CHINESE GEOGRAPHICAL SCIENCE
Volume 14, Number 4, pp. 355–360, 2004
Science Press, Beijing, China

SPATIAL ANALYSIS OF SOIL EROSION AND NON-POINT SOURCE POLLUTION BASED ON GIS IN ERLONG LAKE WATERSHED, JILIN PROVINCE

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ABSTRACT: Data collection, factor composition, nappe analysis and integrative simulation of natural geographical factors in Erlong Lake watershed have been carried out based on GIS. The risk areas where non-point source pollution may occur were compartmentalized and assessed, and the total soil erosion and the runoffs of N and P with rainfall in this valley were worked out by experiment and GIS mapping. The study indicated that the main type of soil erosion was moderate (erosion modulus is 1000–2500t/(km^2•a)) at present , and the intense erosion areas are located in dry land with variable slope east of the lake and the middle-south parts of steep slope mountainous region (erosion modulus is more than 5000t/(km^2•a)). Though the area is small, it should be paid attention to. The trend of non-point source pollution (NSP) of nitrogen and phosphorus loss was corresponded with the soil erosion. Spatial distribution and the reasons of the distribution difference have been presented and it was emphasized that the human activities among the influence factors was the most important. It surely offers a scientific basis to control and prevent non-point source pollution in the watershed.

KEY WORDS: soil erosion; non-point source pollution; Erlong Lake; Geographic Information System (GIS)

CLC number: X522 Document code: A Article ID: 1002-0063(2004)04-0355-06

1 INTRODUCTION

GIS is an advanced technology, which possesses the functions of data collection, storage, management and transfer. It is also a new and quickly developing method to study the soil erosion in small watershed, whose area is less than 500km^2 (MARTHA and WANSDA, 1987; CAO *et al*., 2001; SIVERTUN *et al*., 1988; VIEUX, 1991; WANG *et al*., 1997, ZHANG, 2002). So far, it is still in discussing and experimental phase to study and calculate the non-point source pollution by GIS in bigger watershed whose area is more than 500km^2. This article aims at describing speedily and nicely the area of soil erosion and non-point source pollution with the help of data collection, analysis and simulation functions of GIS; at calculating the quantity of soil erosion and N/P losses by calculating function of great capacity of GIS; and at analyzing the human activities and discussing the reason of non-point source pollution and soil erosion in the watershed. This article can provide the basic data and the scientific guide to water environment management.

2 MATERIALS AND METHODS

2.1 Study Area

Erlong Lake belongs to the upper reaches of the Dongliao River, which lies in the middle of Jilin Province. The geographical location is 43°10′N, 124°47′E (Fig. 1). The watershed area is 3291.71km^2 and the lake surface area is 170km^2. The shallow and mooned lake extends from the south to numberthe north. There is a big dam to control water and drain to the Dongliao River in the west of the lake. The lake has such functions as irrigation, breeding aquatics, drinking, preventing or controlling flood, recreation and hydrological electricity. The irrigated area from the lake water is more than 6667ha and the drinking water from the lake has been supplying for 50 years.

Erlong Lake is located in the transitional zone of hu-

Received date: 2004-06-30
Foundation item: Under the auspices of the National Natural Science Foundation of China (No.50139020-5-2) and Science & Technology Committee of Jilin Province (No. 20010602)

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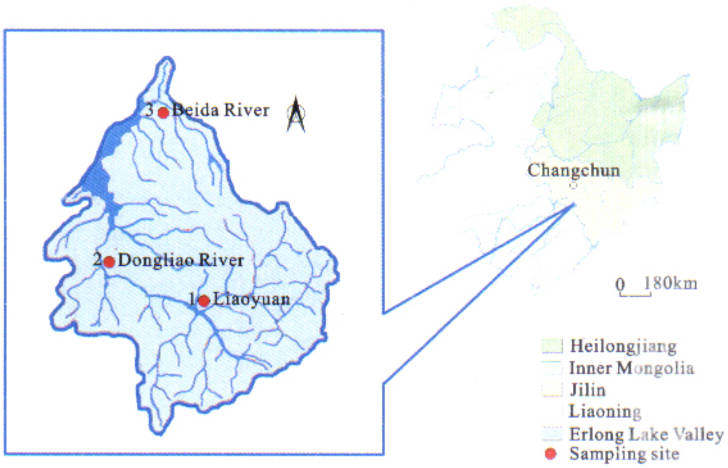

Fig. 1 The location of Erlong Lake

mid climate and semi-humid climate. The average air temperature is 5.8℃ and the annual precipitation is 650mm. This watershed lies in a hilly zone with the height of 200–500m above sea level. The terrain is higher in the south and lower in the north. The slope of the two banks is smaller and there are few of trees in the two banks. The soil erosion is very serious because of the vegetation destruction. A great deal of mud and sand in the runoff flows are deposited in the lake in each flood season. Filled-up mud and sand in the lake are more than 5.0×10^6m^3 per year.

2. 2 Study Methods

2.2.1 Data source

The soil erosion and non-point source pollution were studied by GIS in two aspects: geographic factors simulation and erosion state simulation. Under the support of the GIS software, this article input such natural geographic factors as terrain, relief, vegetation and land-use type and plotted the spatial numeric map; then compartmentalized many grids in this valley and established a geographic factors database.

The variations of land-use type are more complex than other natural geographic factors. Thus 11 land-use types were selected, they are dry land, shrub, beach, sand land, urban residential area, rural residential area, paddy field, woodland, grassland, lake and building soil. Typical land-use type was taken as the sub-district in semi-oriented experimental area, rain runoffs were collected, concentrations of characteristic pollutants were calculated, the relation between rainfall and the N/P loss in every grid was determined, and the load quantity of soil erosion and concentrations of non-point source pollutants were calculated based on the GIS model. According to the simulation results of numeric map and characteristic pollutant load quantity, the distribution rules and spatial difference of the soil erosion and non-point source pollution were analyzed.

2.2.2 Application of GIS

On the basis of the 1∶100 000 aerial survey map of Northeast China, the soil map and the topographic map of Erlong Lake watershed, the contour line, soil and land-use types were extracted as environmental factors and various vector maps were made through the data collection, the track and the normalization used the Arc/info 8.1 software package of GIS.

Under the support of Arc Scene software package in Arc/info 8.1, 1.32×10^6 grids (50m×50m) in this watershed were compartmentalized and the grid map and database of all kinds of factors were made. Finally the soil erosions of all kinds of land-use types were worked out through the calculation function and the Revised Universal Soil Loss Equation (RUSLE) of spatial software.

2.2.3 Sample collection in sub-district

In this article representative land-use types were selected as the sub-district in the semi-oriented experimental area. The sediment samples were collected during rainfall; the concentrations of dissolvable total-N and absorptive total-P in the rainfall samples and total-N and total-P in the sediments were measured under the condition of raining. According to the calculation results of the concentration of N/P and the average runoff and soil erosion, quantity of the dissolvable and absorptive pollutants in the rain runoff were obtained. The sub-districts of the semi-oriented experimental area were chosen in the upriver (1#) and downriver (2#) named the Dongliao River that flows in the south (3#), the three times of rainfalls were sampled from July to August. The sampling site is shown in Fig. 1.

The calculation results and the interrelated data were overlapped and the related map was obtained by the Arc Map function package of Arc/info8.1 software in GIS. The results can help identifying the pollution risk areas and the environmental management.

2.2.4 Selection of model and parameters

The pollutant load quantity includes the pollutant in the rainfall runoff and the pollutant in the erosion soil. The dissolvable N and P concentration multiplied the rainfall and the absorbed N and P concentration multiplied the soil erosion amount, respectively. Then the pollutant loads were calculated. The rainstorm runoff model was simplified(YANG and SONG, 1997), and the model of USLE (Universal Soil Loss Equation) (WANG *et al.*, 2003) and the pollutant load model (JIAO, 1991) were modified. The results are shown in Table 1.

Table 1 Models for calculating non-point source pollutant load quantity

Name	Model	Content	
		Parameter	Physics meaning
Rainstorm runoff	$Q_f = \sum F'\varphi \cdot h_r \cdot 10^{-3}$	Q_f	Runoff (t/a)
		F'	Erosion area (m^2)
		φ	Runoff modulus (t/m^3)
		h_r	Rainfall (mm/a)
Simplified USLE	$A = R \cdot S_t \cdot L_s \cdot C$	A	Average annual soil loss (t/km$^2\cdot$a)
		R	Rainfall-runoff erosivity factor
		S_t	Soil erodibility factor
		L_s	Slope length and steepness factor
		C	Coverage factor
Absorbed pollutant load model	$L_{sij} = \alpha \sum_{i=1}^{m} C_{nj} \cdot X_n \cdot S_n$	L_{sij}	Pollutant load quantity (kg/a)
		C_{nj}	Pollutant concentration (mg/kg)
		X_n	Soil erosion modulus (t/km$^2\cdot$a)
		S_n	Soil area (km^2)
Dissolved pollutant load model	$L_{Dij} = \beta \sum_{i=1}^{m} C_{nj} \cdot Q \cdot S_n$	L_{Dij}	Pollutant load quantity (kg/a)
		Q	Deepness of runoff (mm/d)

3 RESULTS

R and L_s were calculated by experiential formulae. S_t, and C were determined by the soil, coverage characters and land-use type. The pollutant concentrations in the runoff of all kinds of land-use types were obtained by the analysis of water samples from the rainfall runoff in the sub-district of semi-oriented experimental area. The results are shown in Table 2.

Table 2 N and P concentrations in rainfall runoff

Land-use type	Pollutant concentration			
	Absorbed pollutant (mg/L)		Dissolvable pollutant (mg/L)	
	Total-N	Total-P	Total-N	Total-P
Dry land	3.810	0.687	1.621	0.393
Woodland	3.590	0.539	1.152	0.094
Shrub	3.259	0.313	0.536	0.094
Grassland	4.287	0.596	1.740	0.056
Beach	2.114	0.230	0.540	0.080
Urban residential area	6.190	0.331	6.635	0.460
Rural residential area	6.190	0.331	6.635	0.460
Building soil	6.190	0.331	6.635	0.460
Sand land	1.580	0.317	0.170	0.060
Paddy field	3.210	0.551	0.106	0.070

In the Erlong Lake watershed, the total soil erosion was 6.4×10^6t/a. The total rainfall runoff was 5.1×10^8t/a from May to September (in this period the precipitation accounts for 84 % of total yearly precipitation). The N loss load was 654.699t/a, and loss modulus was 197.72kg/(km$^2\cdot$a). The P loss load was 135.252t/a, and loss modulus was 41.09kg/(km$^2\cdot$a). The loss loads of N and P and the soil erosion in all kinds of land-use types were shown in Table 3.

Through the Arc map software package of Arc/info, the contour map of the watershed (Fig. 2), the soil

Table 3 N and P loss and soil erosion in all kinds of land-use types in Erlong Lake watershed

Land-use type	Area (km^2)	Soil loss ($\times10^3$t)	Runoff ($\times10^3$m^3)	N loss (t/a)			P loss (t/a)		
				AN	DN	TN	AP	DP	TP
Dry land	1779.100	5425.0	444233.7	20.670	508.390	529.060	3.730	123.260	126.990
Woodland	567.940	321.4	28359.8	1.153	23.067	24.220	0.170	0.890	1.060
Shrub	467.490	319.1	11838.9	1.040	4.480	5.520	0.100	0.560	0.660
Grassland	92.820	84.3	5394.3	0.360	6.630	6.990	0.050	0.210	0.260
Paddy field	194.180	96.7	2077.0	0.310	0.160	0.470	0.053	0.107	0.160
Lake	129.390	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000
Beach	3.740	9.4	97.9	0.020	0.037	0.057	0.002	0.006	0.008
Sand land	1.270	2.9	62.4	0.005	0.007	0.012	0.001	0.003	0.004
Urban residential area	36.320	98.0	13334.2	0.610	62.450	63.060	0.032	4.328	4.360
Rural residential area	18.490	46.9	5006.2	0.290	23.450	23.740	0.016	1.624	1.640
Building soil	0.930	2.0	332.0	0.012	1.558	1.570	0.001	0.109	0.110
Total	3291.670	6405.7	510736.4	24.470	630.229	654.690	4.155	131.097	135.252

Notes: AN—Absorbed nitrogen; DN—Dissolved nitrogen; TN—Total nitrogen; AP—Absorbed phosphorus; DP—Dissolved phosphorus; TP—Total phosphorus erosion map (Fig. 3), the absorbed N loss distribution map (Fig. 4) and the absorbed P loss distribution map (Fig. 5) were obtained, respectively.

3.1 Risk Areas of Soil Erosion and N and P Losses

The soil erosion was very serious in low-hill area and around the lake area. Through the comparison of Fig. 2 and Fig. 3, it can be seen that:

(1) The soil erosion was slight in the east and west parts of the watershed because there are some of 350–500m high hills with woods and shrubs. The erosion modulus was about 0–1000t/(km^2·a).

(2) The land-use types in the east of the Dongliao River and around the lake were hill dry land. The topography there was characterized of the flatness and the height was only about 200–250m above sea level. The

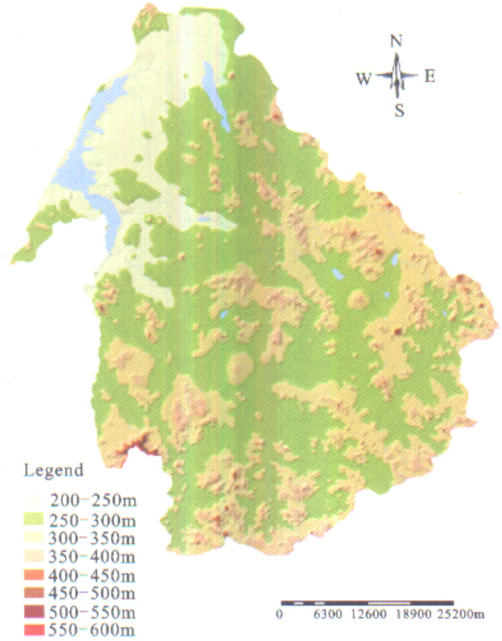

Fig. 2 Contour of the watershed

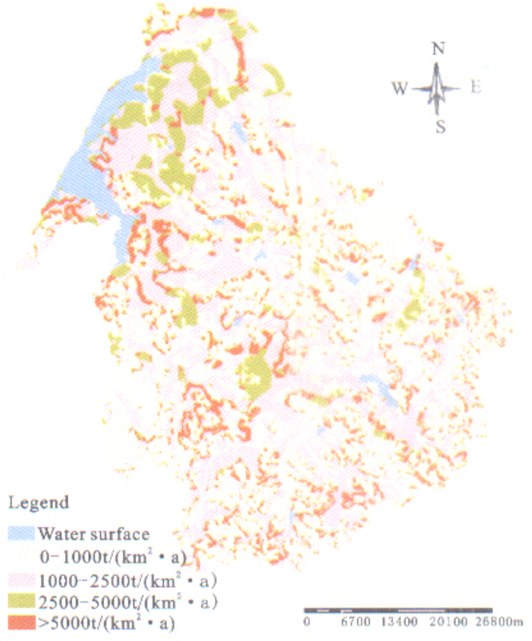

Fig. 3 Soil erosion map

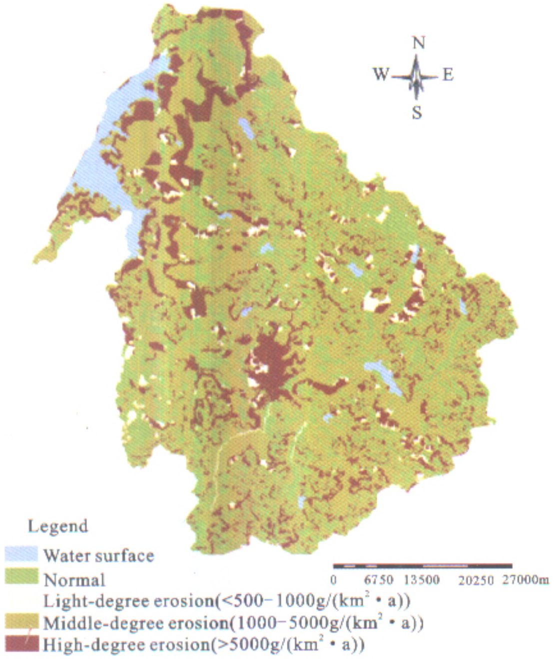

Fig. 4 Absorbed N loss distribution

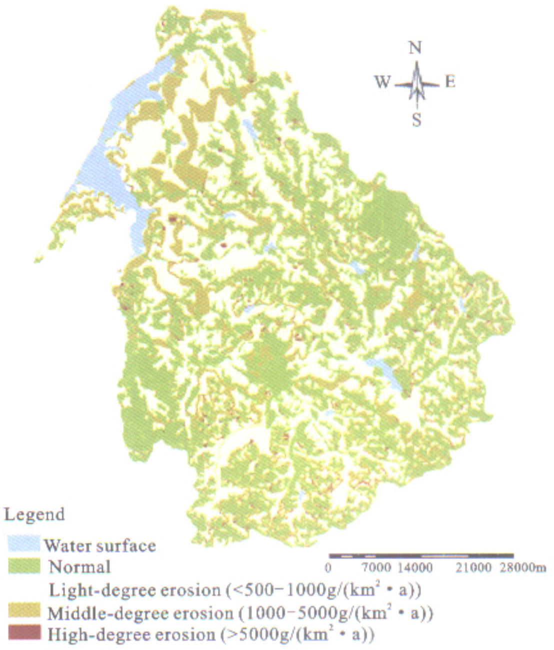

Fig. 5 Absorbed P loss distribution

soil erosion was moderate in this area, with an erosion modulus of about 1000–2500t/ (km^2•a). The soil erosion modulus in some of the east slope area of the lake watershed and in Liaoyuan City (the middle and east parts of the watershed) was about 2500–5000t/(km^2•a).

(3) The area with an erosion modulus of over 5000 t/(km^2•a) scattered in dry land with variable slope east of the lake and the middle-south parts of steep slope mountainous region. Though the area is small, it should be paid attention to as the key area of controlling water and soil losses.

Anyway, the soil erosion was strong because the dry land area was larger and the vegetation coverage was lower around the lake. That is the main reason of the non-point source pollution of Erlong Lake watershed.

It was found from Fig. 4 and Fig. 5 that the trend of the soil erosion and N and P losses is similar. Both the risk areas were in the dry land. The total-N loss was strong (>5000g/(km^2•a)), the total-P loss was in the middle degree (1000–5000g/(km^2•a)). It is possible that human activities such as the tillage and deforestation have caused the soil erosion and N/P losses. Total-N loss was bigger (>5000g/(km^2•a)) in Liaoyuan City. The P loss in rural area (500–1000g/(km^2•a)) was also increasing through rainfall runoff. The results showed that the water quality of the lake was affected by urban domestic sewage that contained high-concentration of nitrogen and phosphorus.

3.2 Distribution Rules of Soil Erosion and N and P Losses

The total soil erosion was 6.4×10^6t/a and the average erosion modulus was 1946.15t/(km^2•a) in this watershed. Compared with other regions, the soil erosion was in the middle degree in/around the lake watershed (XIN and JIANG, 1982). By the comparison of the soil erosion and pollutants in different lands (Table 4), the results indicated that the soil erosion and the N/P losses were very different in the dry land, woodland and shrub.

It was found from Table 4 that the dry land area was 54.05% of the total areas but the soil erosion and N and P losses in the runoffs were 80%–90% of the total quantities. While the total area of woodland and shrub were 17.25% and 14.2% of the total areas, the soil erosions were 5.02% and 4.98% and the total N and P losses in the runoffs were also less because of the strong ability of keeping water in the wood and shrub areas. So it is the key process to lessen the non-point source pollution and to control the soil erosion in dry land. The reasons of the difference in the soil erosion and N/P losses as follows:

The agricultural structure is singleness and a majority of dry land are in sloping field in this watershed. Because of the tillage and deforestation activities, the watershed is prone to be eroded.

Bleached sandy blackland and clay blackland are main soil types in this watershed (The Forest and Soil Institute of Chinese Academy of Sciences, 1980). The soil is loamy if the forest coverage is high. Once be cultivated, it will be easy to form rainfall runoff and form non-permeable layer because the soil is viscid. Thus it could reduce the soil fertility and speed up the water and soil erosion.

The N loss in the runoff is 13% of total loss loads and the P loss in the runoff is serious although the urban and rural areas are only 1.67% of the total watershed. The result showed that the construction of the infrastructure and the administrant measures are very important to avoid the non-point source pollution with the urban development.

4 CONCLUSIONS

This article analyzed the soil erosion and N/P losses in the runoff in Erlong Lake watershed by GIS. On the basis of the analysis the risk area of soil erosion and quantities of the soil erosion and N/P losses in the runoff were assessed. The conclusions are as follows:

Table 4 Comparison of the area and the runoff in different land use types

Land use type	Area (km^2)	Runoff			Area percent (%)	Runoff percent (%)		
		Soil (×10^3t)	N (t)	P (t)		Soil	Total-N	Total-P
Total*	3291.71	6405.0	654.69	135.25				
Dry land	1779.14	5425.0	529.06	126.99	54.05	84.70	80.80	93.90
Woodland	567.94	321.4	24.22	1.06	17.25	5.02	3.70	0.78
Shrub	467.49	319.1	5.52	0.66	14.22	4.98	0.84	0.49
Residential area	54.81	144.9	86.80	6.00	1.67	2.26	13.24	4.44

Note: * The value in total column stands for summary of corresponding calculating results of eleven types of land-use

(1) The main type of soil erosion degree is moderate in Erlong Lake at present and the most erosion modulus is 1000–2500t/(km^2•a), and the intensity erosion areas are located in dry land with variable slope east of

the lake and the middle-south parts of steep slope mountainous region (erosion modulus is more than $5000 t/km^2 \cdot a$). Though the area is small, it should be paid attention to as the key area of controlling water and soil losses.

(2) The trends of the total N and P losses in the runoffs are as same as that of the soil erosion. They are all controlled by the land-use type factor. The results showed that the human activities are the main reason of water environmental deterioration in this watershed.

(3) There are many advantages in the study of soil erosion and N/P losses in the runoff in larger watershed based on GIS. They are speediness, distinctness, nicety and the economization of manpower and material resources. But the results were often affected by the representation of simulating experiments and the applicability of the models. The selection of model, the simulating experiment and GIS technique are the key contents in the study. The presentation of the simulating experiment area is very important and the presentation affects the calculation results.

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