both monthly and annually. The majority of the rainfall occurs between July and September.

The soil layer of the region is superficial. According to Chinese Soil Taxonomy (Chinese Soil Taxonomy Research Group 1995), the soil taxa are mainly mountain meadow soil, brown forest soil, and cinnamon soil. The annual average soil erosion modulus is 12–16 ton/ha and the annual amount of bedloads is about 5.72 million tons carried into the reservoir by runoff. The region has been suffering from serious soil erosion and it was considered a priority area for soil conservation project in China in twenty-first century.

Datasets

The digital elevation model (DEM) with a spatial resolution of 30 m was derived from topographical map at the scale of 1:50,000, surveyed by State Bureau of Surveying and Mapping in 1980s.

Three scenes of Landsat TM (Thematic Mapper) images were collected from July 2003. Landsat TM image were used to derive vegetation fraction (VF) and to prepare land cover data by visual interpreting method. And the classes of land cover include farmland, forest land, grass land, water area, construction area, sandy land, meadow land, alkaline land, naked soil and naked rock.

Risky level systems

The water soil erosion is the loss of surface soil caused by rain and runoff water, and the intensity of it is measured by the mount of soil loss in a year, i.e., the modulus of soil loss, in China (The Ministry of Water Resources of the People's Republic of China 1997; Ma et al. 2002; Yang et al. 2006). The water soil erosion risk could be assessed by the intensity of water soil erosion. The area suffers from water soil erosion with higher intensity and is also at high level risk of water soil erosion. The impact factors on soil erosion intensity mainly involved slope gradient, vegetation cover and land use. Therefore, soil erosion risk can be defined as a response of the regional environment to changes in these factors (Renard et al. 1997; Wang et al. 2005). In the soil erosion survey, these factors can also be used as the indices to evaluate the soil erosion risk. Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) have been developed to quantitatively predict the amount of soil loss by National Soil Erosion Research Laboratory of USA, and have been applied successfully (Yang et al. 2006). In the national professional standard of SL190-96 Standards for classification and Gradation of Soil Erosion (The Ministry of Water Resources of the People's Republic of China 1997), soil erosion intensity was divided into six grades by these affecting factors (Table 1), and the input parameters required by the evaluated model can be easily derived by GIS and remote sensing techniques. With SL190-96 Standards, the monitoring water and soil erosion has been successively carried out at national and regional scales in China (Zhao et al. 2002; Chen et al. 2005).

In the study, the soil erosion risk is also graded into six levels according to water and soil erosion density in SL190-96, i.e., lower, low light, moderate, high, higher and highest risk (Table 2) (The Ministry of Water Resources of the People's Republic of China 1997; Qiao and Qiao 2002; Li and Luo 2006). The water and soil erosion density is scaled by the soil loss modulus or the depth of soil erosion (Yuan 1999).

Fig. 1 Location map of the study area
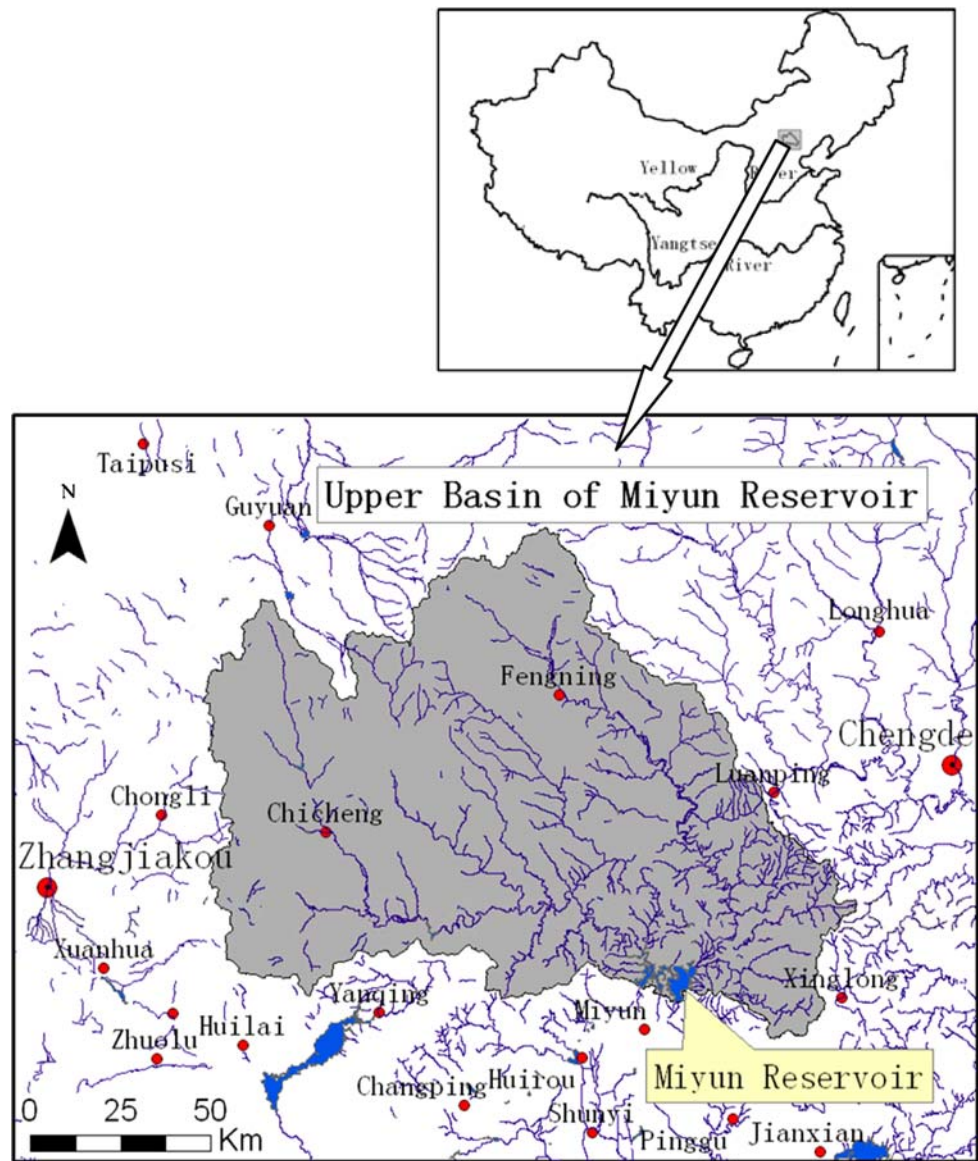
Table 1 Index cross-table of soil erosion intensity

Ground cover	Vegetation fraction (%)	Slope gradient (°)					
		<5	5–8	8–15	15–25	25–35	>35
Non-farmland	>70	ST	ST	ST	ST	ST	ST
	60–70	ST	LT	LT	LT	MT	MT
	45–60	ST	LT	LT	MT	MT	SR
	30–45	ST	LT	MT	MT	SR	MS
	<30	ST	MT	MT	SR	MS	ES
Farmland		ST	LT	MT	SR	MS	ES

ST slight, *LT* light, *MT* moderate, *SR* severe, *MS* more severe, *ES* extremely severe

Table 2 Soil erosion risk level and intensity

Risk level	Intensity	Modulus (ton/ha year)	Depth (mm/year)
Lower	Slight	<10	<0.74
Low	Light	10–25	0.74–1.90
Moderate	Moderate	25–50	1.90–3.70
High	Severe	50–80	3.70–5.90
Higher	More severe	80–150	5.90–11.10
Highest	Extremely severe	>150	>11.10

Method

The soil erosion was dependent mainly on terrain, vegetation cover, soil taxa, rainfall, and land cover (Fan et al. 2004). The intensity, duration and frequency of rainfall affected the amount of soil loss, and the characteristic of rainfall is controlled by the climate and is external soil loss factors. The composition and bond strength of soil taxa decide the erosibility of land surface, and it could be represented indirectly by land cover. Thus the soil

erosion risk can be judged by slope gradient, vegetation cover rate and land cover. With ARC/INFO and ERDAS software, information on slope gradients, vegetation cover and land cover was used to evaluate the soil erosion risk of this region. First, according to the classification indices of soil erosion risk, the datasets of VF and slope gradient were graded on the other land cover types except naked rock. Then, the soil erosion risk was searched in Table 1 for each grid of the other land cover types except naked rock.

Slope gradient had a significant influence on surface runoff and soil erosion. Slope gradient dataset was created by using SLOPE function in ARCGRID of ARC/INFO and the RECLASS function in ARCGRID to create gradient grid classified with the values of 5, 8, 15 25 and 35 (Fig. 2).

VF is a most important index to score the vegetation coverage on the land surface. As the value of radiant energy emitted from each pixel of land surface could be divided into two parts of energy coming from barren soil and vegetation, respectively, the ratio of the vegetation energy to total energy can represent the VF of the pixel. The dimidiate pixel model has been developed to quantify VF from normalized difference vegetation index (NDVI), which is derived from the near red band and red band of the remotely sensed data.

$$NDVI = [NIR - R]/[NIR + R]$$

where NIR is near infra band and R is red band of Landsat TM image in the study. The dimidiate pixel means that the radiate energy of one pixel is assumed to be made of two parts of energy; one comes from the vegetation and the other from barren land.

In the model, VF is calculated by the formula:

$$VF = (NDVI - NDVIsoil)/(NDVIveg - NDVIsoil)$$
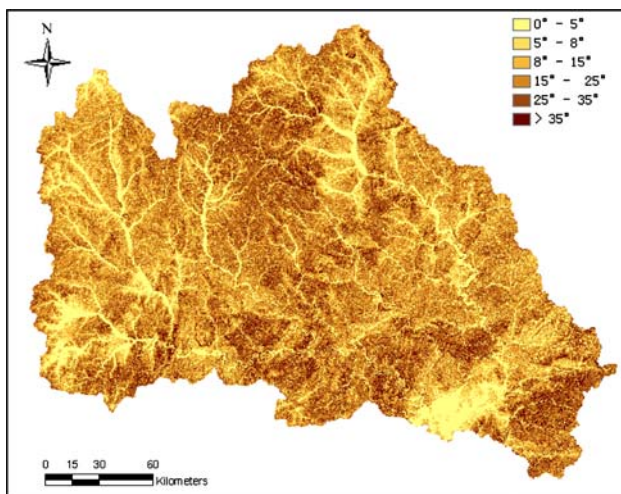
where NDVIsoil and NDVIveg are two input parameters of the model, and they represent the NDVI value of pure pixel of barren soil and vegetation, respectively.

In the study, the model deduced NDVIsoil and NDVIveg with the ancillary data of vegetation map and soil map. Then based on the division units extracted by overlaying the land cover database and soil taxa database, VF data sets in summer of the study area have been estimated for each division unit from NDVI derived from Landsat TM data. Based on the grading scale of 30, 45, 60, and 75, the VF data was reclassified (Fig. 3).

The visual interpretation of TM has been employed to derive land cover data sets. Although this method is labor intensive and time consuming, the mapping accuracy of this method is higher than that of image classification using the algorithms provided by image-processing software because of the low spatial and spectral resolution of TM images (Liu 1996; Zhuang et al. 1999). Therefore, manual visual interpretation and digitization of the TM images was done at a scale of 1:100,000 to generate land cover datasets, with the classification assisted by the ARCMAP software. In order to produce cross-table, they were then reclassified into three major land cover types, i.e., farmland, non-farmland, and naked rock (including constructed area) (Fig. 4).

Results

The results show that 715,848 ha of land suffered from soil erosion and occupied 46.62% of total area (Table 3). Most of the soil-eroded area is on the low and moderate risk level, occupied 45.60 and 47.58% of soil-eroded area, respectively. Therefore, the study area, in general, is exposed to a moderate risk of soil erosion. Only 3.16% of area is on high, higher and highest level of soil-erosion risk.

Fig. 2 Slope gradient map of the study area
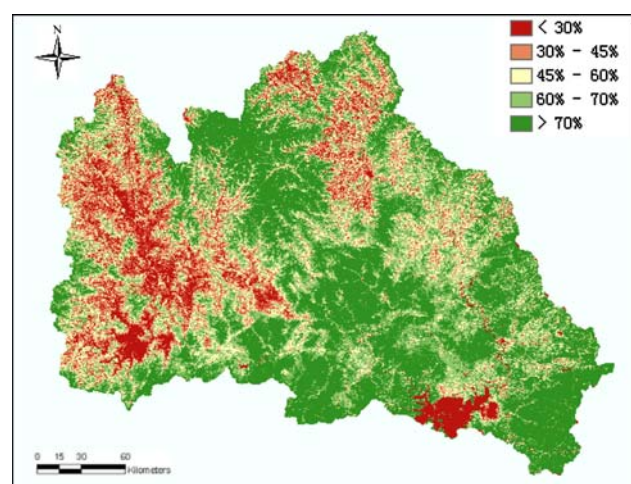
Fig. 3 Vegetation fraction map of the study area
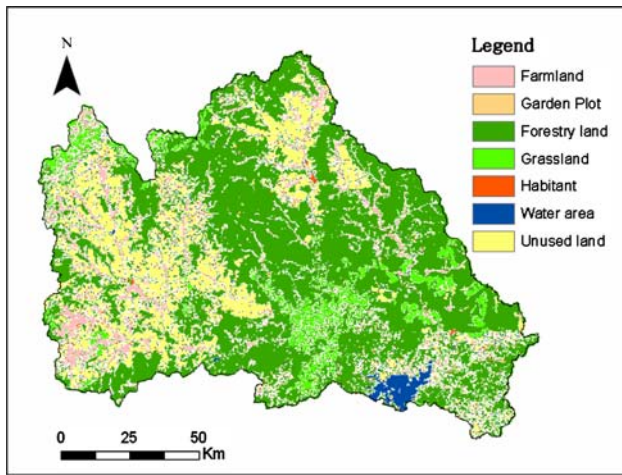
Fig. 4 Land cover map of the study area
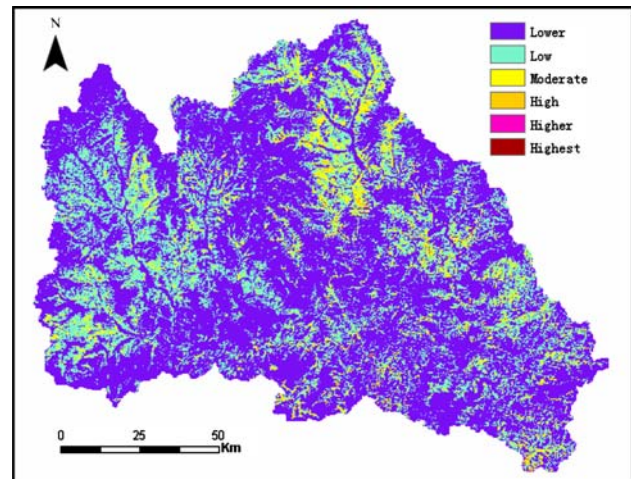
Fig. 5 Soil erosion risk map of the study area

Among all counties and cities, Zhangjiakou City has highest soil-erosion risk, and 73.72 % of land suffered from soil erosion. Chengde has lowest risk, and has only 3.27% soil-eroded area (Fig. 5).

With the spatial pattern, the high level of soil-erosion risk is distributed on the unused land and sparse vegetation area. The area with the larger gradient is mostly covered by high fraction vegetation, and is on lower level of soil erosion risk than that with little gradient.

Conclusions and discussion

This research demonstrates that the model developed at the pixel scale was an effective tool for fast assessment of soil erosion risk in a watershed by the integration of

remote-sensed data with thematic tabular data with the help of GIS. The approach developed was able to determine soil risk quantitatively over a large area. The changes of soil erosion intensity can be detected by the comparison of soil erosion risk in different periods.

From the model, it could be concluded that the soil-erosion risk can be reduced by biological measures to increase vegetation cover, for conversion of farmland to forest land or grass land in the area where slope gradient is greater than 25° and to engineer measures to diminish the slope gradients.

These results can be used as basic data to assist water and soil conservation management and land-use planning, and the methods used in the study are valid for generalized planning and assessment purposes to identify the areas that are vulnerable to water and soil loss.

Table 3 Acreage of different soil erosion risk in of upper basin of Miyun Reservoir

County or city	Total acreage	Lower		Low		Moderate		High		Higher		Highest	
	ha	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Huirou	128,286	97,558	76.05	20,276	15.81	10,211	7.96	191	0.15	40	0.03	9	0.01
Miyun	148,216	105,712	71.32	28,453	19.20	12,774	8.62	1,021	0.69	222	0.15	34	0.02
Yanqing	72,840	56,419	77.46	10,162	13.95	6,126	8.41	130	0.18	3	0.00	0	0.00
Guyuan	38,954	16,622	42.67	11,036	28.33	10,019	25.72	1,168	3.00	106	0.27	3	0.01
Huilai	1,760	935	53.14	489	27.77	334	18.98	2	0.11	0	0.00	0	0.00
Chicheng	526,885	202,024	38.34	106,607	20.23	182,092	34.56	32,258	6.12	3,790	0.72	115	0.02
Zhongli	10,111	3,152	31.17	3,090	30.56	3,416	33.78	406	4.02	45	0.44	3	0.03
Zhangjiakou	2,686	706	26.28	334	12.43	1,380	51.38	205	7.63	53	1.97	8	0.30
Fengning	416,976	204,208	48.97	105,928	25.40	98,751	23.68	7,500	1.80	555	0.13	32	0.01
Xinglong	45,779	43,697	95.45	1,332	2.91	630	1.38	75	0.16	41	0.09	5	0.01
Luanping	141,095	86,766	61.50	38,682	27.42	14,879	10.55	534	0.38	169	0.12	64	0.05
Chengde	1,835	1,776	96.80	30	1.65	21	1.13	5	0.25	3	0.14	1	0.04
Total	1,535,423	819,575	53.38	326,419	21.26	340,633	22.18	43,495	2.83	5,027	0.33	274	0.02

References

Anton V (2006) Satellite remote sensing for water erosion assessment: a review. Catena 65:2–18

Awasthi KD, Sitaula BK, Singh BR, Bajacharaya RM (2002) Land-use change in two Nepalese watersheds: GIS and geomorphometric analysis. Land Degrad Dev 13:495–513

Beijing Municipal Commission of Population and Family Planning (2005) New status and characteristics of population development of Beijing. http://www.bjfc.gov.cn/Article/Detail.asp?UNID=8524

Boggs G, Devonport C, Evans K, Puig P (2001) GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. Land Degrad Dev 12:417–434

Chen WH, Liu LY, Zhang C, Pan YC, Wang JH, Wang JD (2005) The fast method of soil erosion investigation based on remote sensing. Res Soil Water Conserv 12:8–10

Chinese Soil Taxonomy Research Group, Institute of Soil Science, Academia Sinica and Cooperative Research Group on Chinese Soil Taxonomy (1995) Chinese soil taxonomy (Revised Proposal). China Agricultural Science and Technology Press, Beijing

Fan JR, Zhang JH, Zhong XH, Liu SZ, Tao HP (2004) Monitoring of soil erosion and assessment for contribution of sediments to rivers in a typical watershed of the upper Yangtze river basin. Land Degrad Dev 15:411–421

Gao JR (1999) Construction and countermeasures of water protection forest in Miyun reservoir watershed of Beijing City. Bull Soil Water Conserv 19:1–6

Gu ZW, Zhan ZJ, Gao JT, Yao TQ, Chen B (2006) Seismomagnetic research in Beijing and its adjacent area, China. Phys Chem Earth 31:258–267

Lal R (2001) Soil degradation by erosion. Land Degrad Dev 12:519–539

Li ZG, Luo ZD (2006) On method for evaluating soil erosion severity in county scale—index of soil erosion severity and its application. Bull Soil Water Conserv 26:41–51

Liu JY (1996) Macro-scale survey and dynamic study of natural resources and environment of China by remote sensing. China Science and Technology Press, Beijing, pp 113–124

Ma XW, Yang QK, Liu BY (2002) Assessment of China potential soil and water loss based on GIS. J Soil Water Conserv 16:49–54

Qiao YL, Qiao Y (2002) Fast soil erosion investigation and dynamic analysis in the loess plateau of China by using information composite technique. Adv Space Res 29:85–88

Renard KG, Kertesz A, Markus B, Richter G (1997) Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Agricultural handbook No. 537. United States Department of Agriculture, Washington, p 665

Siakeu J, Oguchi T (2000) Soil erosion analysis and modeling: a review. Trans Jpn Geomorphol Union 21:413–429

The Ministry of Water Resources of the People's Republic of China (1997) National professional standards for classification and gradation of soil erosion, SL 190-1996

Wang XD, Zhong XH, Fan JR (2005) Spatial on the distribution of soil erosion sensitivity on the Tibet Plateau. Pedosphere 15:465–472

Yang DZ, Xu XD, Liu XD, Xu Q, Ding GA, Cheng XH, Chen HL, Zhou HG, Wang ZF, Wang WY (2005) Complex sources of air-soil-water pollution processes in the Miyun reservoir region. Sci China Ser D Earth Sci 48((Supp. II)):230–245

Yang QK, Li R, Cao MM (2006) Advances of quantitative assessment on regional soil erosion. Adv Earth Sci 21:848–855

Yu XX, Niu JZ, Xu JL (2004) Effects of closing mountain for forest restoration in the watershed of Miyun reservoir Beijing. For Stud China 6:28–35

Yuan JP (1999) Preliminary study on grade scale of soil erosion intensity. Bull Soil Water Conserv 19:54–57

Zhao XL, Zhang ZX, Liu B, Wang CY (2002) Method of monitoring soil erosion dynamic based on remote sensing and GIS. Bull Soil Water Conserv 22:29–32

Zhou WF, Wu BF (2005) Soil erosion estimation of the upriver areas of Miyun Reservoir located on the Chaobai River using remote sensing and GIS. Trans CSAE 21:46–50

Zhuang DF, Liu JY, Liu ML (1999) Research activities on land use/ land cover in the past ten years in China using space technology. Chin Geogr Sci 9:330–334