Potential and Efficiency of Agricultural Pollution Control in China and Its Influential Factors

Jing LI*, **Hong LI**, **Lijun XIE**

School of Economics, Heifei University of Technology, Hefei 230009, China

Abstract Agricultural pollution has become the dominant source of water pollution in China and the carbon reduction in agricultural aspect is pressing. Based on list analysis method, the COD, TN and TP in agriculture in 28 provinces in China from 1995 to 2010 were evaluated and compared. By dint of directional distance function, the economics mechanism to reduce carbon emission was discussed. The reduction efficiency and potential of three kinds of pollutants were estimated. The regression indicates that the educational degree, income level and work play a crucial role in carbon emission.

Key words Agricultural pollution, Potential of carbon emission, Efficiency of carbon emission, Directional distance function, Influencing factors

1 Introduction

At present, agricultural pollution in China has become the second dominant pollutant of water pollution after the industrial pollution. According to the first national pollutants report, the COD, TN and TP in agriculture industry were up to 13.240 9 million tons, 2.704 6 million tons and 0.284 7 million tons respectively in 2007. After the industrial pollution being controlled, agricultural and rural pollution has become the key of next step. Therefore, in order to ease the pressure of overall emission reduction, reducing the agricultural pollution would inevitably be emphasized. Thus, we have to consider the potential of agricultural pollution emission, and reduction efficiency. In terms of reduction of agricultural pollution, following key problems should be answered: (1) What are the status quo and evolvement of agricultural pollution? What are the distribution characteristics of agricultural pollution in each place? Right now, there is no more specific statistics besides of the basic information in 2007, which hinders the formulation of policies on agricultural pollution emission. (2) What's the potential of agricultural pollution control? How is the disparity of potential and efficiency of carbon emission in each place? These provide actual basis for the formulation of agricultural pollution target and policy. (3) What are the factors that restrain the agricultural pollution control? The emissions of COD, TN and TP in each province in China were evaluated through list analysis method to study the status quo and distribution of agricultural pollution in China. Direction function was applied to study the potential and efficiency of agricultural pollution control. Factors which influence agricultural pollution control in China were analyzed and reasonable countermeasures were put forward.

Received: June 20, 2013 Accepted: August 9, 2013

Supported by National Natural Science Fundation (71103057); Anhui Natural Science Fundation (11040606Q29); Major Project of National Philosophy and Social Science (08ZD&043).

* Corresponding author. E-mail: lyb@hfut.edu.cn

2 Temporal evolvement and spatial characteristics of agricultural pollution in China

It is a daunting task for China to keep 22% of world population alive based on no more than 7% arable lands in the world. To improve the yield per unit area becomes the major objection of modern agriculture in China amid the population growth, industrialization and urbanization. As a result, modern agricultural development model features "high input, high yield, and high-amount of wastes". Especially on the water pollutants, agricultural pollution and rural pollution have become the primary pollution. We takes Taihu Lake as an example. Researches by the Nanjing Soil Research Institute of Chinese Academy of Sciences suggest that industrial pollution only accounted for 10 to 16% of the general exterior pollution, while the non-point pollution of agriculture rose to 59%[1]. Consequently, the pollution control must be changed from pure industrial pollution reduction to agriculture and industry pollution reduction.

However, right now the basic system to investigation agricultural pollution has not been found yet, so it is impossible to learn the agricultural pollution and its distribution. Corresponding studies are based on the pollution unit of agriculture and countryside in each place and the relationship between pollutants and pollution emission. The formula to evaluation the agricultural pollution was as follow:

$$E = \sum_i EU_i\rho_i(1-\eta_i)C_i(EU_i, S) = \sum_i PU_i\rho_i(1-\eta_i)C_i(EU_i, S) \quad (1)$$

Here, E stands for the emission of agriculture and countryside pollution. EU_i stands for the statistics of ith indicator; ρ_i stands for the coefficient of pollution intensity of the ith pollutant; η_i is the coefficient of relevant resources use efficiency; PE_i is the amount of agriculture and countryside pollution, namely maximum potential pollutants in agricultural production and management; C_i is the emission coefficient of pollutant j in unit i. It is determined by unit and spatial characteristics, suggesting influences of region-al environment, precipitation, hydrology and each kind of management measure on agriculture and countryside pollution. In addition, the data for this study mostly come from annual *Statistic Yearbook of China*, *Rural Statistic Yearbook of China*, *Chinese Agricultural Yearbook*, *Compilation of Statistics in New China in* 60 *Years*, and Provincial *Statistics Yearbook*.

2.1 Temporal evolvement of agricultural pollution emission

The discharge of COD, TN and TP in each year is shown in Table 1. Results suggested that the emission of agriculture and countryside pollution was more suitable based on list analysis method, and the analysis methods and indicators are more credible.

Compared with the living COD and industrial COD emission in China, the agricultural COD is larger than living and industrial COD in most years, and so is the emission of TN and TP, which suggests that the agricultural pollution has become the major source of water pollution in China.

The agricultural pollution emission showed phased features from 1995 to 2010. It first increased rapidly and then dropped before increasing slowly, and later decreased again after 2006. In 1997, the drop of produce price, coupled with Southeast Asia financial crisis, the development of entire agriculture was restrained, which made contribution to carbon emission. The COD emission in 1997 was reduced by 1.6267 million ton than that in 1996. Agricultural pollution increased gradually amid the steady development of agriculture. The emission of these three kinds of pollutants grew at the annual average rage of 2%, 1.8% and 1.6% from 1997 to 2005. After 2006, the three pollutants decreased, which was closely related to the changes of agricultural structure and reduction of husbandry scale. In 2010, there three pollutants increased again, rising by 2.02%, 1.37% and 5.95%.

Table 1 Total emission of Agricultural pollution (1995 – 2009) (10^4 ton)

Year	COD	TN	TP	Year	COD	TN	TP
1995	1 359.387 0	329.155 2	43.159 8	2003	1 405.108 0	351.096 2	45.802 2
1996	1 411.824 0	345.722 2	44.331 2	2004	1 440.572 0	363.893 8	46.902 7
1997	1 249.159 0	319.809 5	41.943 5	2005	1 461.147 0	369.382 3	47.521 2
1998	1 318.206 0	334.235 0	43.182 4	2006	1 432.064 0	367.399 4	46.867 0
1999	1 337.970 0	336.874 0	43.736 5	2007	1 281.595 0	341.673 3	45.406 5
2000	1 360.317 0	338.686 6	44.222 9	2008	1 299.530 0	346.084 8	46.152 4
2001	1 359.573 0	340.445 1	44.050 7	2009	1 284.475 0	346.017 5	46.203 4
2002	1 387.197 0	346.749 6	45.296 3	Mean	1 359.208 0	345.148 3	44.985 2

2.2 Spatial characteristics of the agriculture pollution According to Fig. 1, the agricultural pollution emission in different places showed different characteristics. Four categories can be divided based on emission: I represents the one with large emission, such as Hebei, Shandong, Henan and Sichuan, *etc*. II refers to the one with large emission, such as Anhui, Hubei, Hunan, Guangxi, Yunnan, Guangdong and Jiangsu, *etc*. III means places with little pollution, such as Inner Mongolia, Gansu, Heilongjiang, Jilin, Liaoning, Jiangxi and Fujian, *etc*. IV stands for places with little emission, such as Shanxi, Qinghai, Beijing, Tianjin, Shanghai, Shaanxi, and Xinjiang, *etc*. Apparently, I and II areas are major places which produce products. The large population and husbandry plantation are the major reasons of high emissions.

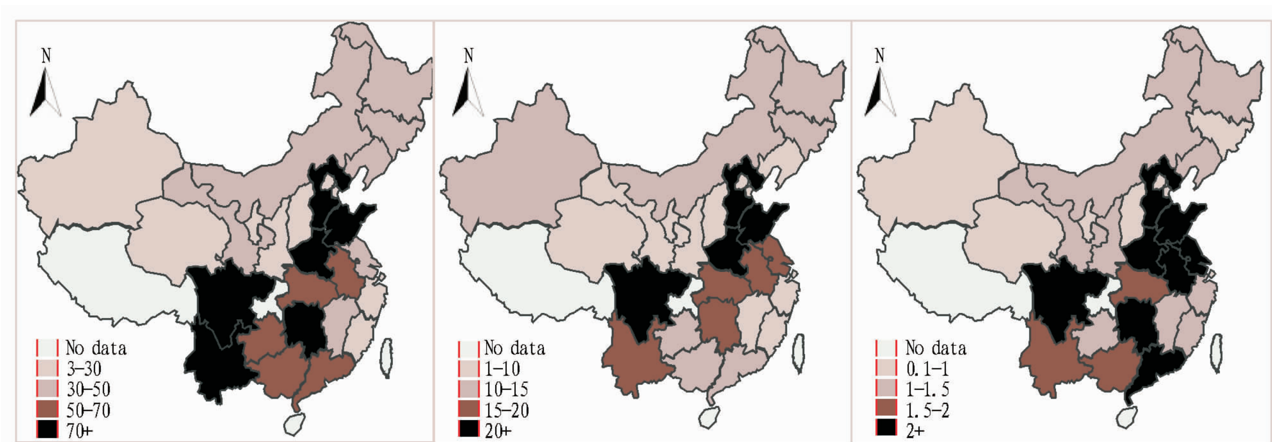

Fig. 1 Annual mean agriculture pollution emission from 1995 to 2009

3 Potential and efficiency of emission reduction agriculture industry in China

3.1 Study methods and concepts According to theories by Chung, Fare and Grosskopf (1907), the environment distance function is defined to get the desirable yield based on given input. The defined input vector , desirable output vector $X = (X_1, \cdots, X_N) \in R_+^N$, undesirableundesirable output, output vector of pollution $Y = (Y_1, L, Y_N) \in R_+^M$. The three vectors are input, pollution discharge, and economic output. Input X stands for agricultural labor force L, fixed asset K and input in agriculture Z, while the economic output refers to the total agriculture production value Y. The possible technological congregation of production

$$P(X) = \{(X^t, b^t, Y^t) \mid X^t \text{ can produce } (Y^t, b^t)\} \quad (2)$$

$P(X)$ can meet the possibility of standard production. First, 0 connection: (K, L, E, Y, C) ∈ P. If C = 0, Y = 0. Second, weak possibility, (K, L, E, Y, C) ∈ P. If $0 < \lambda \leqslant 1$, (K, L, E, Y, λC) ∈ P . Third, desirable strong possibility: (K, L, E, Y, C) ∈ P, if Y' ⩽ Y, (K, L, E, Y', C) ∈ P. Fourth, strong investment. (K, L, E, Y, C) ∈ P, if (K', L', E') ⩽ (K, L, E), (K', L', E', Y, C) ∈ P. Suppose directional vector $g = (g_y, g_b)$, $g \in R_+^M \times R_+^J$, the output directional distance function can be defined as

$$\vec{D}_o(X, Y, b; g_r, g_b) = \max\{\beta: (Y + \beta g_y, b - \beta g_b) P \in (X)\} (3)$$

$\vec{D}_o(X, Y, b; g_r, g_b)$ is shorten for $\vec{D}_o(\cdot)$. Directional vector g determines the addition of desirable output and reduction of less-desirable production[3-4]. The directional vector in this study supposed $g = (y, -b)$.

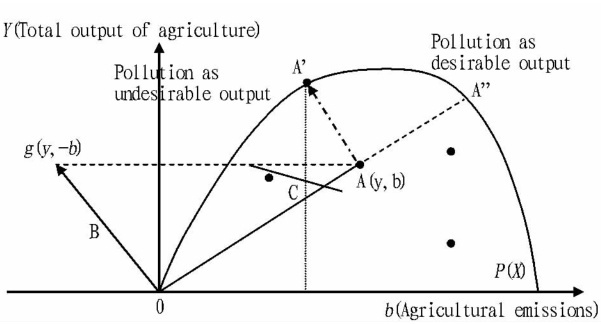

Fig. 2 Economics mechanism of emission reduction in agriculture

$\vec{D}_o(\cdot)$ can get the result through DEA form. Suppose the distance function of the t[th] year in the k[th] province can be written as

$$\vec{D}_o = \max\beta$$

$$\text{s.t.} \sum_{k=1}^{28} \lambda_k^t Y_k^t \geqslant (1 + \beta) Y_{km}^t,\ m = 1;\ \sum_{k=1}^{28} \lambda_k^t b_k^t \geqslant (1 + \beta) b_{kj}^t,\ j = 1 \quad (3)$$

$$\sum_{k=1}^{28} \lambda_k^t X_{kn}^t \leqslant X_{kn}^t,\ n = 1, 2, 3;\ \lambda_k^t \geqslant 0,\ t = 1995, \cdots, 2009,\ k = 1, \cdots, 28 \quad (4)$$

where, X refers to the three input variables, labor force, fixed asset and agriculture intermediate input. The desirable output and undesirable output refers to the general output of agriculture and three kinds of pollutants. is the weight vector of linear planning, and the optimal weight value can be get through DEA. $\sum_{k=1}^{28} \lambda_k^t b_k^t = (1 - \beta) b_{kj}^t$ suggests that it costs to deal with agricultural output and pollution.

3.2 Potential and efficiency of agriculture pollution control

The data and process method in the calculation are similar to that in Shi Hui's experiment[5]. The agriculture input, fixed asset and total production of agriculture were processed according to the fixed price in 19 952. Results were shown in Table 2.

Table 2 is the regression result of the determiner of three kinds of pollutants. Results suggest that the panel data is the optimal option. These three kinds of pollutants are applicable to the fixed effect model as the final evaluation form.

Furthermore, it has been shown that the environment efficiency of output and emission reduction was in a linear relationship with the reduction efficiency of three kinds of pollution, which suggested that the growth of Chinese agriculture was the result of win-win situation.

Table 2 Potential and efficiency of emission reduction of agriculture in each place from 1995 to 2009

Places	Efficiency	COD potential	COD efficiency	TN potential	TN efficiency	TP potential	TP efficiency
Anhui	0.774 8	22.812 2	0.630 9	7.311 4	0.554 6	0.821 5	0.633 7
Beijing	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0
Fujian	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0
Gansu	0.658 7	23.216 9	0.273 5	5.557 2	0.294 2	0.657 4	0.358 9
Guangdong	0.957 1	5.880 8	0.906 6	0.583 9	0.959 3	0.125 3	0.945 1
Guangxi	0.912 4	14.876 1	0.793 3	1.400 5	0.902 1	0.255 3	0.871 1
Guizhou	0.670 9	41.735 1	0.271 0	6.974 8	0.383 0	0.926 6	0.382 2
Hebei	0.714 2	44.872 7	0.427 0	12.022 2	0.434 0	1.229 6	0.535 2
Henan	0.700 9	75.727 7	0.400 5	20.324 5	0.386 4	2.061 8	0.504 2
Heilongjiang	0.827 4	15.144 7	0.646 7	3.479 8	0.683 3	0.209 3	0.829 4
Hubei	0.989 7	0.858 8	0.984 1	0.340 5	0.978 9	0.022 1	0.988 3
Hunan	0.794 5	34.793 9	0.566 7	5.191 7	0.697 0	0.759 3	0.694 6
Jiangsu	0.993 9	0.325 9	0.993 0	0.221 4	0.987 0	0.015 2	0.993 2
Jiangxi	0.918 4	8.051 9	0.827 8	1.189 6	0.882 1	0.182 3	0.874 3
Jilin	0.803 2	14.840 7	0.590 4	4.546 9	0.550 7	0.115 8	0.876 4
Liaoning	0.945 7	4.313 0	0.884 7	0.977 6	0.897 1	0.035 3	0.969 3
Inner Mongolia	1.000 0	0.000 0	1.000 0	0.0000	1.000 0	0.000 0	1.000 0
Ningxia	0.673 9	4.049 1	0.345 2	1.478 7	0.284 6	0.122 9	0.432 8
Qinghai	0.606 3	16.123 7	0.200 1	3.549 1	0.250 1	0.282 3	0.329 6
Shandong	0.809 1	34.308 4	0.664 7	11.091 7	0.618 7	0.843 3	0.764 9
Shanghai	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0
Shaanxi	0.726 8	13.973 9	0.524 7	4.982 5	0.430 5	0.534 1	0.530 0
Shanxi	0.693 8	13.624 9	0.414 7	3.950 9	0.405 3	0.584 1	0.399 4
Sichuan	0.792 0	68.888 5	0.552 5	8.987 8	0.717 7	1.700 9	0.627 3

(Table 2)

Places	Efficiency	COD potential	COD efficiency	TN potential	TN efficiency	TP potential	TP efficiency
Tianjin	0.942 4	0.716 9	0.872 1	0.127 3	0.917 3	0.009 6	0.952 0
Xinjiang	0.883 1	4.345 1	0.846 2	2.769 7	0.732 0	0.141 9	0.853 0
Yunnan	0.717 7	44.121 8	0.382 3	7.450 8	0.504 3	0.861 7	0.537 3
Zhejiang	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0	0.000 0	1.000 0
Sum	0.839 5	507.602 7	0.678 5	114.510 5	0.694 6	12.497 6	0.745 8
East China	0.93 62	90.417 7	0.874 8	25.024 1	0.881 3	2.258 2	0.915 9
Central China	0.812 8	185.854 7	0.632 7	46.335 3	0.642 3	4.756 3	0.725 0
West China	0.764 2	231.330 3	0.518 9	43.151 1	0.549 9	5.483 1	0.592 2

4 Factors influencing the reduction emission reduction of pollution in agriculture

Seeing that there are not any standards on energy reduction and pollution control[1], unlike industry and urban city, factors influence the emission reduction were studied[2]. Considering the characteristics of small scale agricultural production, decisions on agricultural production are restricted by family characteristics and factors. Therefore, factors influencing the agricultural pollution reduction will be considered in the angle of agricultural family.

At first, the education of the farmer is an important indicator of national agricultural modernization, while agricultural technological training is an essential channel to improve farmers' education level. Besides, the role of produce can be reused. Expected education degree is an important factor which affects the emission reduction in agriculture. Next comes income level. There are two effects on carbon emission control which result from the improvement of farmers' income: income effect and replacement effect. Besides, the capacity to engage in agricultural production is an important factor which determines the agricultural pollution and efficiency. The plantation per capita reflects how much people depend on the land. The expansion of sowing area per capita shows scale economic effect. Farmers with high income scale can effectively reduce the fixed income cost and management cost, which can lower the income per capita. With expansion of sowing area per capita, it is possible for farmers to replace organic fertilizer with fertilizer, which in return aggravate the loss of fertilizers. Meanwhile, the mechanism might limit the running efficiency of agricultural production.

The dependent variables in this function include emission efficiency of COD, TN and TP, while the independent variables cover capital, land scale, population and labor force, salary, education and income.

$$EE_{it} = \alpha_0 + \alpha 1 y_{it} + \alpha_2 edu_{it} + \alpha_3 k\ it + \alpha_4 lb_{it} + \alpha_5 pp_{it} + \alpha_6 land_{it} + \alpha_7 ratio_{it} \quad (5)$$

The above-mentioned data are from the annual *Statistic Yearbook in China in each country*.

Table 3 Regression results of factors influencing emission reduction efficiency

Emission efficiency	COD		TN		TP	
	Coefficient	*t* value	Coefficient	*t* value	Coefficient	*t* value
Constant	−1.49*	−1.7	1.202**	2.48	−0.177	−0.329
Capital per capita//K	−0.986***	−2.86	−0.409**	−2.34	−0.325	−0.98
Education degree//edu	0.115*	1.85	0.128*	1.98	0.042***	3.378
Sowing area per capita	−0.045	0.5	−0.065***	−3.21	−0.155***	−2.091
Income level//y	0.0003***	1.86	0.0002***	3.34	0.0002*	1.785
Labor force burden//lb	−0.006	0.41	0.016	0.94	−0.014	−0.618
Population//PP	−0.018	−1.87*	−0.011**	−2.21	−0.013*	−1.883
Salary ratio	0.023	1.74*	0.021	1.53	0.016	1.86*
R^2	0.708		0.762		0.781	
F statistics	24.22***		18.56***		12.69***	
Hausman test	38.11***		34.02***		24.41***	

Note: * stands for significance at the level of 10%, and ** stands for significance at the level of 5%, and *** stands for significance at the level of 1%.

Results suggest that the ratio of education degree per capita, farmers' income and salary are related emissions. Every time the education degree improves for one year, emission efficiency rose by 0.115, 0.128 and 0.042 respectively, which suggest that various education forms are factors influencing the lasting efficiency of energy reduction. In the long run, agricultural emission control must change the extensive business model. The labor forces within the family show some uncertainties. The population within the family restrains the carbon emission as every single man would reduce carbon emission by 0.018, 0.011 and 0.013 respectively, which suggest that too much population would impose great pressure on the production of livestock.

5 Conclusions and policy implications

Agricultural pollution control is an essential part of national carbon emission reduction, as it not only contributes to ecological environment protection, but also improves agricultural production and living condition, which has great significance towards the goal of carbon emission reduction. Because of the deficiency of statistics policy and system of agricultural pollution emission, China would not have given precise information on agricultural pollution. Based on list analysis method, the emission of COD, TN and TP in 28 provinces were evaluated to study the characteristics of temporal rule and spatial distribution.

(1) Compared with popular data, the emission of agricultural pollution through list analysis were reasonable. Results suggest that agriculture pollution has become another large pollution source and hasn't been controlled.

(2) DEA method has been applied to evaluate the potential and efficiency of carbon emission, as well as environment efficiency under the weak process condition. Results show that the reduction of COD, TN and TP in agriculture reached an annual rate of 5.08 million ton, 1.15 million ton and 0.12 million ton respectively.

(3) Based on the features of Chinese agriculture, this paper studies factors influencing the improvement of carbon emission. Results show that education per capita, family income and the salary had positive effect on carbon emission, while other factors, fixed capital, sowing area and labor force coefficient as well as family population would either restrict the improvement of carbon emission, or show certain uncertainty.

The policy significance of this study is as follows:

Firstly, agricultural pollution is another large source of pollution after industrial pollution. As economy booms, agricultural pollution becomes increasingly outstanding, which because the agricultural pollution directly affect food safety as well the living condition. Thus, it is imperative to reduce production. Besides, the potential to reduce carbon emission in Central West China was larger than that in East China, which suggested that the pressure to reduce carbon emission concentrates on the place where agriculture is the primary industry. Agriculture scale and intensive degree are factors which restrict the improvement of efficiency in carbon emission. At last, the agricultural pollution control can not be separated from farmers' participation and enthusiasm. Besides from improving farmers' education level, government will take measures to reduce carbon emission, which can effectively improve the use of fertilizer and agriculture medicine.

References

[1] CHEN MP, CHEN JN, LAI SY. Inventory analysis and spatial distribution of Chinese agricultural and rural pollution[J]. China Environmental Science, 2006, (6): 751 – 755. (in Chinese).

[2] LAI SY. Investigation and evaluation of nonpoint source pollution and its application[D]. Beijing: Department of Environmental Science and Engineering of Tsinghua University, 2004. (in Chinese).

[3] Y. H. Chung, R F? re, S. Grosskopf. Productivity and undesirable outputs: a directional distance function approach[J]. Journal of Environmental Management, 1997, 51 (3): 120 – 130

[4] Kumar S. Environmentally sensitive productivity growth: a global analysis using Malmquist – Luenberger Index[J]. Ecological Economics, 2006, 56 (2): 280 – 293.

[5] SHI H. Spatial dependence and distribution of agricultural productivity among provinces in China[J]. Resources Science, 2010, 32(7): 1323 – 1332. (in Chinese).

(From page 55)

are better than that of bare karst types, so these karst types are usually gathering areas of agriculture and cities; but it is still necessary and meaningful to prevent the occurrence of unreasonable land use, and control or cure problems such as the karst spring exhaustion, secondary karst-rock-desertification and karst collapses *etc*.. In buried karst environments, there are soils and overlying non-soluble rocks above the surface of the carbonate rocks, so these karst types are the best areas for agricultural production. Unreasonable land use which can cause overlaying strata collapse, soil erosion, and supply area pollution of karst springs should be prevented. Exploiting gas and coal may result in deep karst water pollution and land contamination in the mining areas, these phenomena also shall be curbed.

References

[1] YUAN DX. China karstology[M]. Beijing: Geological Publishing House, 1994: 10 – 12. (in Chinese).

[2] XIAO HL, WENG QH. The impact of land use and land cover changes on land surface temperature in a karst area of China[J]. Journal of Environmental Management, 2007, 85(1): 245 – 257.

[3] ZHOU Y, CAI XC, XIE YG, *et al*. Ecological land use in typical karst area——A case of Qingzhen City[J]. China Land Science, 2006, 20(5): 38 – 41. (in Chinese).

[4] JIA YN, YUAN DX. The impact of land use change on karst water in Shuicheng Basin of Guizhou Province[J]. Acta Geographica Sinica, 2003, 58(6): 831 – 838. (in Chinese).

[5] ZHANG ZW, ZHU ZX, WANG Y, *et al*. Soil infiltration capacity and its influencing factors of different land use types in karst slope[J]. Transactions of the Chinese Society of Agricultural Engineering, 2010, 26(6): 71 – 76. (in Chinese).

[6] Li Y B, Shao J A, Yang H, *et al*. The relations between land use and karst rocky desertification in a typical karst area, China[J]. Environmental Geology, 2009, 57(3): 621 – 627.

[7] ZHANG ZW, FU WL, ZHANG H, *et al*. Study on soil erosion of different degrees in karst region by using Cesium^{-137} technique[J]. Journal of Mountain Science, 2007, 25(3): 302 – 308. (in Chinese).

[8] ZHANG XB, BAI XY, LIU XM. Application of a ^{137}Cs fingerprinting technique for interpreting response of sediment deposition of a karst depression to deforestation in the Guizhou Plateau, China[J]. Science in China: Earth Sciences, 2011, 41(2): 265 – 271. (in Chinese).

[9] PEI JG, LI QS. Land use and soil and water loss in typical karst mountain area[J]. Bulletin of Soil and Water Conservation, 2006, 26(2): 94 – 99. (in Chinese).

[10] XIE YQ, YUAN DX. Relationship between land resources and water resources in underground river system[J]. Journal of Soil and Water Conservation, 2002, 16(6): 50 – 53. (in Chinese).

[11] Peng J, Xu Y Q, Cai Y L, *et al*. The role of policies in land use/cover change since the 1970s in ecologically fragile karst areas of Southwest China: A case study on the Maotiaohe watershed[J]. Environmental Science and Policy, 2011, 14(4): 408 – 418.

[12] FU WL, ZHANG ZW, ZHANG H, *et al*. Study on characteristics of soil erosion on karst hill slope[J]. Journal of Soil and Water Conservation, 2007, 21(5): 38 – 41. (in Chinese).

[13] DIAO CT, CHEN F, LV T, *et al*. Land use and land arrangement in karst ridge-trough——A case study in Huangtian Region, Fuling, Chongqing [J]. Carsologica Sinica, 2002, 21(1): 14 – 18. (in Chinese).

[14] LUO JY, FU WL. Effects of tunnel excavation in the Zhongliang Mountains on their water resources——A case study of the tunnel of Yuhe highway [J]. Journal of Southwest Agricultural University (Natural Sciences), 2006, 28(1): 154 – 160. (in Chinese).