Original research article

Evaluating and modeling ecosystem service loss of coal mining: A case study of Mentougou district of Beijing, China

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ABSTRACT

With fast urbanization and industrialization, the unreasonable exploitation of the natural resources has led to some environmental problems in the world. It needs to evaluate the ecological and environmental loss resulted from resource exploitation and set up an effective ecological compensation mechanism to promote the sustainable using of resources. Taking the Mentougou district of West Beijing in China as the case study, comprehensively applying the theory of ecosystem service, ecological economics, social investigation and analysis, and other research methods, the mined coal value and its corresponding loss of ecosystem services in Mentougou district of Beijing, China were evaluated in this paper. According to the research results, the economic value of mined coal resource in Mentougou district was about \$870 million, and the corresponding loss of ecosystem services caused by coal mining was approximately \$2001 million, including the loss due to land occupancy by waste coal, mining sink, reclamation for mining waste land, and water and soil loss in the past 50 years. So, in fact, the ecological and environmental loss caused by coal mining was far more than its economic benefits. This article can provide a scientific basis for ecological restoration and compensation of natural resource protection and utilization in other similar areas in China as well as in Western countries.

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1. Introduction

The world is becoming an increasingly urban place. About 65% of the world's population is expected to live in urban areas by the year 2025 (Barbier, 1994; Costanza et al., 1997). Due to the fast pace of urbanization, natural ecosystems are increasingly replaced by cities. Urbanization promotes rapid social and economic development, but at the same time, leads to many ecological and environmental problems, such as population concentration, traffic jams, housing shortages, resource loss, biodiversity reductions, "heat island" effects, noise, air and water pollution (Daily, 1997; Loomis et al., 2000; Li et al., 2005; McNeely et al., 1990; Norberg, 1999; OECD, 1995; Pearce and Moran, 1994; Seidl and Moraes, 2000; Wang et al., 2004). Human–environmental systems are challenged by current and upcoming ecological and socio-economic problems all over the world (Ma and Wang, 1984; Wang, 1986; Editorial, 2010; Wang et al., 2010). People are increasingly realizing the importance of the urban sustainable development that will mitigate or eliminate these problems, and many countries

have already enacted strategies to promote urban sustainable development (Li et al., 2008, 2009).

Mentougou district is located at the west Beijing, China, ranging from East longitude 115°25'00" to 116°10'07" and North latitude from 39°48'34" to 40°10'37", stretching over 62 km from the East to the West and 34 km from the North to the South. It totally covers an area of 1455 km², 98.5% of which is the mountainous region, plain area only accounts for 1.5%. Mentougou district belongs to the middle latitude continental monsoon climate with annual average air temperature of 11 °C and annual average sunshine of 2470 h. Average annual rainfall is about 563 mm in this area. The soil of Mentougou district belongs to zone brown soil. Plants in this area are abundant and there are about 1100 kinds of higher plants, belonging to 135 families and 485 genus. The major forest arbor species is birch, aspen and pines and larch. This area also abounds in mineral resources such as coal, limestone granite and so on. The total population of Mentougou district is 236,000 (Mentougou Statistical Bureau, 2006). Mentougou district has the history of excavating coal for more than 100 years. Coal mining has already brought about some ecological and environmental problem to this area, which affected the sustainable development of Beijing region. The costs and benefits to the ecosystem of different human activities may be achieved through the identification of the impacts of human activities and through the quantification of their

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consequences for the supply of ecosystem services (Pinto et al., 2010; Daily, 1999; Daily et al., 2002, 2009; Daily and Matson, 2008; Yapp et al., 2010). Services by ecosystem mean activities offered to the user of ecosystems and they could therefore be measured by the work capacity (Jørgensen, 2010). The evaluation of economic value and its ecological and environmental effect of coal resource exploitation were carried out in this paper. It is useful to provide scientific basis for the optimization of ecosystem services and the establishment of ecological compensate mechanism.

2. Ecological and environmental influence of coal mining in Mentougou district of Beijing

2.1. Landscape damages

The land occupied by coal waste covers an area of 1.8 km² in Mentougou district. Landscape destroy is one of the effects of coal resource exploitation and processing. Large amount of exposed coal stack occupies lots of farmlands and destroys the neighbouring landscape. Moreover, the powders coming from coal mining get up with the wind. After it falls to the plants, it affected their nutrients, photosynthesis and production (Gettings et al., 2004; Sandhu et al., 2010).

2.2. Changes of land use structure

Due to the coal mining, the area of farmlands in Mentougou district reduced 4965 hm² from 1991 to 1995, 2534 hm² from 1995 to 2001 and 437 hm² from 2001 to 2005. The total decreased area of farmlands is about 7935 hm² from 1991 to 2005 (Mentougou Statistical Bureau, 2006). Fortunately, the coal mining was already under better control in order to protect eco-environment of Beijing region in recent years.

2.3. Geological disasters

Coal mine exploitation resulted in many cracks and subsidence of lands. The area influenced by land sinks covers about 218 hm², having serious potential damage. The coal mining directly destroyed about 6 km² of the land surface, formed about 45 km² of sink area, and among them, the subsidence in urban area is about 4 km² (Mentougou Statistical Bureau, 2006).

2.4. Influences on ground water resources

Underground exploitation of coal mining and water drainage of mine pit brought about the decline of underground water level and resulted in a funnel area. It also changed the natural flow of ground

water and its condition of supplying and draining. The decline of the underground water level led to the using and drinking water problem for residents in mining area and the neighbouring areas. The eluviation and penetration of mining wastes brought harmful effects to the regional water environment in the rainy seasons (Tiway, 2001; Lacitignola et al., 2007).

2.5. Effects on vegetation

The exploitation of coal mine destroyed the vegetation around mountains, reduced the vegetation coverage and decreased the plant productivity (Yapp et al., 2010). The coal stacked, buried or pressured is not good for vegetation growth. Sulfur in coal dust affected the respiration of the crops. If it reacts with dew and rainwater, it will produce the acidic compound which would burn the crop lamina and reduce the photosynthesis activity and crop outputs (Rodríguez and Arias, 2008).

2.6. Loss of soil and water

The soil and water loss due to coal mining in Mentougou district is serious. According to the National Third Time Soil Erosion Investigation finished in China in 2000, the area of soil and water loss in Mentougou district is 759 km². Among them, the area of light degree is 610 km², the area of middle degree is 149 km². The modulus of soil erosion is 2000 t/km² per year, the annual average soil erosion amounts to 2.9 million tons. The exploitation of coal and limestone is the main influencing factor that results in ecological and environmental problems in this area. Unreasonable stack of the coal mining residues is extremely apt to bring about the loss of soil and water (Paetzold et al., 2010).

3. Research methodology

3.1. Structure of coal resources value system

The structure of coal resources value system includes market value, labor value and ecological and environmental value (Fig. 1).

3.2. Evaluation method for coal resources value

Considering the data importance and its obtainment feasibility, through the general analysis, the authors decided that the evaluation indicators are as follows: loss due to solid waste occupancy, loss due to the coal mining sinks, loss due to land cultivation, soil and water loss, etc. (Table 1). The evaluation contents and methods for coal mining value in Montougou district of Beijing are listed in Table 2.

Fig. 1. The structure of coal resources value system.

Table 1

Factor identification and feasibility analysis for coal mining on eco-environment.

Key elements	Various effects	Affecting degree			Evaluation feasibility		
		Heavy	Common	Light	High	Middle	Low
Solid wastes	Loss due to coal wastes treatment	●			●		
	Loss due to lands occupied by coal wastes	●			●		
Geological environment	Autoignition of coal waste		●			●	
	Loss of migration in coal mining sinks	●			●		
	Mud-rock flow and sliding		●				●
Water resource	Reclaimed fees for abandoned lands of coal mining		●		●		
	Waste water of coal processing		●				●
	Loss of mining pit draining		●			●	
Atmosphere	Loss of water lack	●			●		
	Loss due to coal transportation and pollution	●					●
Soil, biology and landscape	Cleaning charges		●				
	Loss of the agriculture yield			●		●	
	Loss of biodiversity		●				●
	Loss of water self-restraint		●		●		
	Loss of soil and water	●					
	Landscape damage		●				●

Table 2

The evaluation contents and methods for coal mining value in Montougou district of Beijing.

Key elements	Various effects	Evaluation methods
Solid waste	Loss due to coal wastes treatment	Market Value Method
Geological environment and coal mining sinks	Loss due to lands occupied by coal wastes	Opportunity-Cost Method
	Loss of farmlands	Opportunity-Cost Method
	Loss of water resource	Shadow-Project Method
	Loss of abandoned land in mining area	Restoration-Cost Method
Soil, biology and landscape	Loss of migration	Market Value Method
	Loss of water self-restraint	Shadow-Project Method
	Loss of soil and water	Shadow-Project Method

4. Modeling formula and result analysis

4.1. Assessment of indirect economic value of coal mining

Adopting the Market Value Method to calculate the economic value of coal mining, the calculation equation is as follows:

$$V = (P - C)Q \quad (1)$$

where V is the indirect economic value of coal mining; P describes the market price of coal resource; C represents the cost of coal exploitation per unit; whereas Q stands for the exploitation amount of coal mining.

The author uses the exchange rate of January 1, 2009 (683.66 Yuan RMB = \$100) to calculate the value in the following section. According to the investigation results, the coal exploitation in Mentougou district amounted to 0.15 billion tons since 1949. The average selling price of \$44.4/t of coal resource in 2006 and the mean cost of coal exploitation is \$38.6/t.

$$V = (44.4 - 38.6) \times 0.15 = \$870 \text{ million}$$

So, the direct economic value of coal exploitation in Mentougou district is about \$870 million.

Table 3

Loss caused by coal solid wastes.

Influence	Detailed effects	Loss (\$)
Solid wastes	Coal ash treatment	31,448,380.1
	Coal stone treatment	26,328,876.9
Farmlands	Loss of farmland cultivation	40,888,745.9
	Loss fruit cultivation	1,406,678,758.4
Water self-restraint value	Forest	347,602,609.5
	Lawn	32,791,153.5
Total		1,885,738,524.0

4.2. Loss caused by coal solid wastes

Using Market Value Method and Opportunity-Cost Method (Spangenberg and Settele, 2010; Trepel, 2010), The loss caused by coal solid wastes can be calculated by the following formula:

$$V = S_1 + S_2 = \sum_{i=1}^n F_i C_i + \sum_{i=1}^n V_i \quad (2)$$

where V represents the total loss caused by coal wastes. S_1 is the treatment expense for all kinds of coal wastes; S_2 is the total loss caused by the occupancy of mining residue; F_i is the amount of certain kind of solid waste in mining area; C_i is deemed as the treatment expense of certain kind of solid waste per ton; V_i stands for the loss caused by certain kind of mining residue occupancy. i is the type number of different mining wastes.

Table 4

Loss caused by coal mining sinks.

Detailed effects	Loss (\$)
Loss of migration	18,649,621.2
Loss of water resource	1,608,986.9
Loss of farmlands	83,374,776.9
Total	103,633,385

Table 5

Value of water and soil loss.

Detailed effects	Loss (\$)
Soil nutrition loss	305,853.8
Water loss	112,629.1
Total	418,482.9

Table 6

Total loss of ecosystem services resulted from the coal mining in Mentougou district of Beijing.

Types of ecosystem services loss	Detailed effects	Value (\$)
Loss due to the coal solid wastes	Cost for coal ash treatment	31,448,380.1
	Cost for coal stone treatment	26,328,876.9
	Loss of farmlands and productivities	40,888,745.9
	Loss of fruit cultivation	1,406,678,758.4
Loss of water self-restraint value	Forest	347,602,609.5
	Lawn	32,791,153.5
	Loss of migration	18,649,621.2
Loss due to the coal mining sinks	Loss of water resource	1,608,986.9
	Loss of farmlands	83,374,776.9
	Cost for and reclamation	11,400,000.0
	The nutrition loss	305,853.8
Reclamation of the abandoned lands	Water loss	112,629.1
Loss of the soil and water		
Total		2,001,190,392

According to the above equations, the loss caused by the coal solid wastes is as follows (Table 3).

4.3. Loss caused by mining sinks

Using Market Value Method, loss caused by mining sinks can be calculated by the following formula:

$$V = V_a + V_b + V_c \quad (3)$$

$$V_b = H_b F_b \quad (4)$$

where V is the total loss resulted from mining sinks; V_a describes the loss of water resource; V_b is the loss due to people's migration; V_c stands for the loss of farmlands and productivities; H_b represents the number of families of migration; F_b is deemed as the cost per family migration.

Loss of farmlands and productivities (V_c) can be calculated by the following equation:

$$V_c = \sum_{i=1}^n S_i M_i \quad (5)$$

S_i is the productivity of certain kind of crops per unit area; M_i stands for the market price of the certain kind of crops.

According to above calculation, the loss caused by coal mining sinks is as follows (Table 4).

4.4. Reclamation cost for the abandoned lands in coal mining area

According to some relative research reports (Mentougou Statistical Bureau, 2006), the average direct cost of reclamation in different coal mining area in China is \$13063.57/hm². There are 8686 hm² coal mining areas abandoned in Mentougou district. Using Restoration Cost Method and Shadow-Project Method (Spangenberg and Settele, 2010; Trepel, 2010), if \$13164.4 is needed for per hm², then the direct cost of reclamation is about \$11.4 million.

4.5. Loss of water and soil

The loss of soil nutrition includes the loss of organic matter and nutrient elements. Nutrient elements are N, P, K, and so on. Using Market Value Method and Shadow-Project Method, it can be calculated by the following formula.

$$V = V_1 + V_2 \quad (6)$$

where V is the loss of the soil nutrition; V_1 is the loss of N, P, K elements; V_2 is the loss of the organic matter.

$$V_1 = Q_i \sum_{i=1}^n P_{1i} P_{2i} P_{3i} \quad (7)$$

$$V_2 = WPS \quad (8)$$

where Q_i describes the soil erosion (t/a); P_{1i} represents the N, P, K proportion in the soil (%); P_{2i} is the proportion of pure N, P, K proportion in fertilizer (%); P_{3i} stands for the selling price of fertilizers in the market (\$); W is the amount of the organic matter; P describes the selling price of the organic matter (\$/t); S represents the transforming parameter (%).

The water loss can be calculated by Shadow-Project Method. The formula is as follows:

$$V = EP \quad (9)$$

$$E = \frac{QW}{K} \quad (10)$$

where V is the value of the soil water loss (\$); E is the amount of water loss (m³); P is the expense for constructing 1 m³ reservoir (\$/m³); Q is deemed as the amount of soil erosion per year (t); W describes the proportion of water in volume in the soil; K represents the volume weight of the soil (t/m³). According to above calculation, the water and soil loss is as Table 5.

4.6. Total loss of ecosystem services resulted from the coal mining

Throughout the estimation of the ecosystem services loss resulted from the exploration of coal resource mentioned above, the authors calculate that the total ecological and environmental loss caused by coal mining is about \$2001 million (Table 6).

5. Concluding remarks

As the study results, the value of mined coal resource in Mentougou district of Beijing was about \$870 million, at the same time, the corresponding loss of ecosystem services caused by coal mining was approximately \$2001 millions in the past 50 years. So, in fact, the indirect ecological and environmental loss resulted from coal exploitation was far more than its direct economic benefits. Fortunately, several years ago, the mining activity in Mentougou district had been forbidden by Beijing's government to protect the environment, improve people's life quality and promote the sustainable development in Beijing region.

The mined coal value and its corresponding loss of ecosystem services in Mentougou district of Beijing were evaluated in this

research. Our data was just a rough estimate of the ecosystem service value. It can provide a decision-making basis for ecological restoration and compensation of natural resource for the authorities and governments in Beijing region as well as in other similar areas. Nevertheless, some parts of ecosystem service cannot be evaluated by economic value. From the ecological compensation aspect, it involves three levels: national level, district level and enterprise level. The ecological restoration and compensation from the national level mainly focuses on finance and policies; it mainly centralizes on investment, material and education from the district level; it mainly assembles in restoration projects from the enterprise level. Only through this approach, can the whole Beijing region develop toward a sustainable ecopolis.

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