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Impacts of acid mine drainage on water quality of Le An River-Poyang Lake area

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Abstract—This paper aimed at studying the impacts of acid mine drainage on water quality of Le An River and Poyang Lake. It is emphasized that the concentration species, and transport of heavy metals in aquatic ecosystem of Le An River and Poyang Lake were investigated, and the potential risk on water quality were assessed.

Keywords: opencast copper mine; water quality; heavy metals.

INTRODUCTION

Impacts of acid drainage on water quality of Le An River and Poyang Lake are being studied, the concentration, species, and transport of heavy metals in aquatic ecosystem of Le An River and Poyang Lake have been investigated, and the potential risk on water quality were assessed.

SITE DESCRIPTION

The study is conducting on Le An River system, northeastern part of Jiangxi Province (Fig. 1). The river from at mountain Huiyueshan (Lat. 29′ 11″), an elevation of 860 m, which drains 9616 km^2 and 279 km long running into Poyang Lake through Dexing, Leping and Poyang County (Lat. 29′ 2″) at an elevation of 32 m. The stream gradient varies from 1 to 0.065 m / km. It may be divided into three segments (Table 1).

Table 1 The segment of Le An River

Segment	Length, km	Gradient, %	Width, m	Depth, m
Upstream	61.4	1.0	50–100	1–2
Middle	83.6	0.34	100–200	2–5
Downstream	72.5	0.065	> 200	5–10

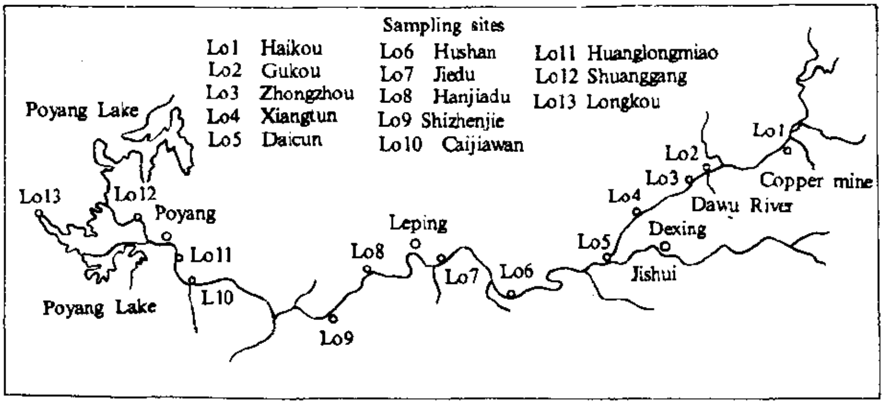

Fig. 1 Sketch on Le An River-Poyang Lake area

The average temperature is 17.1℃, high 29.6℃, low 0.64℃. Average rainfall is 1882 mm, 150 raining days, from April to June. Dry season starts from October to February next year. River flows are estimated by the record from hydrological stations for 10 years (Table 2).

Table 2 The average hydrological records, 10 years

Station	Av. runflow, m^3/ a	Av. flow, m^3/ s	Av. velocity, m / s
Xiangtun	40.7×10^8	129	0.06–3.0
Hushan	68.8×10^8	218	0.06–1.0
Shizhenjie	115.0×10^8	298	0.01–0.46

The upper 46.5 km of the river is lightly buffered with an alkalinity of 0 to 3 mg / L $CaCO_3$ and is classified as being sensitive or highly sensitive to acid pollution. The middle segment of 47.5 km is buffered with 3–8 mg / L $CaCO_3$as being sensitive as well. The down stream of 72.5 km is alluvial plain, as sensitive with 8–10 mg / L $CaCO_3$ not much limestone in the red soil area.

The annual amount of wastewater received from cities and counties nearby Poyang Lake is about 34.19 millions m^3 containing organics (COD, BOD), CN, CrO_4, Cu, Zn and sulfur-bonding matters and so on, the metal concentration in sediment near estuaries reached tens to hundreds ppm. This study is aimed Le An River from Dawu River mouth at Dexing mining area to Poyang Lake about 210 km long.

FIELD STUDY, SAMPLING AND ANALYTICAL PROCEDURES

Le An River in Dexing County includes two tributaries, named Dawu River and Jishui River, surrounding by four mines. The largest opencast copper mine of China located at the upstream of Dawu River, while the other mines located at the Jishui riverbank, named Fujiawu Copper Mine, Damaoshan Copper Mine and one lead smelter plant, and Yinshan Lead Zinc Mine as well.

Sampling was conducted at 13 sections and four sources of acid mine drainage in raining season and dry season from 1987 to 1990 (Fig. 1). The pH and E_H were determined with portable pH meter. Flows at mouth of the tributary were measured with flow meter. River water sample, suspension matter, and sediments were sampled. Duplicated water samples were collected at each section, one treated with 2 ml HNO_3, the other filtrated with 0.45 μ membrane, filtrate was used to measure anions and dissolved metal ions. Suspensions matter were collected and filtered with 0.45 μ membrane in 10 or 20 liters. The samples were refrigerated and digested with HNO_3 and analyzed with ICP and AAS, and with Dionex ion chromatograph for anions.

RESULTS AND DISCUSSION

Composition of acid mine drainages

The acid mine drainages sampled at four mines from 1987 to 1990 were analyzed. The pH of combined seepage at Dexing Copper Mine ranged from 2.22 to 2.75, Fe concentration from 8250 to 35724.2 ppm, sulfate 8250 to 11150 ppm, copper 72.53 to 129.2 ppm, Al 741.8 to 1300.4 ppm, Pb, Zn, Cd, Ni and As ranged from several to tens ppm. The amount of drainage is about $6–7\times10^7$ tons/ a.

Table 3 The typical composition of acid mine drainages

Elements	Concentration, ppm			
	Dexing	Fujiayu	Damaoshan	Yinshan
pH	2.51	3.59	2.41	2.50
Ca	235.17	201.54	147.89	63.12
Mg	538.63	61.93	119.72	102.30
K	47.07	14.71	5.93	5.27
Na	3.11	4.11	3.51	15.97
Cu	102.15	64.91	328.09	2.94
Pb	0.427	0.124	0.171	0.445
Zn	2.38	0.677	3.820	454.10
Cd	0.131	0.103	0.176	1.266
Ni	4.47	0.444	2.027	1.351
Fe	23478.90	36.63	5700.17	171.40
Mn	65.94	7.746	19.17	106.57
Al	979.46	14.414	248.22	49.57
As	2.268	0.002	0.002	0.424
SO_4^{2-}	9716.67	769.50	10825.00	1950.00
HCO_3^-	2.37	0.00	0.00	0.00
NO_3^-	0.73	5.40	13.05	1.66
Cl^-	0.53	0.60	0.28	0.00

The pH of Fujiawu Copper Mine drainage is 2.54 to 3.72, the concentration of the heavy metals are similar to Dexing Mine drainage, the amount of wastewater is around 6–7 × 10^6 tons / a.

The pH of drainages in Damaoshan mines ranged 1.97 to 2.34 that is more acidic than other drainages as it combined the wastewater from pyrite and copper mine, and higher concentration of Fe, Cu, SO_4^{2-}, As, and the amount of 2–3 × 10^7 tons / a.

The Yinshan lead-zinc acid drainage is higher in concentration of zinc, lead, and As and the amount ranged 5–6 × 10^6 tons / a.

The typical results (in average) are listed in Table 3.

The typical results in Dawu and Jishui river mouth are shown in Table 4. The water flows are 65 to 85.8 and 586.5 million tons / a, respectively.

Table 4 Typical composition of elements in tributaries

Elements	Concentration, ppm			
		Dawu		Jishui
	(1)	(2)	(3)	(4)
pH	5.28	4.60	5.05	7.15
Ca	180.91	157.60	139.08	19.70
Mg	47.16	73.50	79.09	4.15
K	88.95	2.49	9.21	3.28
Na	21.77	6.83	6.52	8.70
Cu	4.27	11.75	8.59	0.003
Pb	0.00	0.12	0.08	0.052
Zn	1.03	0.98	0.31	0.112
Cd	0.04	0.05	0.014	0.005
Ni	0.46	0.22	0.20	0.005
Fe	21.03	218.89	22.23	0.007
Mn	4.52	4.14	6.14	0.002
Al	17.06	80.96	61.70	0.032
SO_4^{2-}	240.30	467.57	177.00	19.76
HCO_3^-	1.03	2.12	0.98	6.60
NO_3^-	2.30	1.73	1.00	1.33
Cl^-	6.20	4.65	1.10	2.46

(1) dry; (2) raining; (3) normal season at Dawu River; (4) dry season at Jishui River

Water quality of Le An River

The impacts of acid mine drainage on Le An River were assessed. The field investigation shows that the pH and concentration of Fe, Mn, Al, SO_4^{2-}, Cu, Pb, Zn in surface water changed dramatically; the contents of suspended matter and composition of sediments changed as well. The concentration of metals in surface water is shown in Table 5. Copper, zinc, lead, and cadmium are the main elements accumulated at the sediments and suspendec matter as well (Table 6, 7). The concentration of metals reached at several thousands to hundreds mg / kg, hundreds, folds higher than the background level in this area.

Table 5 Total concentration of metals in river water, mg / L

No.	Lo. 1	Lo. 2	Lo. 3	Lo. 4	Lo. 5	Lo. 6	Lo. 7	Lo. 8	Lo. 9	Lo. 10
Cu	0.002	7.497	0.205	0.035	0.015	0.016	0.015	0.014	0.020	0.035
Pb	0.023	–	0.015	0.015	0.011	0.034	0.015	0.023	0.023	0.015
Zn	0.080	0.283	0.072	1.104	0.108	0.089	0.145	0.104	0.041	0.033
Cd	0.002	0.007	0.003	0.004	0.003	0.001	0.002	0.003	0.003	0.004
Fe	0.170	80.753	2.279	0.882	0.313	0.716	0.321	0.321	0.231	0.322
Al	0.069	43.3	0.236	0.585	0.222	0.387	0.238	0.328	0.163	0.078
Mn	0.020	5.415	0.138	0.252	0.087	0.109	0.056	0.047	0.046	0.015
Cr	0.000	0.008	0.128	0.067	0.115	0.003	0.127	0.055	0.000	0.000

Table 6 Content of suspended matter and its metal concentration, mg / kg

No.	Lo. 1	Lo. 2	Lo. 4	Lo. 5	Lo. 6	Lo. 7	Lo. 8	Lo. 9	Lo. 10
Sus.	14.8	160	18.4	16.4	13.4	6.1	6.5	12.1	18.0
Cu	34.9	10199.7	613.6	292.1	1251.5	1097.6	1908.5	728.5	392.7
Pb	470.9	217.0	240.0	327.1	356.9	722.8	1044.1	1110.3	59.7
Zn	2445.3	5921.6	2598.3	33141.5	3724.7	5583.6	12606.9	981.7	1150.7
Cd	31.4	72.4	25.9	30.5	24.2	61.7	182.6	13.3	11.0
Fe	57836.1	150352.3	29048.5	18718.4	72785.1	64467.2	108208	31658.3	10987.4
Al	220371.6	157954.5	154753.7	164038.5	140706	377936	1046462	23114.6	4417.2
Mn	502.3	1822.4	476.4	528.4	871.3	1244.2	2461.3	895.2	205.4
Cr	257.4	966.4	271.0	96.4	302.3	2263.0	751.9	279.5	90.3

Table 7 Metal concentration in sediments, in normal season 1989, mg / kg

No.	Lo. 1	Lo. 2	Lo. 3	Lo. 4	Lo. 5	Lo. 6	Lo. 7	Lo. 8	Lo. 9	Lo. 10
Cu	33.5	3109	2689.3	1648.0	670	1400.1	586.2	5[illegible]2.2	517.4	526.7
Pb	45.4	0.9	15.9	38.3	139.1	72.8	116.1	75.7	67.4	79.9
Zn	245.0	53.2	92.4	183.5	1040.0	707.0	787.1	608.0	496.8	2229.7
Cd	3.5	1.7	2.4	3.0	4.6	4.4	5.8	4.5	4.3	5.7
Fe	31237.5	4105	20967.5	38575	35890	37322.5	45295	6402.5	30845	25775
Mn	713.8	18.7	231.7	748.9	604.2	1442.9	1354.0	1246.7	1360.7	1728.8
Al	44370	28657.5	21130.3	13826	12642.8	10366.3	94607.5	27460	3100.3	11139.3
Cr	95.5	47.0	104.8	79.4	72.7	84.0	44.5	112.1	81.4	110.0

Fig. 2 shows that pH of river water changes from Gukou River mouth where acid mining drainage discharged downwards about 30 km. The impacts of acid drainage on water quality in dry season is less than in flood season as the amount of acid drainage in dry season is less than in rainy season. The concentration of metal decreased steeply along the river.

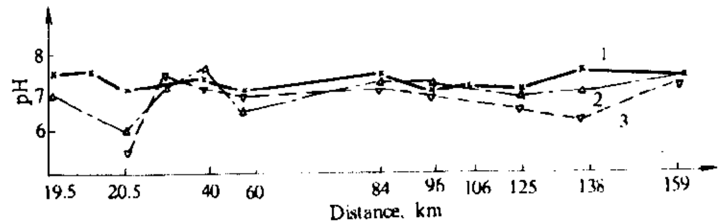

Fig. 2 pH changes along Le An River

1. 1989, 4; 2. 1989, 12; 3. 1990, 4

Modeling of the water quality of Le An River

It is very complicated to simulate the fate, transformation, and transport of the acid mine drainage in Le An River. A series of effects should be considered in the water quality modelling for heavy metals. There are some processes that depend on the path and time in which the pollutants would be transformed and transported. Kinetically controlled processes are often very important. The sedimentation of suspended solid, adsorption of metal ions on particles, and kinetically controlled dissolution and precipitation are slow processes. In phenomenology, some processes behaves like the dispensation of concentration in reactor. In the model, the sedimentation coefficient and partition coefficient were used to simulate these processes in steady state. Following model was assigned (Salomon):

$$\frac{dC}{dt} = D\frac{\partial^2 C}{\partial x^2} + V\frac{\partial C}{\partial x} - K \times C + R, \tag{1}$$

where, C: the concentration of metals in suspended particulates, g / m^3; D: the diffusion coefficient, L / s; V: the average velocity of flow, m / s; K: the sedimentation coefficient, L / s; R: the non-point source discharge, g / s.

In the model, the concentration of metal in water was supposed to divide into two parts as dissolved and particulate species; the particulate species include active phase and inert phase. The partition coefficient of metal between the suspended particulates and water is defined:

$$K'p = \frac{Cse}{Cwd}, \tag{2}$$

where, Cse: the active part concentration of metal in suspended particulates, mg / kg; Cwd: the dissolved concentration of metal in water, mg / L; $K'p$: the partition coefficient of metal, L / kg.

The sedimentation coefficient is defined as follows:

$$Ks = \frac{Sp}{H},\tag{3}$$

where, Sp: the velocity of the suspended particulates sedimentated to bottom, m / s; H: the depth of water in segment, m; Ks: the sedimentation coefficient, L / s.

The partition coefficient above can be estimated from the speciation distribution of metals in suspended matter and sediment and the dissolved concentration of metal in water. The sedimentation coefficient may find out from the field investigation and experiment (Lin, 1990).

In the model, the balance of the suspended matter in water is

$$SSt = SSi + SSp - SSout - SSd,\tag{4}$$

where, SSt: total mass of suspended matter in water compartment, g; SSi: mass of suspended matter from upstream, g; SSp: mass of suspended matter from lateral boundary, g; $SSout$: output mass of suspended matter to downstream, g; SSd: mass of suspended matter sedimentated to bottom, g.

$$SS = SSt / Vq,\tag{5}$$

where, SS: concentration of suspended matter in water, g / m^3; Vq: the volume of water at the compartment, m^3.

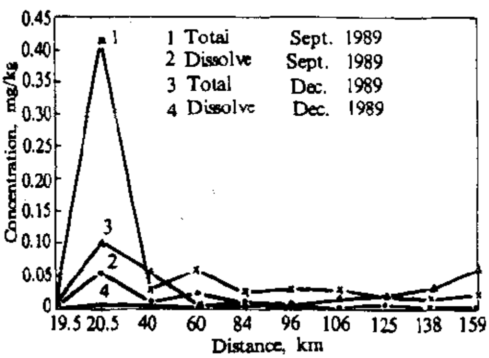

Fig. 3 The concentration of copper in water

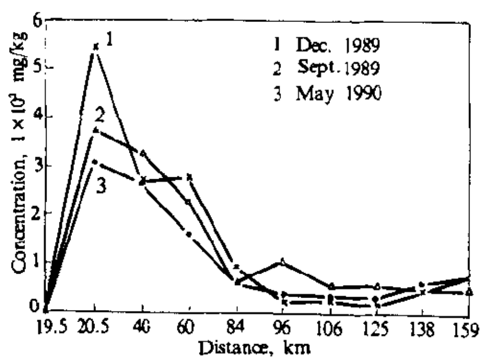

Fig. 4 The concentration of Cu in sediment

The concentration of Cu in water, sediments and suspension matter calculated from the above model are shown in Fig. 3 and Fig. 4. The tendency of the variation of copper concentration from the discharging mouth to the downstream was concordant with the field survey data (Table 4, 5, 6), the Cu concentration in sediments and suspended matter is 1700 to 3700 ppm in flood season and dry season, much higher than the background value (Lo. 1). The copper concentration in sediment near Poyang Lake is 100 to 370 ppm (Fig. 4). A series of reactions, neutralization, precipitation and flocculation, will occur at the segment near the discharging mouth depending on the velocity and flows in river. The results indicated that the concentration of metals in sediments in dry season will be much higher than that in flood season at Lo. 2 to Lo. 4, but in downstream the concentration is in the reverse order, that is, flood season higher than dry season. The Cu concentration in water is less in dry season, as the amount waste water is decreased, the flow and velocity of the river water are lower. Thus water quality will be degraded particularly in the beginning of the flood season.

The thermodynamic equilibrium model (MINTEQA2) can be used to calculate the species distribution of metals in the river water based on the monitoring data of water quality in various segments. The concentration of the cations and anions and pH of water (Table 7) was filled in the input file at the computer programme.

The result shows that the species distribution of metals in water will change dramatically depending on the pH and species of anions E_H and the dissolved oxygen are almost similar in the whole river, E_H 190 mV and the pressure of oxygen in air is 1×10^{-3} atm.

The toxicity of metal ions is different from one species to another depending on the environmental condition and the species distribution of metal. For examples:

1. Aluminum forms a series of species in water that are pH dependent. Free Al predominates below pH 5.0. The results (Table 7) show that the percentage of free Al ion exceed 50% of the total concentration in Lo.2 (64.2%) and in Dawu River mouth (52.8%). Secondary species is $AlSO_4^+$ (31.9%) in Gukou and in Dawu River mouth (38.9%). The main minerals formed might be alunite $3Al_2O_3 \cdot K_2O \cdot 4SO_3 \cdot 6H_2O$ in Gukou and in Dawu River mouth. $Al(OH)_3$ (58.3%) predo- minates in Lo.3 from pH 4.79 to pH 6.64. Free Al ion concentration is very low in middle and downstream to Poyang Lake. A literature review of Al toxicity to the affected species reveals that dissolved concentration over 1.5 mg/ L would cause drastic physiological change for the warm water fish, and 0.5 mg/ L would be set as standard for the warm water fish (Moore, 1984). It is the serious problem that a large amount of Al discharged from acid mine drainage to Le An River. These Al concentration appears to exceed national level for the fish and other aquatic organisms especially in the flood time with lower pH, the most toxic effect of Al will occur from Lo. 2 to Lo. 5. Thus Al impacts on Le An River should pay attention to the water quality.

2. Copper is highly toxic to aquatic plants, invertebrates, and fishes, the copper concentration in Dawu River mouth and Lo. 2 exceed the standard of fishery and reaches at 1.944 mg/ L. Free Cu^{2+} predominates below pH 5.0, the most toxic effects will be occurred from Lo. 2 (Gukou) to Lo. 3 (Zhongzhou), and the total concentration in downstream almost exceeds the standard of fishery 0.01 mg/ L.

3. Other elements

The concentration of Cd, Zn and Pb almost exceed and reach at the national standards for fishery, especially in dry season. Free Cd in Lo. 3 predominates below pH 5.65, $CdCO_3$ will predominate in pH 7.25. The solubility of $ZnCO_3$ and $Zn(OH)_2$ is higher, so the dissolved Zn in water is higher.

There is no standard of fishery for Fe in China, but Fe in national standard for drinking water is 0.3 mg / L. It is impossible to predict impacts of iron to aquatic biota, but it exceeds the standard of 1.5 mg / L for warm water fishery.

The toxicity of Mn to aquatic species are limited, but the maximum acceptable toxicant concentration of 0.77 mg / L for rainbow was reported, the maximum recommended concentration of 1.0 mg / L for drinking water. This large amount of Fe and Mn will cause the water treatment problem for city supply.

CONCLUSION

The pH, aluminum, copper are important elements for impacts of acid mining waste water on water quality in Le An River.

A large amount of heavy metals deposited and precipitated in the polluted plume zone near the Dawu River mouth, the concentration of copper, zinc, iron, manganese and aluminum in sediment increased dramatically, and transported downwards. The results from the model shown that a large amount of suspended matters transported to downstream and deposited in riverbed and estuary.

The combination of the river transport model and the equilibrium models (MINTEQA2) can describe the water quality in more detail, it is useful to predicate the water quality.

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REFERENCES

Baker, J. P. and Schofield, C. L., Water, Air, and Soil Pollution, 1982, 18:289

Daniel, L., Ramsey and Donald, G., Branoon., Water, Air, and Soil Pollution, 1988, 39:1

Moore, J. W. and Ramamoorthy, S., Heavy metals in the natural water, New York: Springer-Verlag, 1984:268

USEPA., MINTEQA2 computer program for calculating aqueous geochemical equilibria, Envir. Res. Lab. R. and D. Office, Athens, Georgia, 30613

Sun Baoguo, The first symposium of environmental protection for mining processes, 1986:81

(Received October 9, 1991)