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Biogeochemical sulphur cycle in Haihe River Basin

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Abstract—The characteristics of biogeochemical sulphur cycle in Haihe River Basin were discussed in this paper basing on the storage and fluxes of sulphur in the hydrosphere, atmosphere, pedosphere and biosphere through a study on the distribution character and content in them.

Keywords: hydrosphere; pedosphere; atmosphere; biosphere; sulphur cycle.

1 Introduction

Sulphur is an essential element for the growth of plants and one of the principal elements to sustain human survivor on earth. It is very important to study the biogeochemical cycle of these elements in the pedosphere, hydrosphere, atmosphere and biosphere for protecting natural resources and improving the eco - environment.

2 The study area

The Haihe River Basin covers four rivers: Yongding River, Daqing River, Zhanghe River and Wenhe River, with an area of 2.6×105 km^2. This area belongs to the warm temperate semi - humid physical geographical zone. The average annual temperature is around 8°C—12°C, and the annual rainfall is about 500—700 mm. The landform develops in steps from west to east in the following types: moderately high hill, basin, low hill, hillock, alluvial fan or terrace, alluvial plain, flooding plain and marine plain. The highest summit is about 2800 meters above sea level. The granite and schist outcrop extensively in the western mountain area, and the alluvium, lacustrine and marine deposits constitute the dominant surface material in the eastern part. The soils in this region are formed in three main types, the cinnamon soils, fluvo - aquatic soils and salinized fluvo - aquatic soils, and distributed in belt from west to east. The main stream flows into the Bohai Sea from northwest to southeast under the control of topographical feature (Liu, 1993).

3 Materials and methods

3.1 The storage capacity of sulphur in hydrosphere

The content of sulphur and the amount of river runoff and underground water are calculat-

ed. The result is shown in Table 1 and Table 2.

Table 1 The storage capacity of sulphur in the river run - off

	North canal	Yongding River	Daqing River	Ziya River	East Heilonggang River	Zhangwei canal	Main stream of Haihe River	Tuhai River
Run - off $\times 10^8$								
m^3/a	41.61	20.29	41.7	40.41	9.21	38.81	1.57	15.24
Average content of sulphur					69.269			
Total amount					1.45×10^9kg/a			

Table 2 The storage capacity of sulphur in underground water

	Run - off, $\times 10^8 m^3$					The content of sulphur	Undergr. run - off
	Bedflow	Leaching	Underflow	Spring	Mining		
North part of Haihe	20.8	9.2		0.30	1.76		
South part of Haihe	53.14	11.27	1.57	1.173		13.45	
Whole basin	73.22	20.47	1.57	1.473	1.76		
Total			98.49				1.31×10^8

3.2 The storage capacity of sulphur in soil

Sulphur exists in soil with various specifications that are closely related to the soil type, microbe and some other factors. The storage capacity of sulphur in different forms can be obtained by finding the product of the content of sulphur and the volume of soil, which are listed in Table 3.

Table 3 The storage capacity of sulphur in different specifications of soil **Soil depth**: 40 cm

Type of sulphur	Content of sulphur, $\mu g/g$	Average value	Total amount of S., kg
Soluble sulphur	3.98—54.37	19.9	4.09×10^9
Insoluble sulphur	5.55—33.78	13.6	2.79×10^9
HCl - soluble sulphur	90.71—920.40	398	8.18×10^{10}
Organic sulphur	39.51—666.0	205.8	4.23×10^{10}
Total sulphur	382.0—1518.0	684.3	1.41×10^{11}

3.3 The storage capacity of sulphur in the parent materials

The sulphur in soil was derived mainly from the weathering of plutonic rocks. Sulphide in primary minerals is released and oxidized to sulphate during the weathering process. The total amount of sulphur that exists in parent materials within 40 cm is about 5.34×10^{10} kg, which is based on the content (260 ppm carat) in crust estimated by Tailor in 1962 (Liu, 1984).

3.4 The amount of sulphur contained in the excrement of human and livestock

Human and livestock have a close relation with the soil. They absorb sulphur by eating plants and return it to the soil through excrement (Liu, 1994). The total amount of sulphur from the excrement is calculated on the basis of the population and livestock statistics (Table 4 and 5).

Table 4 The amount of sulphur from human excrement **Population: 8.27×10^7**

	Excrement, kg/(p. a)	$(NH_4)_2SO_4$	Percentage of S in $(NH_4)_2SO_4$	K_2SO_4	Percentage of S in K_2SO_4	Total sulphur, kg	Loss of sulphur, 61.8%	Remainder of sulphur
Human excrement	90	37.2	0.25	5.8	0.183	9.7×10^5	6.67×10^5	4.17×10^5
Urine	700	144.7	0.25	22.9	0.183	1.09×10^5		

3.5 The amount of sulphur coming from the chemical fertilizers, green manure and crop straws returned to soil

3.5.1 Chemical fertilizer

One important source of sulphur in soil is the application of sulphur chemical fertilizers and pesticides, which result in the increase of sulphur. Some controlling - release fertilizers can produce a S^0 cover on the vegetation, such as the sulphur - covering carbamide, about 20% of the sulphur was oxidized into SO_4^{2-} by microorganism in soil (Ivanov, 1983). Knowing the annual amount of chemical fertilizer used in this region, the total amount of sulphur can be found (Table 6).

Table 5 The amount of sulphur in the excrement of livestock

Total number livestock	Excrement, kg/p. a	Total excrement, kg	Amount of $(NH_4)_2SO_4$, 0.25%	Amount of K_2SO_4, 18%	Loss of sulphur	Remainder of sulphur
3.23×10^8	23979	8.1×10^{10}	2.01×10^8 1.45×10^8 3.46×10^8	2.2×10^8	1.36×10^8	0.92

Table 6 The amount of sulphur from the chemical fertilizers and pesitides

Applyment of chemical f. *, kg	Net amount of chemical f. *, kg	Loss of chemical f. *, 15.5%	Amount remained, 84.5%	Loss of sulphur, kg	Sulphur remained, kg
6.89×10^9	1.76×10^9	2.73×10^8	1.49×10^9	2.18×10^6	1.19×10^6

Note: *f* is the fertilizer

3.5.2 Green manure

It is very helpful for increasing the content of organic matter in soil. It can raise the yield of fodder to a large extent for the livestock and produce much more protein for human and livestock. In this region, the area of green manure plants is about 24360 ha (Dai, 1988) with a product of 30000 kg/ha. Since the amount of sulphur content in organic matters is lacking the content of sulphur in grass ashes (about 1.81%) is used to calculate the total amount in green manure which is 1.32×10^7 kg each year.

3.5.3 The amount of sulphur returned to soil from the crop straw

Even though a great deal of crop straw was produced in this area each year, only a small part is used as green manure returning to farmland. The total amount of crop straws produced in Haihe basin is obtained by comparing the area of cultivated land between Haihe River basin (10.1×10^6 ha) and Hebei Province (6.59×10^6 ha), because the actual amount of crop straws yield is unavailable in this region and otherwise it is known in Hebei Province about 3.5×10^{10}

kg. Thus the total amount of crop straws produced, in Haihe River basin each year is nearly 5.36×10^{10} kg. Supposing 30% of them is used to return to the farm field, then the total amount is about 1.609×10^{10} kg and the amount of sulphur it contains is about 2.89×10^{8} kg.

3.6 The amount of sulphur in urban garbage

The garbage produced by the people in the three big cities and fifteen medium-sized cities is listed in Table 7. The total amount of sulphur included in it reaches Ca 3.79×10^{6} kg each year.

Besides those garbage which are taken to the disposal factory for reutilization, the organic matters, contained in the leaves, garbage from the open market and daily rubbish, are taken into account to calculate the amount of sulphur. Actually, only a small part of the garbage is disposed at present in China through three means, as much as 70% of them is used for filling materials, 25% is burnt and 5% is used as green manure. The amount of sulphur, contained in garbage disposed in above three means is about 2.78×10^{5} kg, 9.93×10^{5} kg and 1.99×10^{5} kg each year, respectively.

Table 7 The amount of sulphur contained in the urban garbage

Items*	Beijing	Tianjin	Shijiazhuang	The other 15 cities**	
population	7.8×10^{6}	6.92×10^{6}	2.1×10^{6}	7.655×10^{6}	
Total garbage,		72.66		27.56	
10^{10} kg/a		(1.2 kg/p.d)		(1 kg/p.d)	
Organic matter,		21.80		4.68	26.48
10^{10} kg/a		(30%)		(17%)	
Amount of sulphur,		3.27		0.70	3.97
10^{6} kg/a		(0.15%)		(0.15%)	
Sulphur contained in filling garbage			2.78×10^{8} kg/a (70%)		
Sulphur contained in burned garbage			9.93×10^{5} kg/a(5%)		
Sulphur in garbage for green manure			1.99×10^{5} kg/a		
Total, 10^{8}kg			100.22		

* : according to "Compilation of data on disposal of garbage", compiled by the division of information of Southwest Academy of Engineering-design for Urban Construction in China, 1986:193—197

** : according to the "Annual Economic Statistics", China Statistics Press, 1988

3.7 The amount of sulphur in the flying ashes and falling dust

China, as one of the major countries in the world living on coal-combustion, emit Ca 1.3×10^{6} SO_2 each year. Among them, about 3.3×10^{4} kg is from Beijing, 3.0×10^{4} kg from Tianjin and 8.6×10^{4} kg is from Hebei Province. It will continue to increase with the development of energy industry, which will engender much influence on the air quality.

The amount of sulphur in flying ashes is obtained on the basis of the content collected by sampling in the big cities on coal-combustion in June of 1988 and the volume of air (Liu, 1994). The deposit rate of dry deposits defined by Chamberlain is the ratio between the amount of deposits and the content of certain gas or particle in the air, which can be expressed as follows:

$$-\text{Flux} = Vd.c\ .$$

If the values of Vd and C are given, the total amount can be found easily. The dry deposit rate, at the height of 1—1.5m above ground and 10—15m above sea level, released in the pub-

lished papers, is around 10—180 cm/s. It is changeable with the topographic nature. The results are shown in Table 8.

Table 8 The amount of sulphur contained in flying ashes

Deposit ratio, cm/s	Content of sulphur, $\mu g/m^3$				The percentage of vegetation, %
	Langfang	Nanpi	Dingzhou	Xizhou	
	12.56	13.61	15.4	17.99	
0.005	0.0195	0.0211	0.0239	0.0279	34.4 (leaves, $Vd=89393\ km^2$)
1	3.906	4.233	4.789	5.595	2.6 (grass, $Vd=6625\ km^2$)
7	27.343	29.629	33.535	39.164	51.8 (farmland, $Vd=10085\ km^2$)
Average value	16.8751 g/m^2a				4.33×10^6 kg/a

The amount of sulphur in falling dust is calculated on the basis of the measured content collected in Dingzhou and Xinzhou cities (Table 9).

Table 9 The content of sulphur contained in falling dusts

	Dingzhou 1988	Xinzhou 1988	Dingzhou 1989	Xinzhou 1989	Total area, km^2	kg/a
Content of sulphur, $kg/km^2.a$	3.76	0.54	3.20	0.98	256869	5.51×10^8

Clearly, the sulphur content in falling dusts in the western mountain area is much higher than that in the eastern plain.

3.8 The fluxes and storage of sulphur in plants

Plants can uptake sulphur directly from surrounding for growth. The sulphur content in different kinds of plants is quite different, even through for the same plant it is still varied widely with the different parts of plants (roots, trunks, leaves and fruits) and with the seasons. According to the types and area of the 62 plants in this region, the total amount of sulphur coming from plants is about 2.71×10^8 kg and those still remain in vegetation is Ca 3.16×10^7 kg.

For discussing the balance of input and output of sulphur from the ecosystem view-points, the calculated results of the crops, forests and grassland are summarized in Table 10 and Table 11.

Table 10 The flux and storage of sulphur in different plants

Type of vegetation	Area, ha	Output, kg/a	Input, kg/a
Crops	15269300	2.48×10^8	3.15×10^7
Forest	5565300	3.40×10^6	
Grassland	3253300	1.05×10^7	1.59×10^5
Total	24587900	2.71×10^8	3.16×10^7

4 Result and discussion

Sulphur exists extensively in living organisms and is an imperative element for plant growth. Fig. 1 shows the amount contained and sulphur cycle in different compartments based on the above results.

4.1 Biogeochemcial cycle of sulphur (Fig. 1)

Table 11 The fluxes and storage of sulphur in different inventory in Haihe River basin Unit: kg/a

Compartments of sulphur	Storage of sulphur
Soil	1.41×10^{11}
Parent materials	5.34×10^{10}
Remainder in human urine	4.17×10^{5}
Loss with human urine	6.67×10^{5}
Remainder in excrement of livestock	1.36×10^{8}
Loss with excrement of livestock	2.20×10^{8}
Output of crops	2.48×10^{8}
Input of crops	3.15×10^{7}
Output of forest	3.40×10^{6}
Input of forest	—
Output of grassland	1.05×10^{7}
Input of grassland	1.59×10^{5}
Returned from crop straws to farmland	2.89×10^{8}
River run-off	1.45×10^{9}
Underground water	1.31×10^{8}
Flying ashes	4.33×10^{8}
Dry deposits	5.51×10^{8}
Wet deposit	7.55×10^{8}
Remainder in chemical fertilizers	1.19×10^{6}
Loss with chemical fertilizers	2.18×10^{6}
Garbage as filling materials	2.78×10^{6}
Burnt garbage	9.93×10^{5}
Garbage as green manure	1.99×10^{5}
Green manure	1.32×10^{7}

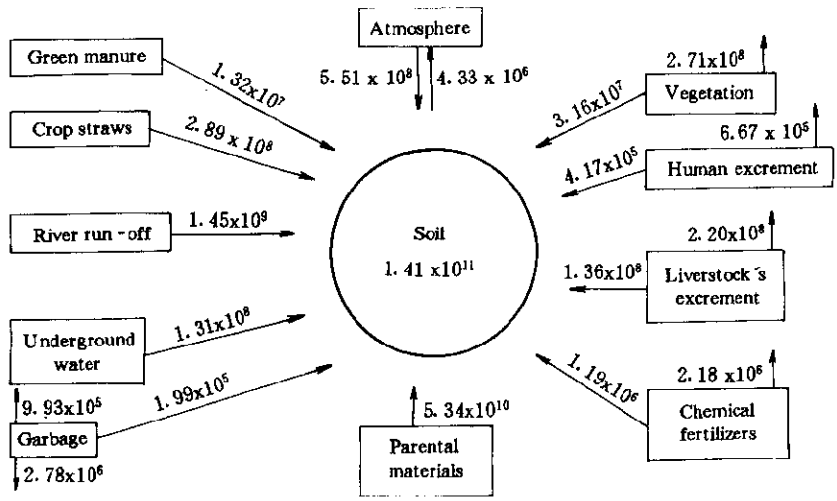

Fig. 1 Sketch map of cycle of sulphur in Haihe River Basin

4.2 The balance of sulphur

The calculation of input and output of sulphur in Haihe River Basin is carried out by taking the agricultural ecosystem as the mainbody and the forest ecosystem and air - particle as the principal influencing factors to the cycle of sulphur. The total input, excluding the amount from parent materials, in agricultural ecosystem is about 2.59×10^9 kg/a and the total output is Ca 6.20×10^8 kg/a, it indicates an accumulation process for the agricultural ecosystem (Fig. 2, Table 12).

Table 12 Comparison of input and output of sulphur in Haihe River Basin

Types of ecosystem	Input of sulphur	Output of sulphur	Balance comparison	Difference
Agricultural	2.59×10^9	6.20×10^8	23.9%	1.97×10^9

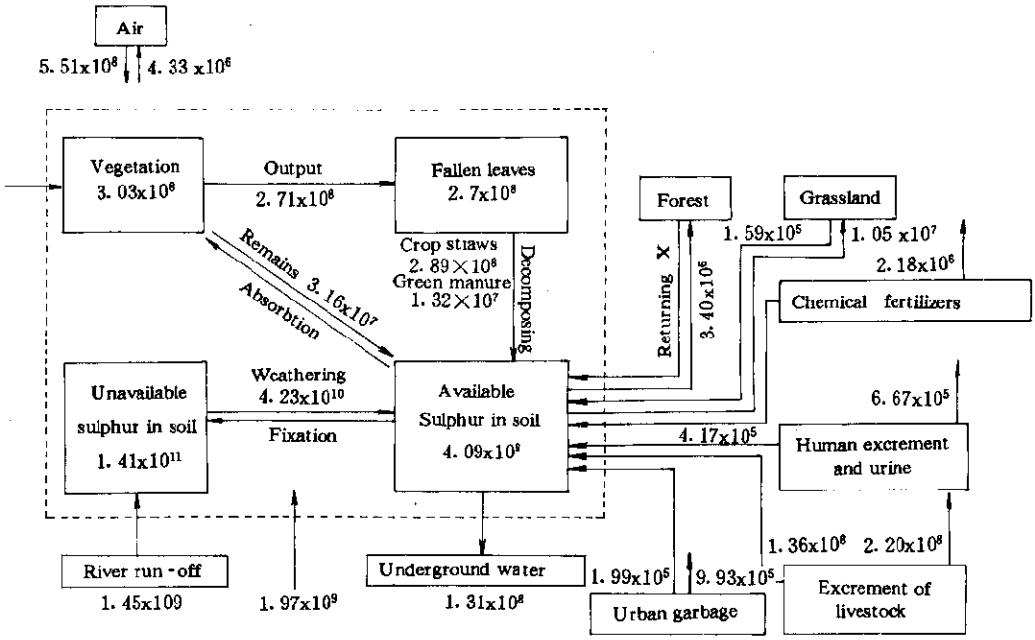

Fig. 2 The balance of sulphur in Haihe River Basin

It is concluded that the input of sulphur is much higher than the output of sulphur. The sulphur content in agricultural ecosystem is increasing with the time, this could result in the acidification of soil and hinder the growth of plants. Upon the above discussion, there are two large contributor for the increase of sulphur in soil.

The increase of the sulphur from the air deposits, which is up to 5.51×10^8 kg/a, could be

the most important reason to cause the increase of sulphur in soil.

The increase of sulphur fixed and returned to soil by the plants is another reason of the increase in soil. The amount of sulphur returning to soil from the millet is about 46 kg/(ha. a) and the total amount is about 2.89×10^8 kg each year in this region. The accumulation of sulphur in plant leaves is also very important, which accords with the phenomenon studied by Zhang Fuzhu (Zhang, 1991) on penis - tabulaeformis forest ecosystem in Huairou Mountain region.

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