

Environmental Effects of Heavy Metals in Xiangsi River of Tongling, China

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Abstract- The environmental effects of heavy metals in waste rocks, soils, sediments and waters by metalliferous mining activities in Tongling were studied. In this study, samples collected from waste rocks, soils, sediments and water of Xiangsi River were analyzed. The heavy metal contents increased along the middle area of the river valley. The maximum contents of the heavy metals in the area were higher than the background value and the quality standard value of environment due to the acid mine drainage (AMD) generated by the waste rocks, indicating the potential mining activities of causing environmental problems.

Keywords- Heavy Metal Elements; Environmental Effects; Xiangsi River; Acid Mine Drainage (AMD)

I. INTRODUCTION

Tongling city of Anhui province lies in the middle of the iron-copper-gold polymetallic metallogenic belt of the middle-lower reaches of Yangtze River. It is one of the important mineralization areas in China. Xiangsi River lies in the east-south area of Tongling city, originating from the Fenghuang Mountain, and flowing into the Yangtze River. Fenghuangshan Copper Mine and two reservoirs are located in the upper river valley. Xinqiao Pyrite Mine lies in the middle of Xiangsi River. Mining activities in Tongling city have been booming for very long time. The exploitation of mineral resources brings huge economic benefits to the development of the society, but it leads to a series of environmental contamination problems at the same time. One of the universal problems of mining activities is the pollution of heavy metals. As a result, elevated levels of heavy metals can be found in and around discussed metalliferous mines due to discharge and dispersion of mine wastes into nearby agricultural soils, food crops and stream systems. Eventually, they may pose a potential health risk to residents in the vicinity of mining areas. Many studies have been conducted on heavy metal contamination in soils, plants, waters and sediments from metalliferous mines throughout the world ^{[1]-[7]}. Some scholars have discussed the transportation of heavy metal elements influenced by their chemical composition and the possible environmental problems ^{[8]-[10]}.

The objective of this study is to make a systematic investigation of the migration and distribution of heavy metals in Xiangsi River. The goal is to determine the

environmental effects of the heavy metals by comparing the heavy metal contents with the background values in Tongling and the quality standard value of environment, and find out the degree of influence to the local environment.

II. STUDY AREA

Tongling is a developing industrial city focusing on the exploitation of mineral resources. Its mining history can trace back to the period of the Xizhou dynasty more than 3000 years ago. After the 1960s, mining activities became more prosperous. At present, large-scale mining activities are still carried out in this district ^[11].

The eastern suburbs of Tongling are one part of the mining area for Tongling nonferrous metals. The south and middle of these suburbs are the Fenghuangshan Copper Mine and the Xinqiao Pyrite Mine, respectively; the two mines are still being exploited. Two large tailing ponds have been built for the Fenghuangshan Copper Mine, at Linchong and Xiangsigu. The north of the area has farmland and a water network, which connects to the Yangtze River.

The Xinqiao pyrite deposit is a large copper-bearing pyrite mineral deposit. Two ways of underground mining and surface mining have been used to mine ores. The waste rocks stripped by surface mining are piled up on the hillside near the mine. Parts of the waste rocks are used to back-fill the mining tunnel. The sulfur-concentrates from which Cu, Au and Ag have been separated are transported to other places to produce vitriol, so no tailings are produced.

III. MATERIALS AND METHODS

Sampling of waste rocks, soils, sediments and waters in Xiangsi River were carried out for the study. The sketch map showing the locations of all samples is shown in Fig. 1. Heavy metal concentrations of samples were measured in the central geological laboratory of Anhui province.

Seven waste rocks samples were taken from the waste heap of Xinqiao Pyrite Mine by color at random. The waste rocks were then broken up by hammer, and also ground to 200 micron with a carnelian mortar. The powder samples were kept in polyethylene plastic bags. The concentrations of heavy metals were measured by automatic fluorescence spectroscopy (AFS, AFS-230E), Atomic Absorption Spectrometer (AAS, AASZEEEnit60) and inductively

coupled plasma optical emission spectrometry (ICP-OES, Iris advantage).

Eleven soils samples were collected from farmland nearby the river from the upriver area to the downriver area (shown in Fig. 1 as S1-S11 and located in Table I) kept in

sealed plastic bags. The samples were taken into a clean hop-pocket, dried in a thermotank at a temperature of 40 for three days. Then the soil samples were broken up by hammer, ground to 200 micron with a carnelian mortar. The measure methods were same as the sediment samples' measure.



Fig. 1 The location of samples in Xiangxi River Valley

TABLE I THE LOCATIONS OF SOIL SAMPLES

Sample No.	Name of Samples	The Locations of Sampling
S-XS-1	Soil of hillside	The hillside of the inlet to Xiangxi country
S-XS-2	Soil of cole	Upriver, riverside of Xiangxi River, 2 km away from Xinqiao Pyrite Mine, the soil of planting coles
S-XS-3	Soil of moutan	The soil of planting moutan in Xiangxi country
S-FH-1	Soil of dry land	100m away from the waste heap of Fenghuangshan Copper Mine
S-FH-2	Soil of moutan	500m away from the waste heap of Fenghuangshan Copper Mine
S-XS-4	soil	200m away from Xinqiao town Upriver
S-XS-5	soil	Downriver, riverside of Xiangxi River, 1.5 km away from Xinqiao Pyrite Mine
S-XQ-1	Soil of farmland	100m away from the waste heap of Xinqiao Pyrite Mine
S-XQ-2	Soil of hillside	The hillside down the dam of Shengchong Reservoir
S-XQ-3	Soil of cabbage	Down the dam of Shengchong Reservoir, the soil of planting cabbage
S-XS-6	Soil of cole	Between the road and the railway, the soil of planting coles

Four sediments samples were collected from 4 different points in the river (shown in Fig. 1 as Sed1-Sed4 and located in Table II). Approximately 2 kg of sediment were collected at each of the sampling points at the sediment–water interface (surface river sediments) using a plastic scoop and kept in polyethylene containers. Once in the laboratory, samples were air dried, and taken into a clean hop-pocket,

dried in a thermotank at a temperature of 40°C for three days. They were broken up and then sieved using nylon sieves to 200 micron and stored in polyethylene bottles at room temperature. The concentrations of heavy metals were measured by automatic fluorescence spectroscopy (AFS, AFS-230E), X-Ray fluorescence spectroscopy (X-Ray FS, ZSX100C) and Atomic Absorption Spectrometer (AAS, AASZEEEnit60).

TABLE II THE LOCATIONS OF SEDIMENT SAMPLES

Sample NO.	Name of Sample	Color of Samples	The Location of Sampling
Sed-1	Sediment of Xiangsi River	Dark taupe	2km upriver Xinqiao Pyrite Mine
Sed-2	Sediment of Xiangsi River	Taupe	Near the opencaste working field of Xinqiao Pyrite Mine
Sed-3	Sediment of Xiangsi River	Gray and yellow	200m away from Xinqiao town Upriver
Sed-4	Sediment of Xiangsi River	Black and yellow	Between the road and the railway

Ten waters samples were taken from Xiangsi River upriver to downriver (shown in Fig. 1 as W1-W10 and located in Table III). The water samples were collected at the depth of 0.5 m below the surface and stored in 500 ml polyethylene bottles pre-cleaned with deionized water and rinsed with the sample to be collected from different sites.

The water samples were acidified to $\text{pH} < 2$ using concentrated nitric acid and then stored in the dark at 4°C . The concentrations of heavy metals were measured by inductively coupled plasma optical emission spectrometry (ICP-OES, Iris advantage) and automatic fluorescence spectroscopy (AFS, AFS230E).

TABLE III THE LOCATIONS OF WATER SAMPLES

Sample NO.	Name of Sample	The Location of Sampling
W-XS-1	Water in the reservoir	Xiangsigu tailing reservoir
W-XS-2	Water down the dam	Xiangsigu tailing reservoir
W-XS-3	Water of well	Xiangxi country
W-XS-4	Water of farmland	Farmland in the East of Xiangsi River
W-XS-5	Water of Xiangsi River	2km upriver Xinqiao Pyrite Mine
W-XQ-1	Water of pit	Xinqiao Pyrite Mine
W-XQ-2	Water of reservoir	Shengchong Reservoir
W-XQ-3	leachate	Waste heap of Xinqiao Pyrite Mine
W-XQ-4	Waste water of mill run	Xinqiao Pyrite Mine
W-XS-6	Water of Xiangsi River	200m upriver Xinqiao Pyrite Mine

IV. RESULTS AND DISCUSSION

A. Neutralization Potential and Possibility of Producing Acid Mine Drainage of Waste Rocks

The acid mine drainage (AMD) is water with $\text{pH} < 5$, originating from mine tailing ponds, waste rock piles and oxidation of sulphide ores^[11]. The AMD not only dissolves a great deal of soluble Fe, Mn, Ca, Mg, Al, SO_4^{2-} but also dissolves heavy metals such as Pb, Cu, Zn, Ni, Co, Cr, As, Hg and Cd, etc. If handled unreasonably, it can pollute the groundwater and result in deterioration of the soil and water eco-environment^[12]. The uppermost sulphide in a mining environment is usually pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, etc. These metal sulphides will produce severe AMD containing heavy metals under the action of leaching^[13]. The acid potential (AP) and the neutralization potential (NP) are two important indexes in the exploiting

security assessment of the metal sulphide mine. When $\text{AP} > \text{NP}$, AMD is generated.

In this study, the S element was tested by the non-aqueous titration combustion method. AP that was tested by the counting method of Sobek et al.^[14] is maximal, counted in the light of the S element content. The unit of the acid potential is $\text{kg}(\text{H}_2\text{SO}_4)/\text{t}$. It can be changed into $\text{kg}(\text{CaCO}_3)/\text{t}$. The results are illustrated in Tables IV. NP was tested by the improved neutralization potential acid-alkali counting method mentioned by Lawence and Wang^[15]. With two grams of samples, the quantum (quantity) of consumed HCl (1.0 mol/l) and NaOH (0.1 mol/l) were used to calculate NP using the formula: $\text{NP}[\text{kg}(\text{CaCO}_3)/\text{t}] = \{[\text{volumes of HCl (ml)} \times \text{the mole density of HCl (mol/l)} - \text{the volumes of NaOH (ml)} \times \text{the mole density of NaOH (mol/l)}] \times 50\} \div \text{the weigh of the samples (g)}$. The experimental results were all listed in Table IV.

TABLE IV TEST RESULTS OF THE WASTE ROCK SAMPLES IN THE XINQIAO PYRITE MINE BY THE METHOD OF IMPROVED NEUTRALIZATION POTENTIAL ACID-ALKALI COUNTING AND THE POSSIBILITY OF PRODUCING AMD

Sample No.	S%	AP	HCl (ml)	NaOH (ml)	NP	The Possibility of Producing AMD
R1	0.42	13.12	2.40	23.00	2.50	Yes
R2	0.04	1.20	2.40	23.70	0.75	Uncertainty
R3	0.05	1.56	2.40	23.20	2.00	Uncertainty
R4	1.42	44.37	2.00	11.90	20.25	Yes
R5	0.62	19.37	4.20	0.60	103.50	No
R6	0.33	10.31	2.10	20.40	1.50	Yes
R7	3.44	107.5	2.50	23.60	3.50	Yes

The difference in the contents of S in the seven random samples of the Xinqiao Pyrite Mine was large, from 0.04% to 3.44%, illustrating the different acid potential counted from the S content (Table IV). Furthermore, the difference in

NP of the samples chosen at random was also very large because their mineral components were different. One sample the neutralization potential of which was larger than the acid potential ($\text{NP} > \text{AP}$), did not produce the acid mine

drainage. There were two samples with NP less than AP. In other words, the waste rocks generally produce AMD. Combining the geological characters of the ore body in the Xinqiao pyrite deposit, the wall rocks in which the ore body occurs are mainly sand-shale, with low carbonate content, according with the random sampling instances mentioned above.

B. Heavy Metal Elements in Soil

The concentration of heavy metal in soils upriver were lower than those in the middle area and nearly all samples (except the concentration of Cr in upriver area and Hg) were higher than background values of soils elements of Tongling area (Table V). The concentrations of Cr and Hg were lower than Quality standard of soil environment (GB15618-1995) (II). It indicated soil pollution of Cr and Hg did not occur in the study area. The concentrations of Cr, Pb, Zn, As, Hg in Sample No.S-XS-4 and the concentrations

of Cu, Cd in Samples No. S-XS-6 were highest in all samples, and these two samples locate in the middle area. Generally, the concentrations of heavy metals in the middle area are higher than Quality Standard of Soil Environment (GB15618-1995) (Level II, pH < 6.5). Xinqiao Pyrite Mine in this area is responsible for the results. On one hand, sedimentation of heavy metals enters to soils by dust in the process of mine; on the other hand, Xinqiao Pyrite Mine will generate AMD (as we discussed above), much of heavy metal elements will dissolve in the AMD and flow into soils following surface water. Fig. 2 shows that the variations of Cu, Pb, Zn, Cd, As, Hg conform to the same trend. The concentrations of these metals were lower upriver while increased in the middle area. Generally trend is the concentrations which are lower far away from the waste heap of Fenghuangshan Copper Mine. In addition to the mining activities of Xinqiao Pyrite Mine, the waste heap of Fenghuangshan Copper Mine was also responsible for the higher concentrations of heavy metals.

TABLE V CONCENTRATIONS OF HEAVY METAL ELEMENTS IN SOILS OF XIANGSI RIVER VALLEY (10^{-6} MG/KG)

Sample NO.	Cr	Cu	Zn	Pb	Cd	As	Hg (10^{-9})
S-XS-1	35.50	121.80	80.7	25.00	0.20	13.0	38
S-XS-2	35.60	258.30	149.6	68.10	0.32	25.4	42
S-XS-3	46.20	95.00	243.3	126.80	0.60	29.2	112
S-FH-1	58.80	903.40	541.6	146.30	2.00	85.5	93
S-FH-2	16.60	120.50	155.2	69.70	0.44	11.6	48
S-XS-4	102.00	1264.60	2245.5	863.90	25.00	259.8	183
S-XS-5	71.55	246.05	332.0	230.25	2.60	33.5	73
S-XQ-1	74.65	663.10	127.9	111.35	2.45	34.9	86
S-XQ-2	76.70	34.80	80.6	31.80	0.90	19.3	44
S-XQ-3	95.40	62.00	351.7	220.40	4.30	34.1	112
S-XS-6	59.50	1543.70	1121.4	374.10	28.95	135.8	156
Standard	150.00	50.00	200.00	250.00	0.30	40.00	0.30
Background	62.00	32.15	85.50	47.79	0.086	12.44	0.25

Standard: Quality standard of soil environment (GB15618-1995) (Level II)

Background: background values of soil elements of Tongling area (Qi 2006)

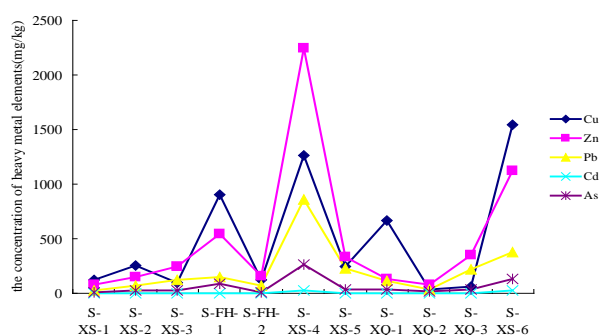


Fig. 2 Concentrations of heavy metals in soils of Xiangsi River valley

TABLE VI CONCENTRATIONS OF HEAVY METAL ELEMENTS IN SEDIMENT'S OF XIANGSI RIVER (MG/KG)

Sample NO.	Cr	Cu	Zn	Pb	Cd	As	Hg(10^{-9})
Sed-1	30.60	949.80	504.60	67.30	2.15	81.20	84
Sed-2	33.00	885.10	582.30	67.00	1.70	75.20	73
Sed-3	40.20	1768.20	1444.80	222.10	48.90	125.00	110
Sed-4	47.10	2181.80	2162.50	410.00	79.55	138.40	93
Background	69.25	58.80	118.15	56.70	0.050	18.00	0.08

Background: Background values of sediment elements of Tongling area

C. Heavy Metal Elements in Sediment

Table VI shows the concentrations of heavy metal elements in sediments. It indicates that the concentration variation range of Cu, Pb, Zn, Cd, As are extraordinary. Their concentrations are much higher than the background values of sediments elements of Tongling area. Figs. 3-5 showed that the concentrations of heavy metal elements in sediments of Xiangsi River were lower upriver and they all increased in the middle area. They reached the highest values in Sed-XS-5 generally (except Hg).

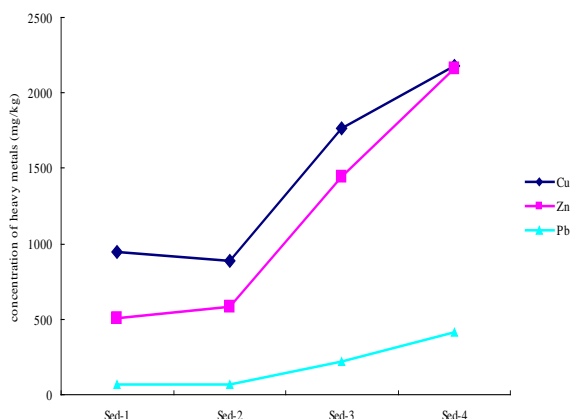


Fig. 3 Concentrations of heavy metals in sediments of Xinagsi River valley

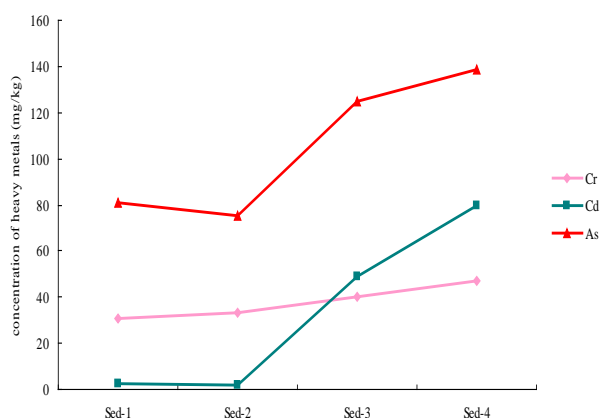


Fig. 4 Concentrations of heavy metals in sediments of Xinagsi River valley

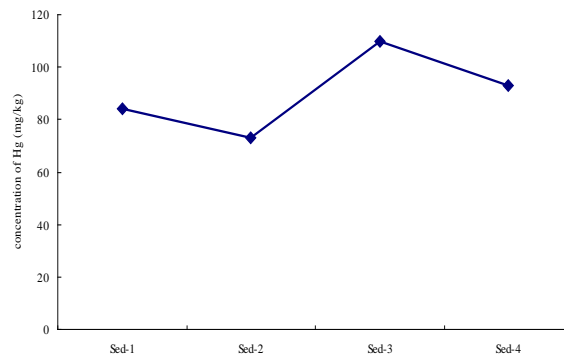


Fig. 5 Concentrations of Hg in sediments of Xinagsi River valley

Xinqiao Pyrite Mine in the middle area is responsible for the results just as the results to the soils. In addition to the process of sedimentation and rain, much of heavy metal elements dissolved in the AMD will flow into Xianfsi River following surface water. The pH value of AMD will increase by dilution function of river water. Then some absorption reaction and precipitation reaction will happen between the sediment and the water. This is also responsible for the increase of the concentrations of heavy metal elements.

D. Heavy Metal Elements in Water

The concentrations of heavy metal elements of Xiangsi River water are shown in Table VII. A wide range of the pH values was lower in mine waters (especially leachate) and higher in upstream waters. The relatively low water pH of mine waters is due to the dissolution and decomposition of sulfide minerals including pyrite in mine waste dumps (tailings and waste rocks) [16].

TABLE VII CONCENTRATIONS OF HEAVY METAL ELEMENTS IN XIANGSI RIVER (MG/KG)

Sample NO.	pH	As	Hg	Cu	Pb	Zn	Cd	Cr
W-XS-1	5.5	0.0012	0.000011	0.032	ND	0.017	ND	0.002
W-XS-2	6	0.0004	0.000044	0.011	ND	0.008	ND	0.002
W-XS-3	6	0.0007	0.000006	0.003	ND	0.004	ND	0.002
W-XS-4	6	0.0017	0.000050	0.017	ND	0.015	ND	ND
W-XS-5	6	0.0010	0.000058	0.021	ND	0.009	ND	ND
W-XQ-1	4	0.0007	0.000012	1.775	0.050	2.84	0.958	0.002
W-XQ-2	6	0.0002	0.000025	0.038	ND	0.23	0.006	0.002
W-XQ-3	2	0.1070	0.000012	25.08	ND	29.88	0.365	0.056
W-XQ-4	4.5-5.5	0.0005	0.000012	4.420	0.049	6.28	0.482	0.003
W-XS-6	6	0.0006	0.000040	0.374	ND	0.72	0.083	0.002
Standard	6-9	0.1	0.001	1.0	0.1	2.0	0.01	0.1

Standard: Quality standard of surface water environment (GB3838-2002) (Level V)

ND: Not detected

In general, metal concentrations in natural waters are very low due to their low solubility in the aquatic environment. The concentrations of As, Hg, Cu, Pb, Zn, Cd and Cr in water samples are also shown in Table VII. The heavy metal elements contents in upriver area were lower than the quality standard of surface water environment (GB3838-2002) (V). High concentrations of heavy metals existed in W-XQ-3 and W-XQ-4. In sample W-XQ-3, the

heavy metal contents exceeded the standard, with maximum contents of 0.107, 25.08, 29.88, 0.365 and 0.056 mg/kg of As, Cu, Zn, Cd and Cr respectively. These concentrations may be derived from heavy metals dissolution in AMD and interaction of rain with tailings containing elevated levels of these metals. Thus, they can be continuously discharged downstream and decreased exponentially with distance from the mine.

V. CONCLUSIONS

The acid potential (AP) is larger than the neutralization potential (NP) in the waste rocks of Xinqiao Pyrite Mine. Thus they produce AMD.

Soils, sediments and waters of Xiangsi River in Tongling have been contaminated by mining activity in the past. Generally, the concentrations of heavy metal elements were lower in upriver area. High concentrations of heavy metal elements were found in the middle area of the valley. Xinqiao Pyrite Mine was responsible for the results. The one reason was sedimentation of heavy metal elements enter to soil, water and sediment by dust in the process of mine and rain; the other was much of heavy metal elements dissolved in the AMD flowed into River and soils nearby following surface water. Then some absorption and precipitation processes occurred between the sediment and the water.

VI. RECOMMENDATIONS FOR POLLUTION MINIMIZATION

The results obtained show that required treatment should be provided to reduce environmental load caused by the mine wastes. Effective ways of liquid and solid waste treatment have been developing using natural (clay, peat, limestone, etc.) and modified materials (organic-mineral complex, etc.) on the basis of the sulfide waste investigations^[17]. Limestone and the peat-humic agent (PHA) can be used for neutralization of acid mine drainage^[18-20]. Mixture of clay, limestone and the peat-humic agent can be used to create a complex organic-mineral geochemical barrier which has similar properties as the hardpan to significantly decrease water, oxygen and element migration. This barrier neutralizes acid mine drainage and retains heavy metals because of the process of complexation, sorption and hydrolysis of some compounds. The proposed cost-effective method will reduce the hazardous effect of mining activities on the environment.

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REFERENCES

- [1] I. Thornton. Geochemical aspects of heavy metal pollution and agriculture in England and Wales. Inorganic Pollution and Agriculture MAFF Ref. Book 326. HMSO, 105-125, 1980.
- [2] R. Fuge, C. F. Paveley, and L. N. Holdham. Heavy metal contamination in the Tanat Valley, North Wales. Environ. Geochem. Health, 11: 127-135, 1989.
- [3] G. Merrington, B. J. Alloway. The transfer and fate of Cd, Cu, Pb and Zn from two historic metalliferous mine sites in the U. K.. Appl. Geochem., 9: 677-687, 1994.
- [4] M. H. D. Pestana, M. L. L. Formoso, and E. C.. Teixeira. Heavy metals in stream sediments from copper and gold mining areas in southern Brazil. Explor. Geochem., 58: 133-143, 1997.
- [5] N. C. Woo, M. J.. Choi. Arsenic and metal contamination of water resources from mining wastes in Korea. Environmental Geology, 40(3): 305-311, 2001.
- [6] S. Earman, L. Ronald. Hershey water quality impacts from waste rock at a carlin-type gold mine, Elko country, Nevada. Environmental Geology, 45: 1043-1053, 2004.
- [7] A. Oliveira, C. Palma, and M. Valença. Heavy metal distribution in surface sediments from the continental shelf adjacent to Nazaré canyon. Deep Sea Research Part II: Topical Studies in Oceanography, 58: 2420-2432, 2011.
- [8] V. Milu, J. L. Leroy, and C. Peiffert. Water contamination downstream from a copper mine in the Apuseni Mountains Romania. Environmental Geology, 42: 773-782, 2002.
- [9] J. M. Hammarstrom, R. R. Seal, A. L. John, and J. C.. Jackson. Weathering of sulfidic shale and copper mine waste: Secondary minerals and metal cycling in Great Smoky Mountains National park, Tennessee and North Carolina, USA. Environmental Geology, 45: 35-57, 2003.
- [10] A. P. Reis, C. Patinha, E. Ferreira da Silva and A. J. Sousa. 2011. Metal fractionation of cadmium, lead and arsenic of ceogenic origin in topsoils from the Marrancos gold mineralisation, northern Portugal. Environmental Geochemistry and Health (online first). 2011.
- [11] X. C. Xu, S. M. Lu, F. Chen. Acid Mine Drainage and Heavy Metal Pollution from Solid Waste in the Tongling Mines, China. Acta Geologica Sinica (English Edition), 82:146-153, 2008.
- [12] N. Z. Xu, Y. X. Tao, and N. H. Gao. Metal deposit environmental pollution and its remediation. Volcanology & Mineral Resource, 22(1): 63-70, 2001.
- [13] A. Aykol. Heavy metal pollution and acid drainage from the abandoned Balya Pb-Zn sulfide mine NW Anatolia, Turkey. Environmental Geology, 45: 198-208, 2003.
- [14] A., Sobek F. W. J. Schuller, and R. Smith. Field and laboratory methods applicable to overburdens and mine-soil, (West Virginia University, Morgantown College of Agriculture and Forestry). EPA report no. EPA-600/2-78-054, 47-50, 1978.
- [15] R. W. Lawrence, Y. Wang. Determination of neutralization potential for acid rock drainage prediction. Wttawa: Canadian Centre for Mineral and Energy Technology, 1997.
- [16] C. J. Myung. Heavy metal contamination of soils and waters in and around the Imcheon Au-Ag mine, Korea. Applied Geochemistry, 16: 1369-1375, 2001.
- [17] A. A. Bogush, E. V. Lazareva. Behavior of heavy metals in sulfide mine tailings and bottom sediment (Salair, Kemerovo region, Russia). Environ Earth Sci, 64:1293-1302, 2011.
- [18] A. A. Bogush, A. N. Trofimov. Application of peat-humic substances for reduction of man-caused influence of mine wastes on environment. Chem Industry, 82:153-158, 2005.
- [19] A. A. Bogush, V.G. Voronin. Application of a peat-humic agent for treatment of acid mine drainage. Mine Water Environ, 30(3):185-190, 2010.
- [20] A. A. Bogush, V. G. Voronin, O.G. Galkova, N.V. Ishuk. Application of natural and modified materials for treatment of acid mine drainage. Proceedings of the 1st international water quality conference, 23-24 June 2010, Leeds, UK, pp. 24-27.