Письма в ЭЧАЯ. 2014. Т. 11, № 2(186). С. 324–337

INAA FOR DETERMINATION OF TRACE ELEMENTS IN BOTTOM SEDIMENTS OF THE SELENGA RIVER BASIN IN MONGOLIA

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Instrumental Neutron Activation Analysis (INAA) was used for the determination of major, minor and trace elements in samples of bottom sediments of the inflows of the Selenga river basin to assess the impact of the contamination from the industrial complex Erdenet and other industrial enterprises in Mongolia. A total of 42 elements (Na, Mg, Cl, K, Ca, Al, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Zr, Nb, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Tm, Hf, Ta, W, Au, Hg, Th, and U) was determined by combination of conventional and epithermal neutron activation analysis at the IBR-2 reactor, FLNP, JINR, Dubna. For the first time such a large set of elements was used for characterization of the bottom sediments as accumulating media which may reflect industrial contamination of the water basin. The concentrations of heavy metals and other trace elements in the samples from three inflows of the Selenga river basin were compared with data of the previous studies. It was shown that the industrial zone of the Erdenet Mining Corporation (EMC) and gold mining zone Zaamar are the sources of strong environmental contamination. The concentrations of Cu and Sb determined in sediment samples of the Rivers Khangal and Govil near the EMC exceed average crustal rock and soil values by factors of 50 and 15, respectively. In the area of gold mining zone Zaamar, concentrations of Au, As, and Sb exceed crustal rock and soil values by factors of 4, 25, and 6, respectively. The relatively high levels of As, V, Zn, Cu, and Sr concentrations in the sediments of the studied rivers are obviously due to the discharges of untreated wastewater of desalination plant, electrical power station, textile industry and mining activities as well as domestic wastewater.

Инструментальный нейтронный активационный анализ (ИНАА) использован для определения макро-, микро- и следовых элементов в образцах донных отложений притоков бассейна реки Селенга с целью оценки воздействия загрязнения от промышленного комплекса Эрдэнэт и других промышленных предприятий в Монголии. С помощью обычного и эпитеплового методов нейтронного активационного анализа на реакторе ИБР-2 ЛНФ ОИЯИ (Дубна) в донных отложениях определены концентрации 42 макро-, микро- и следовых элементов (Na, Mg, Cl, K, Ca, Al, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Zr, Nb, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Tm, Hf, Ta, W, Au, Hg, Th, и U) как биогенного, так и токсичного характера. Информация о концентрациях такого большого набора элементов в составе донных отложений впервые была использована для характеристики промышленных загрязнений исследуемого водного бассейна. Концентрации тяжелых металлов и других следовых элементов в образцах из трех притоков бассейна реки Селенга были сопоставлены с данными предыдущих исследований. Показано, что горно-обогатительный комбинат (ГОК) г. Эрдэнэт и предприятия по добыче золота зоны Заамар являются источниками сильного загрязнения окружающей среды. Концентрации Cu и Sb, определенные в пробах донных отложений рек Хангал и Говил рядом с ГОК, превышают средние значения для земной коры, горных пород и почв с факторами 50 и 15 соответственно. В области золотодобывающих предприятий зоны Заамар концентрации Au, As, Sb превышают значения для земной коры, горных пород и почв с факторами 4, 25 и 6 соответственно. Относительно высокий уровень концентраций As, V, Zn, Cu, Sr в донных отложениях исследованных рек связан, очевидно, со сбросами неочищенных сточных вод завода по опреснению воды, электрической станции, предприятий текстильной промышленности и добычи полезных ископаемых, а также бытовых сточных вод.

PACS: 28.50.Ky; 82.80.Jp

INTRODUCTION

Monitoring studies of concentration of heavy metals and other trace elements in the sediments of the inflows of the Selenga river basin are important for assessing the effect of contamination by pollutants from industrial, urban and agricultural areas.

The river plays a significant role in the surrounding ecosystem and the environment, as well as in the economic development of the country.

The state of ecosystem in any water body is significantly governed by its tributaries, the water quality in which is largely dependent on the processes developing in their catchment areas. Bottom sediments of a river accumulate substances flowing from its catchment area, reflect the quality of river water, and can serve as a reliable indicator of general state of the river.

Sediment is the loose sand, clay, silt and other soil particles that settle at the bottom of a body of water (United State Environmental Protection) [1]. It can come from soil erosion or from the decomposition of plants and animals. Wind, water and ice help carry these particles to rivers, lakes and streams. Sediments comprise an important component of aquatic ecosystems, providing habitat for a wide range of benthic and ephibenthic organisms. Exposure to certain substances in sediments represents a potentially significant hazard to the health of these organisms.

In any river system, an understanding of the concentration, and fate, of trace elements is extremely important in addressing their impact on the regional environment. The ultimate sink for elements in solution is the bottom sediment [2].

Urbanization and industrialization have led to major ecological and environmental problems throughout the world [3]. Trace elements such as heavy metals may be released into aquatic systems by both natural processes and anthropogenic activity.

Many studies have found that urban and industrial influents are major sources of heavy metals in rivers [3, 4]. During last decade, the Selenga river basin in Mongolia experienced a strong effect of rapidly developing gold mining. As a result, vast area of the basin dramatically changed, and the ecosystems there were virtually destroyed. It is known that any kind of activity (including industrial copper and gold mining) that destroys the structure of bottom sediment in the water bodies can markedly affect the water quality in them [5, 6]. Compared to other countries, Mongolian water reservoirs have been less affected by anthropogenic activities. However, population growth and rapid urbanization during the last 30 years have led to increased exploitation of water, increasingly adverse impacts of industries on the environment, deterioration in the natural water regime, water resource shortage, pollution, and ecological degradation [7].

Increased industrial activity, environmental pollution with domestic and municipal wastewater and agricultural runoff inputs into the river have disturbed the equilibrium of its ecosystem. Information on elemental content in sediments is of great use for assessing the pollution level in the study area and river water.

In addition, the problem of water degradation is becoming more serious when it comes to the case of placer gold mines, which dominantly use water through their recovery procedures. Annually, 160–300 million cubic meters of water are consumed only for the placer gold mining, and that much of effluent water is discharged to the river [8].

Heavy metal concentrations determined in river sediments of the Tuul, which is one of the inflows of the Selenga river basin, evidence for a considerable impact of urban activity [9]. Previous studies [10, 11] had determined the levels of heavy metals and toxicological status of bottom sediments of the Selenga river basin. Toxic bottom sediments were also found in a brook in the region of the Erdenet Mining Corporation (EMC), as well as in the Eroo and Bukhlyn rivers, which experience the effect of intense gold mining.

For obtaining the detailed and complete information through analysis of the above-mentioned objects multi-elements INAA was chosen as most adequate analytical technique widely used for river pollution studies [12–14].

The main goal of our study was to determine the concentrations of heavy metal and other trace elements in bottom sediments from Mongolia to reveal possible sources of pollution and to assess the impact from industrial complex Erdenet and Zaamar gold mining zone on the ecosystem.

STUDY AREA

The country's largest river system, the Selenga river basin is a transboundary water system, which rises in the Khanghai Mountains in Mongolia and the major inflow into Lake Baikal, which is the world's largest fresh water reservoir.

In the Selenga river basin three major cities of Mongolia (Ulaanbaatar, Darkhan and Erdenet) are allocated being the country's political, economic and cultural life centers. Approximately 67% of Mongolia's total population lives in this basin. Ulaanbaatar has over one million of population. The number of population in Darkhan and Erdenet reached 87 and 80 thousand, respectively. Erdenet is the big center of mining, concentration and primary processing of the copper and molybdenum ore, and in Darkhan ferrous metallurgy, dressing of leather, production of chemical compounds and building constructions are concentrated.

The Erdenet copper–molybdenum mine is located in the Bulgan Aimag of Northern Mongolia about 350 km northwest of the capital of Ulaanbaatar.

Erdenet Mining Corporation (EMC) is one of the largest ore mining and ore processing factories in Asia. It has been operating since 1978 as a Mongolian–Russian joint venture. Erdenet mines 22.23 million tons of ore per year, producing 126.700 t of copper and 1954 t of molybdenum [15]. Usually porphyry deposits are mined by open pit method which exposes sulphide minerals to the surface weathering condition accelerating natural chemical weathering process and releasing acid metals and sulphate to the environment.

The Tuul river flows through the Ulaanbaatar and is the main source of water for the capital city. The Kharaa river passes Selenga and Darkhan. It originates at the mountains north of Ulaanbaatar, emptying into the Orkhon river, and discharges together with the Orkhon river into the Selenga river.

The Orkhon river is one of the largest rivers of Mongolia. Originated in province Arkhangai, it passes through the north-west part of province Uvurkhangai, and then flows through the eastern part of provinces Arkhangai, Bulgan, and Selenga, emptying into Selenga river near the Sukhbaatar. The largest tributaries are Tamir and Tuul rivers. The study was carried out in these river catchments in central and northern Mongolia.

The Zaamar Goldfield is located within the Tuul river basin which has an area of 49840 km^2 and is part of the Orkhon–Selenga river basins, which contribute approximately 50% of the total lake inflow to Lake Baikal. Gold mining activities occur over a distance of approximately 20 km along the river valley.

Large-scale placer gold mining has been operating in the Zaamar region since 1992, and the village (soum) gold production in 1998 was 4.080 kg [16]. Gold production continues to increase annually, and new mines are expected to be opened in the Zaamar Goldfield each year for the foreseeable future.

The area is heavily invaded by placer gold mining activities, and its impacts on the river system are very significant since the use of water is the main method to recover the gold-bearing sands and soils. Damage results from both open pit extraction of gold-bearing sand and gravel deposits on the valley's floodplain, terraces, and alluvial fans, and also from injection of large amounts of silt and suspended sediment into the Tuul river from improperly operated mine washing plants and process water settling ponds. Other sources of suspended sediment entering the Tuul river include runoff from improperly designed open mine pits, mine roads, unreclaimed and improperly reclaimed areas where mining is finished.

MATERIALS AND METHODS

Sampling and Sample Preparation. Sampling sites enlisted in Table 1 and shown in Fig. 1 were selected in the places of the anthropogenic activities along the rivers.

Sediment samples were dried during 24 h in oven at 105 °C. After drying samples were powdered in an agate mortar and homogenized. Samples of about 0.3 g were heat-sealed in polyethylene foil bags and packed in aluminum cups for short and long irradiation, respectively, and stored until irradiation at the IBR-2 reactor.

Table 1. **Sampling places of the sediment samples**

Samples No.	Collecting place	Map localization
1	Tuul	Ulaanbaatar (south part)
2	Dundgol	Peace bridge, Ulaanbaatar
3	Selbe	Lion bridge, Ulaanbaatar (central part)
4	Uliastai	Uliastai bridge, Ulaanbaatar (east part)
5	Govil	Erdenet town
6	Govil	Erdenet town (central part)
7	Shariingol	Bridge, Selenga aimak
8	Kharaa	Darkhan bridge, Darkhan
9	Khangal	Ulaantolgoi, Erdenet
10	Khangal	Erdenet bridge, Erdenet (central part)
11	Tuul	Zaamar bridge, Central aimak
12	Tuul	Ovoot bridge, Central aimak
13	Tuul	Gachurt bridge, Ulaanbaatar (east)
14	Tuul	Altan Dornot, Zaamar, Central aimak

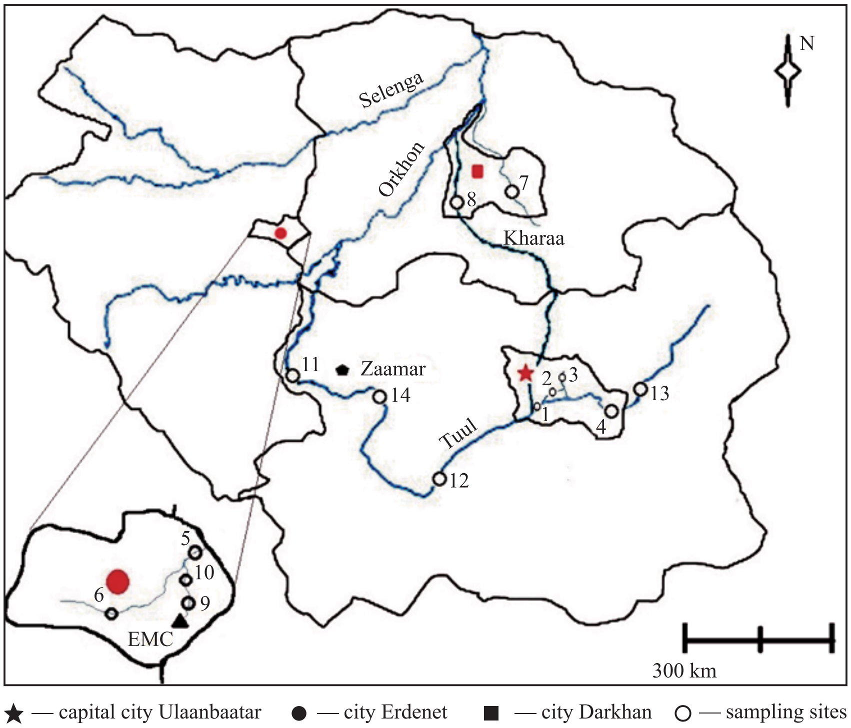

Fig. 1. Sampling map localization

Analysis. The concentration of elements in the sediment samples was determined by a multi-elemental instrumental neutron activation analysis using fast, thermal and epithermal neutrons (ENAA) at the IBR-2 reactor, FLNP, JINR, Dubna.

Thermal NAA takes advantage of the high intensity of neutrons available from the thermalization of fission neutrons and the large thermal neutron cross sections for most isotopes. Epithermal NAA (ENAA) is a useful extension of INAA in that it enhances the activation of a number of trace elements relative to the major matrix elements. Epithermal is taken to be neutrons with energies from the Cd «cut-off» of 0.55 eV up to approximately 1 MeV. In general, the activation cross sections of the matrix elements of environmental samples are inversely proportional to the neutron energy. The trace elements also follow this general trend but many of them have large activation cross section at specific energies in the epithermal energy region [17].

The ENAA has certain advantages over conventional instrumental activation analysis for many trace elements in terms of improvement in precision and lowering of detection limits, reduction of high matrix activity.

The analytical procedures and the basic characteristics of the employed pneumatic system are described in detail elsewhere [18].

Two types of irradiation were done. One is a short irradiation of 3–5 min to analyze for short-lived isotopes (Al, Ca, Cl, I, Mg, Mn, and V). After a decay period of 5–7 min the irradiated samples were measured twice, first for 3–5 min and then for 10–15 min. A long irradiation of 4–5 days was used to analyze for long-lived radionuclides.

After irradiation the samples were re-packed and measured twice: first after 4–5 days for 40–50 min to determine As, Br, K, La, Na, Mo, Sm, U and W, and after 20 days for 2.5–3 h to determine Ba, Ce, Co, Cr, Cs, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, Yb and Zn. The gamma spectra of the samples were measured with a Ge–Li detector with a resolution of 2.5–3 keV for the ^{60}Co 1332 keV line and HPGe detector with a resolution of 1.9 keV for the ^{60}Co 1332 keV line.

The processing of the data and determination of the concentrations of elements were performed using certified reference materials and flux comparators and with the help of software developed at FLNP, JINR [19].

RESULTS AND DISCUSSION

The concentrations of the macroelements (Na, K, Mg, Ca, Cl); biogenic or essential microelements (Fe, Cu, Zn, Mn, Cr, Se, Co, V, Ti, Ni, As); non-biogenic or other elements (Hg, Sb, Ba, Sr, Cs, Al, Rb, Zr, Nb, Au, Br, Sc, La, Tm, Hf, Ta, W, Th, U and some REEs: such as Ce, Nd, Sm, Eu, Tb, Dy) are presented in Tables 2 and 3. In the last columns data for the world's crustal rock and soil [20] are given for comparison. Sediments from all the three river basins commonly have higher elemental concentrations than the crustal abundances, including As and Sb. In Table 4, the results obtained for heavy metals are compared with the relevant data for the other studied rivers in the Selenga basin.

Table 2. **Elemental content of the bottom sediment samples of the Tuul river and its tributaries (in mg/kg)**

Elements	No. 1	No. 2	No. 3	No. 4	No. 13	No. 11	No. 12	[20]
Na	24800	16900	18200	18100	28100	21400	21400	25400
Mg	27900	32000	27900	23700	22900	30700	23600	16400
Al	58900	80300	71500	67400	65700	70600	74000	78300
Cl	3.22	3.22	3.22	4.91	3.22	8.86	3.22	350
K	28000	23500	27400	23800	34600	26300	24200	25600
Ca	48100	36000	93500	21000	21200	30900	32600	31500
Sc	9.98	12.1	9.60	5.90	4.00	8.51	4.35	14
Ti	4150	5110	4730	2950	2800	4120	4240	3300
V	114	101	140	63.1	42.9	93.5	74.8	140
Cr	54.3	66.7	60.7	26.3	20.8	29.0	20.8	69
Mn	880	610	921	473	576	878	542	770
Fe	26200	31400	25200	18100	10500	21500	9460	41700
Co	11.7	13.2	13.6	5.76	3.94	9.20	3.61	17
Ni	14.0	21.8	22.8	8.42	8.26	17.2	9.17	55
Cu	< 30	< 30	< 30	< 30	< 30	< 30	< 30	36
Zn	97.7	**120**	**160**	63.9	31.5	57.3	20.6	67
As	**14.0**	**7.61**	**20.7**	**7.16**	**8.72**	**10.2**	**3.58**	1.6
Se	**0.29**	0.016	**0.22**	0.016	**0.23**	**0.31**	0.016	0.14
Br	**7.06**	**6.28**	**12.2**	1.96	**6.3**	**7.42**	1.62	2.1
Rb	74.1	102	72.4	84.2	67.1	63.4	49.6	110
Sr	316	318	310	309	192	214	183	350

End of Table 2

Elements	No. 1	No. 2	No. 3	No. 4	No. 13	No. 11	No. 12	[20]
Zr	**315**	**345**	176	203	181	227	248	170
Nb	**22.3**	**23.7**	13.2	14.7	10.9	16.7	16.4	15
Sb	**2.38**	**2.41**	**3.29**	**2.06**	**0.77**	**1.06**	**0.536**	0.2
Cs	**5.41**	**6.47**	**6.12**	3.96	2.43	4.03	1.95	3.7
Ba	502	677	523	629	405	383	347	570
La	**51.8**	37.0	47.3	22.4	33.4	44.4	26.7	30
Ce	**124**	**126**	**107**	77.3	66.2	94.4	46.4	58
Nd	22.8	34.0	17.0	11.0	13.8	17.1	21.5	26
Sm	**8.85**	**8.01**	**8.98**	5.00	5.51	**8.25**	4.85	4.5
Eu	ND	1.09	ND	ND	0.588	0.346	0.626	1.1
Tb	0.679	0.828	0.604	0.516	0.380	0.591	0.386	0.6
Dy	6.40	6.37	**9.96**	3.83	5.67	5.12	5.93	3.5
Tm	ND	1.12	ND	0.601	ND	ND	0.549	0.32
Hf	8.0	8.39	4.06	5.56	4.05	5.02	5.96	4.0
Ta	0.99	1.17	0.74	0.76	0.51	0.76	0.61	1.5
W	11	9.73	13.9	5.40	4.2	5.17	3.94	1.3
Au	ND	0.012	0.047	0.003	ND	ND	ND	0.002
Hg	ND	ND	ND	ND	ND	ND	0.076	0.08
Th	15.5	17.0	13.8	9.27	10.3	10.9	6.26	11
U	**10.5**	**8.13**	**12.4**	4.19	**9.98**	**7.41**	5.01	2.8

Note. ND — no detected.

Table 3. **Elemental content of the bottom sediment samples of the Kharaa, Orkhon rivers and their tributaries (in mg/kg)**

Elements	No. 5	No. 9	No. 10	No. 7	No. 8	No. 6	No. 14	[20]
Na	18000	28000	22400	30900	22300	14000	6020	25400
Mg	31800	27400	29400	23500	27700	28900	33800	16400
Al	75400	76700	68200	61800	74700	61600	75200	78300
Cl	13.1	5.76	12.1	3.22	4.36	5.00	3.22	350
K	20900	23600	21600	25500	19800	19400	19700	25600
Ca	99600	58200	53900	47300	44800	39500	33000	31500
Sc	4.80	9.64	6.85	7.87	7.80	11.8	14.1	14
Ti	6510	7610	4260	4530	4830	5550	6240	3300
V	143	165	98.6	81.8	88.6	120	137	140
Cr	32.5	56.1	37.7	20.8	42.6	58.1	20.8	69
Mn	900	831	611	628	684	839	863	770
Fe	12000	27100	19300	16300	16500	**31500**	**35200**	41700
Co	5.90	9.48	8.76	5.81	5.84	13.0	15.3	17
Ni	13.5	15.4	13.9	9.30	8.24	20.7	41.5	55
Cu	**1030**	**1510**	**1630**	< 30	< 30	< 30	< 30	36
Zn	24.9	50.0	52.8	41.0	27.8	82.7	20.6	67
As	**8.35**	**19.1**	**16.1**	**3.34**	**5.50**	**9.53**	**50.5**	1.6
Se	**0.249**	**1.23**	**0.518**	**0.249**	0.017	0.017	0.023	0.14
Br	**9.54**	**4.86**	2.68	**3.52**	1.93	**7.02**	0.324	2.1

End of Table 3

Elements	No. 5	No. 9	No. 10	No. 7	No. 8	No. 6	No. 14	[20]
Rb	27.7	51.1	42.9	49.7	61.0	68.3	71.9	110
Sr	176	385	351	283	291	371	125	350
Zr	111	330	197	**482**	**514**	**312**	205	170
Nb	8.01	22.4	14.7	**31.8**	**32.9**	16.7	16.4	15
Sb	**0.414**	**1.85**	**2.70**	**0.37**	**0.66**	**1.18**	**1.27**	0.2
Cs	1.51	1.90	1.63	2.03	2.35	3.58	1.95	3.7
Ba	226	452	453	412	451	579	425	570
La	31.2	35.6	23.7	44.8	30.7	30.6	29.6	30
Ce	42.9	81.1	54.8	80.8	83.4	97.0	84.8	58
Nd	ND	20.1	11.1	ND	17.8	21.2	25.6	26
Sm	**7.08**	**8.17**	4.91	**8.47**	**7.29**	**7.13**	**7.13**	4.5
Eu	ND	0.881	0.374	1.02	0.986	0.916	1.14	1.1
Tb	0.283	0.541	0.382	0.626	0.661	0.687	0.622	0.6
Dy	**6.89**	**6.05**	**7.21**	**5.99**	3.83	**6.54**	**6.48**	3.5
Tm	ND	1.14	0.471	ND	0.776	0.771	0.638	0.32
Hf	2.43	**7.69**	4.97	11.1	**12.0**	2.43	4.75	4.0
Ta	0.343	0.787	0.537	1.01	0.922	0.965	0.719	1.5
W	3.68	5.60	5.46	3.97	4.40	3.89	5.61	1.3
Au	ND	ND	0.0083	ND	0.0033	ND	**0.008**	0.002
Hg	ND	ND	ND	ND	0.128	ND	0.076	0.08
Th	5.11	7.60	5.42	9.71	9.52	12.5	9.67	11
U	**4.82**	**5.63**	**3.64**	**7.71**	**5.16**	**4.52**	**4.60**	2.8

Note. ND — no detected.

Table 4. **Average element content of heavy metals, trace elements in bottom sediment samples from studied rivers and references (in mg/kg)**

Elements	Our study			Other study	
	Tuul	Kharaa	Orkhon	[8]	[20]
As	**50**	4.4	**13.2**	9	1.6
Pb	—	—	—	20	17
Zn	**78.7**	34.4	52.6	69	67
Cu	—	—	**1570**	13	39
Ni	14.5	8.7	15.8	18	55
Cr	39.8	31.7	46.1	98	69
V	89.9	85.2	131.5	51	140
Sr	263.1	287	320.7	251	350
Nb	16.8	**32.3**	15.4	26	15
Zr	**242.1**	**498**	**237.5**	6	170
Th	11.8	9.6	7.6	128	11
Sc	7.7	7.8	8.2	7	14
Br	**6.1**	2.7	**6**	6	2.1
Ti	4014.2	4680	**5982.5**	3	3300

Result on the Tuul River. The main tributaries of the Tuul river are Selbe, Dundgol, and Uliastai which flow through the east and central parts of the capital Ulaanbaatar. Elemental concentrations in the bottom sediment samples for sites 1, 2, 3 and 4 are shown in Table 2. There are some trace elements in the sediment, e.g., Na, Al, K, Sr, Ba and Ce, detected at all collection sites of the Tuul river and in its tributaries (Selbe, Dundgol, Uliastai, and Gachuurt). However, the concentrations of As, Zn, Co, Ni, and V were detected only along the Dundgol and Selbe rivers (sites 2 and 3), which are most affected by urban activity, high traffic emissions and the main industries. The results obtained are in agreement with those reported for the Tuul sediment in [8].

The highest concentrations of U and Th were observed in the sediments of the Tuul river (south and east parts). They are about 2–3 times higher than in the other cases. This can be explained by possible impact of thermal power plants and domestic heating in the study area. On the other hand, one of the pollution sources is wastewater from the Central Wastewater Treatment Plant (CWTP). This is the main artificial point source of pollution to the river. The CWTP collects approximately 245.000 m^3/day of wastewater from households and industries; of this, 70% is treated before discharge, but the remainder is untreated and is discharged directly to the river [7]. During recent ten years, the population of Ulaanbaatar city has been increased 1.6 times and car park is about doubled. Along with industries and traffic, thermal power plants, the individual stoves in private houses (gers — traditional round dwelling) which combust brown coal should be considered as considerable pollution sources in all the cities [21].

Two samples (sites 11 and 14) were collected from the Tuul river near the Zaamar soum in province Tuv. The first site locates in the center of Zaamar, the second one is in the Zaamar goldfield area. The highest concentrations of Sc, Fe, Co, Ni, and As in comparison to the other sediment samples were determined in sediment sample of the goldfield. Furthermore, the concentration of As in sediment sample from this area is 3–30 times higher than in samples collected from other sites. The main source of heavy metal loading at this site is the mining waste in the Zaamar region due to the practice of dredge mining and the presence of hundreds of open waste heaps in the valley of the Tuul river.

The concentration of Ti, V, Cr, Fe, Co, and Zn is higher in the sediment samples from the central part of the Zaamar than in samples from the goldfield area, but these values are similar to those for Ulaanbaatar city. Cl and Mn concentrations are also the highest in sediment samples from this area.

The upper part of the Tuul river basin is 40 km east of Ulaanbaatar city and it is comparatively less affected by human activity, representing mainly pastureland for cattle owned by local residents. The Gachuurt is one of the main tourist zones in Mongolia located to the east of Ulaanbaatar. A small stream flows through Nalaikh town from south to north before merging with the main channel of the Tuul river. We selected the relatively clean sites by the Gachuurt Bridge (site 13) and Ovoot (site 12) along the Tuul river. The level of some heavy metals and other trace elements in the bottom sediments is 3–10 lower than at other sites from the industrial and urban areas. A comparison of the results on these two sites showed that for the Gatsuurt Bridge site the concentration of heavy metals is higher than in the Ovoot Bridge site. The concentrations of Mg, Ca, Ti, Zn, Br, Ce, Sm, and U in bottom sediments of the Tuul river (within the city) are higher than those in the crustal rock and soil.

Result on the Khangal and Govil Rivers. As seen from Table 3, the highest concentrations of Sc, Mn, Cu, Ce, W and heavy metals such as Ti, V, Ni, Co and As were detected along the Khangal and Govil rivers (sites 5, 9, and 6) where the Erdenet Mining Corporation (EMC) and gold mining areas are allocated. The concentration of Cu was determined only in the sediment samples of the rivers Khangal and Govil near the EMC. Environmental study around the EMC shows that element distribution in soil and river water varies by distance and direction from mine [14, 22]. The vicinity of the mine of about 5 km in radius is much more polluted by Cu and Fe. The east and south-east side is obviously polluted. Possible reasons of Cu and Fe enrichment can be explained by dominant wind and stream directions from west and northwest.

The concentrations of Cu, Zn, As, Mn, Ti, V, Sb, Se and Fe are higher in the sediment from the Govil and Khangal rivers near the EMC than in samples from the city center, even though they do not exceed the maximal permissible levels. It is shown that the main pathway of these elements to sediments from sites 5, 9, and 10 is from the polluted area and the wastewater of the rivers Khangal and Govil near the storage place of slag-heap tail [23]. The concentrations of Cu and Sb determined in sediment samples of the rivers Khangal and Govil near the EMC exceed average crustal rock and soil values by factors of 50 and 15, respectively.

Result on the Kharaa River. The problems of the Kharaa arose in the late 1950s and early 1960s when the communist government found the industrial town of Darkhan changing the traditional pasture system into an agro-industrial farming complex with an extensive cultivation of cereals and potatoes. Discharge of poorly treated municipal and industrial wastewater, as well as land-use alterations (extensive tillage for cereal production, deforestation, overgrazing, etc.) have reduced the naturalness in the lower and middle reaches. Following the economic and political collapse after 1990, agricultural productivity was much lower than before and the out-dated wastewater technology led to higher inputs of poorly treated wastewater. In addition, activities of gold mining industry led to several hazardous situations with the release of mercury and cyanide compounds.

The sediment samples were collected along the Kharaa (site 8) and Shariingol (site 7) rivers which flow near Darkhan city. The results of our study of sediments from these rivers showed the highest concentrations of such elements as Rb, Sr, Zr, Nb, Ba, and Ce. The concentration of Hg was determined only in one sediment sample from the river Kharaa (site 8).

Major accumulation of these elements in Darkhan city was derived from tanning-production, gold mining and heat-and-power engineering and an industrial district which includes a cement factory, steel and agricultural companies.

To assess the ecological status in Ulaanbaatar, Darkhan and Erdenet, the obtained concentrations of heavy metals in sediment samples were compared with concentrations in crustal rock and soil [20] and other studies for river's sediments in Tuul [8] (Table 4), and Orkhon [24]. The elevated concentration of As in the Zaamar part of the Tuul river is in agreement with that one obtained by other researchers. On the other hand, the placer gold mining industry naturally is of great potential for negative impact on the water pollution. The adoption and application of advanced, clean and environment-friendly technologies would be the most crucial factor to minimize its impact on water pollution [25].

The highest average concentrations of As, Cu, Ti, V, and Sr were determined in samples from Khangal and Govil rivers. They are 0.5–2 times higher than those in sediment samples from other rivers.

The composition of riverine sediments depends on the composition of soil and bedrock in the catchment area of the river. Therefore, metal concentrations in soils of EMC were used for comparison. As follows from [26, 27], besides Ti and V, high Ni concentrations in soil and river waters around Erdenet were observed.

The concentration levels of Fe and Al at all sampling sites showed themselves as the highest ones. This may reflect the peculiar features of the earth crust in the study area.

Factor Analysis. In order to achieve a better resolution of contributions from different sources, the data set was subjected to factor analysis. Factor analysis is a multivariate statistical technique commonly used in environmental studies to deduce source from data set [28]. Four factors explaining 21% of the total variance were distinguished (Table 5). From the knowledge of the element composition of each factor and values of factor loadings, the major sources may be identified.

Table 5. **Rotated factor matrix for sediment samples from inflow rivers of the Selenga river basin. Loadings and explained variance for 4 factors are listed**

Element	Factor 1	Factor 2	Factor 3	Factor 4
Al	–0.16	0.33	0.21	–0.12
Ca	0.33	0.05	**0.73**	–0.31
Sc	0.29	**0.88**	–0.10	0.35
Ti	–0.18	0.64	**0.65**	0.13
V	0.19	0.67	**0.67**	–0.04
Cr	0.69	0.28	0.35	0.38
Mn	0.30	0.56	0.40	–0.17
Fe	0.35	**0.86**	–0.04	0.28
Co	0.50	**0.84**	–0.01	0.06
Ni	0.11	**0.95**	–0.12	–0.22
Cu	–0.23	0.00	**0.86**	–0.10
Zn	**0.96**	0.12	0.00	0.08
As	–0.03	**0.83**	0.00	–0.32
Se	–0.01	0.01	**0.79**	0.14
Rb	0.52	0.27	–0.65	0.27
Sr	0.42	–0.09	0.40	0.59
Zr	–0.08	–0.07	–0.06	**0.92**
Sb	**0.76**	0.20	0.16	–0.05
Cs	**0.89**	0.11	–0.31	0.14
La	0.66	0.02	0.04	0.21
Ce	**0.72**	0.37	–0.27	0.48
Hf	–0.04	–0.19	–0.05	**0.79**
Ta	0.37	0.23	–0.30	**0.83**
W	**0.93**	0.19	0.01	–0.04
Au	**0.73**	0.18	0.08	–0.34
Th	**0.75**	0.24	–0.44	0.35
U	**0.80**	–0.17	–0.14	–0.06
Variance, %	**7.72**	**5.72**	**4.21**	**3.82**

Factor 1 has particularly high loadings for Zn, Cs, W, Au, and U. Sb, Ce, and Th are also associated with this component. All these elements are typical for crustal material, and most probably, this component with a crustal character appears to be mainly associated with the urban area, and predominantly with the industrial activities. The factor scores (Fig. 2)

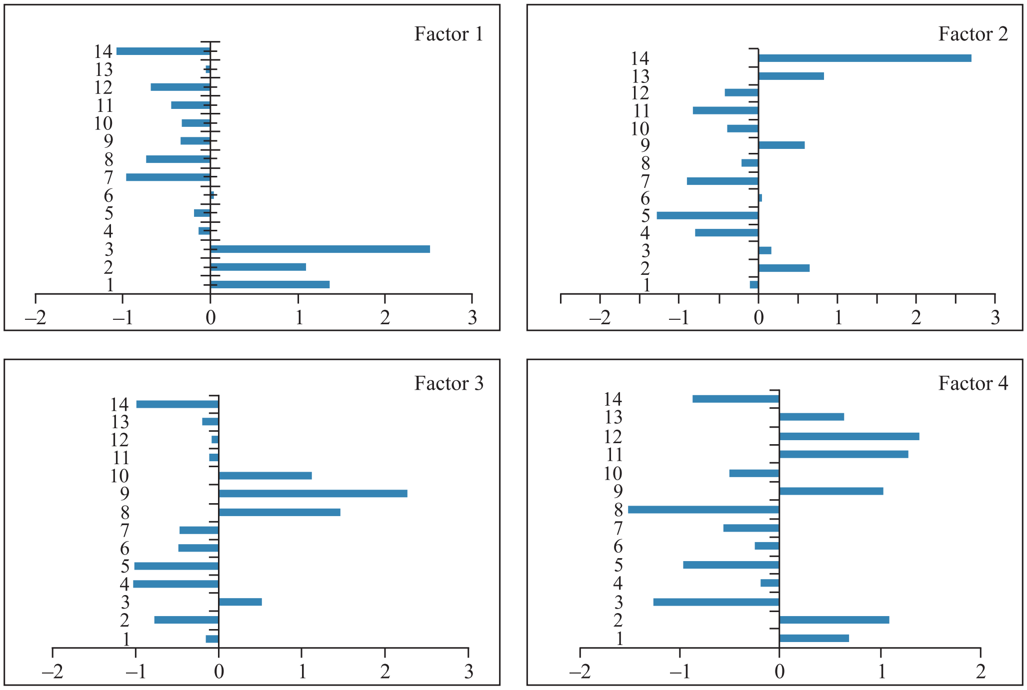

Fig. 2. Factor scores (y — sampling points, x — factor scores)

are the highest in the central and industrial part of the capital. The high concentration of U in sediment of the river Tuul near the capital is possible due to burning of brown coal by thermal power plants and domestic heating.

Factor 2 with high loadings for Sc, Fe, Co, Ni, and As represents different industrial sources. Furthermore, the main reason for high level of As is gold and copper mining industry. The factor score (Fig. 2) is the highest in the area of Zaamar goldfield.

Factor 3 with high loadings for Cu, Se, and Ca, in addition to Ti and V, seems to be a characteristic signature of emissions from EMC. The mentioned elements are likely to be of natural and anthropogenic origin. The geographical distribution of the relevant factor scores points out the Cu pollution source affecting the rivers Khangal and Govil near the slag-heap tailing of the EMC.

Factor 4 with high loadings for Zr (0.93), Hf (0.79), and Ta (0.73) characterizes some industrial activity in the town of Darkhan known for its ferrous metallurgy and cement production (see factor scores in Fig. 2).

Multivariate analyses, including factor analysis used in this study, provide an important tool for better understanding of the sources of pollutants.

CONCLUSIONS

Instrumental neutron activation analysis at the pulsed fast reactor IBR-2 with fast and epithermal neutrons allowed determination of previously not reported elements including rare-earth elements and uranium and thorium. It was shown that the environmentally toxic metals such as As, Zn, Cu, Ni, Sr, and V are enriched in the urban and industrial parts of the basin (within the cities areas) due to mining processing activities.

The growing intensity of gold mining in the countries situated southward of the Selenga river basin suggests the necessity for regular monitoring of the level of pollution within this basin.

It was demonstrated that the Erdenet Mining Corporation continues to be the source of contamination of the environment. Multi-element chemical analysis of river bottom sediments showed itself as a valuable tool for monitoring purposes in Mongolia to be used in the environmental regulation for water quality and management strategies for the Selenga river basin.

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Received on April 2, 2013.