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Anthropogenic Waters in the Komsomolsk, Kavalerovskii, and Dalnegorsk Mining Areas of the Far East and Their Impact on the Hydrosphere

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Abstract—Potentially high charge of wastewaters with toxic metals in mining areas depends on the composition of ores, mineralization of the ore environment, and anthropogenic processes that are responsible for contamination of pore solutions and mine, slime, and drainage waters. As a result, the concentrations of toxic elements, such as Cu, Zn, Pb, As, B, Fe, etc., in the surface and ground water considerably exceed background levels. Anthropogenic impact of mining systems made environmental situation in the examined regions stressed and critical.

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INTRODUCTION

Mining and primary processing of mineral raw materials lead to degradation and partial loss of land, water, and forest resources, deterioration of the environment, and a number of other ecological problems.

Mining industry in the Far East has been developed long ago. Cassiterite and cassiterite–sulfide deposits in the Komsomolsk (Khabarovsk Territory) and Kavalerovskii regions (Maritime Territory) have been extensively exploited over a period of more than 70 years by both open-pit and underground mining methods, while cassiterite–sulfide and polymetallic deposits in the Dalnegorsk region (Maritime Territory) have been exploited over a period of more than 100 years. Up to now, most deposits have been exhausted, mines and ore-dressing and processing plants in the Komsomolsk and Kavalerovskii regions were shut down, and mining is now continuing only in the Dalnegorsk region; however, the amounts of mined and processed ore decreased.

Both open-pit and underground mining leaves very large mine openings on the daylight, such as strip pits, trenches, clearings, and waste piles of host rocks; large amounts of mine wastes (tailings) with a high concentration of heavy metals are impounded in tailing dumps. As a result, anthropogenic mining systems appear, where sulfide minerals become more accessible to weathering. This leads to their extensive oxidation, i.e., enhancement of supergene processes and transition of a system to anthropogenic stage. Anthropogenic processes are the most intense in oxidized ores of the supergene zone, where they strongly favor extension of its boundaries (by a factor of 20 and more), accelerate oxidation processes, and promote increased ejection of oxidation products and extensive pollution of ecosystems. After oxidation of first portions of sulfide material, rainwater falling onto tailing dumps is converted into an acid sulfate solution. Sulfide degradation is a long process; for example, pyrite can be oxidized over 800 years [1]. Thin coats, crusts, and films consisting of sulfates, carbonates, silicates, arsenates, etc., appear on the surface and in the bulk tailings, especially in drought periods [2, 3].

After ore dressing and extraction of a target component, the remaining material is transported to tailing dumps with slime water which contains all reagents used in ore processing. Tailing dumps in operating factories are pits containing waste materials and covered with slime water, which look like lakes; if a factory is shut down, there is no water. Tailing dumps are generally located in the vicinity of ore-dressing plants and residential areas.

Taking the above stated into account, the goal of the present work was to estimate the environmental effect of mine wastes on the hydrosphere with a view to ensure ecological safety in the region. The following tasks were formulated: (1) to analyze and summarize published data on the impact of industrial wastewaters on the hydrosphere; (2) to examine the composition of mine, slurry, and drainage waters in the Komsomolsk, Kavalerovskii, and Dalnegorsk regions and estimate their effect on the surface and ground waters; and (3) to develop proposals to reduce negative effect of industrial wastewaters on aquatic ecosystems.

MATERIALS AND METHODS

Ore-dressing plants in the Komsomolsk tin-ore region produced Sn, Cu, Pb, Zn, Ag, and W. During the *Perestroika* period tailings from the first tailing dump were partly reprocessed. There are four large ore deposits, two ore-dressing and processing plants, and three tailing dumps in the region. The tailing dumps occupy an area of 90.8 ha, and they accumulate 41.49×10^6 tons of mine wastes. The concentrations of metals in tailings are as follows, g/ton: Sn, up to 0.2; Cu, 0.46; Zn, 0.094; Pb, 0.123; Ag, 1.227; As, 0.629. Two tailing dumps have been drained completely, and one tailing dump is partly covered by slime water.

Tin was always the main and the only mined metal in the Kavalerovskii region, although In and Ag were extracted concomitantly during Perestroika, while the other elements, such as Cu, Pb, and Zn, were wasted to tailings despite their recoverable concentration. Mining plants are located mostly in the basin of Zerkal'naya river; they include five mines, four ore-dressing and processing factories, and six tailing dumps. There are three tailing dumps in the valley of Fabrichnyi settlement; their area amounts to 15 ha, and the volume of tailings is estimated at 43.688 million tons. The remaining three tailing dumps reside in Dubrovskii, Vysokogorskii, and Taezhka settlements, where 5.204 million tons of wastes accumulated. The tin content of tailings range from 0.122 to 0.183%, copper content is up to 0.26%, and Zn content is about 1%. Three of the six tailing dumps are partly covered by slurry lakes.

In the Dalnegorsk region, cassiterite–sulfide ores from the Smirnovskoe deposit were processed at the Krasnorechensk Ore-Dressing Plant (KODP). The main concomitant components were Ag, Sb, Cd, Bi, Cu, and In. After extraction of the target component, tailings were impounded in two locations nearby the plant, old and new tailing dumps, which occupy an area of 2.160 km^2 and contain 6.8 million tons of wastes. Ores from ~20 polymetallic deposits were processed at two Central Ore-Dressing Plants (CODP), and the tailings were impounded in the old and new tailing dumps with an overall area of 0.825 km^2 and a capacity of 32.2 million tons. The old tailing dumps in KODP and CODP have been drained, while the new ones are partly covered by slurry lakes. The concentration of Ag in the KODP tailings is 39.5 g/ton. The CODP tailings contained the following metals, %: Zn, 0.27–0.29; Pb, 0.11–0.18; Cu, 0.01–0.03; Fe, 4.37–4.6; Ag, 5–6 g/ton.

Development of a mining anthropogenic system is accompanied by pollution of the atmosphere, ground, and vegetable cover [4], deterioration of land surface, variation of conditions responsible for water runoff, etc. Large volumes of mine and drainage water come out of mine drainage system and contaminate surface, ground, spring, and drinking waters. The most harmful to the environment is aggressiveness of industrial wastewaters (i.e., mine, drainage, and slime waters) due to high concentrations of sulfide decomposition products and reagents entering with slurry. Untreated wastewaters containing Zn, Fe, Cu, Pb, and other elements at concentrations exceeding their background levels by one, two, and even three orders of magnitude are discharged round the clock in large amounts, and they strongly affect the chemical composition of surface and ground waters, which changes natural geochemical background in the examined regions [2, 3, 5–16].

Industrial wastewaters were studied over a period from 2001 to 2011 by atomic emission spectroscopy using a Plasmaquant-110 instrument. The following elements were determined: Cu, Pb, Zn, Sn, Co, Ni, Cr, Fe, Mn, Sr, Li, Ag, Al, B, Ba, Na, Ca, Mg (Tables 1–3). The concentration of Sb, Se, Hg, Bi, Cd, Ag, Co, Cr, Ni, Pb, and Cu in most samples was lower than detection limit.

RESULTS AND DISCUSSION

Detailed analysis of the results showed that pH values of the examined water samples ranges from 1 to 7 and that most hydrochemical samples may be regarded as near-neutral. It is known that the latter are less mineralized than acid water [11, 12]. Acid and strongly acid waters (Tables 1–3) were detected in the

Table 1. Concentration of chemical elements (mg/l) in industrial wastewaters in the Komsomolsk region[a]

Sampling site	pH	Zn	Cd	Li	Sr	Fe	Mn	Al	Cu	Pb	Ca	Mg
Reference freshwater[b]	–	0.005	0.0002	–	0.050	0.500	0.005	0.200	0.001	0.003	–	–
Background values[c]	7.2	0.018	0.00005	–	–	0.14	0.005	0.007	0.003	0.003	–	–
2002												
Dolgii spring	5.0	0.012	0.002	–	0.023	0.067	17.100	0.011	0.031	<DL	5.80	1.02
Drainage water, 1st TD	5.0	3.160	0.022	–	0.623	139.00	8.740	9.630	0.216	0.089	103.0	25.20
Slime water 3rd TD.	5.5	9.350	0.051	–	0.165	14.400	14.500	1.210	0.515	0.904	49.00	10.10
Mine water, Pereval'noe deposit	5.5	77.500	0.514	–	0.085	71.400	0.286	1.890	36.60	1.320	35.60	11.20
2004												
Mine water, Festival'noe deposite	4.0	24.970	0.133	–	0.554	14.800	20.800	17.50	153.00	0.002	143.0	30.80
Drainage water, 2nd TD	5.0	0.141	<DL	–	0.191	0.612	0.857	0.351	0.297	<DL	51.20	4.510
Slime water, 3rd TD	5.5	0.076	0.001	0.187	0.256	<DL	2.450	0.083	0.004	<DL	89.10	10.60
Mine water, Pereval'noe deposit	5.0	60.100	0.349	0.187	0.111	32.200	12.100	2.830	48.300	1.200	40.30	11.30
Kholdami river 2 km from Solnechnyi city	6.0	0.141	<DL	-	0.097	0.085	0.017	0.085	0.086	0.029	17.10	3.29
Silinka river, downstream of Solnechnyi city	6.0	0.295	<DL	0.214	0.079	0.078	0.053	0.081	0.023	<DL	16.40	3.15
2010												
Mine water, Festival'noe deposit	4.2	10.230	0.038	0.016	0.358	17.430	11.830	6.500	46.510	0.013	104.60	19.58
Mine water, Pereval'noe deposit	3.4	25.64	16.150	0.005	0.088	42.300	5.090	1.460	16.150	1.560	38.140	8.61
Slime water, 3rd TD	3.8	0.368	0.001	0.002	0.024	1.020	0.763	0.133	0.120	0.274	11.720	1.56
Drainage water, 3rd TD	4.6	8.940	0.005	0.019	0.568	87.200	26.010	0.120	0.384	0.045	206.50	40.92
Kholdami river, 2 km from Solnechnyi city	4.9	0.137	0.001	0.001	<DL	0.051	<DL	0.077	0.043	0.004	14.83	2.79
Silinka river, downstream of Solnechnyi city	6.3	0.425	0.001	0.001	<DL	0.161	0.194	0.104	0.051	0.002	8.73	2.17

[a] Dash denotes that the concentration was not determined; TD stands for tailing dump; DL stands for detection limit. [b] Data of [17]. [c] Data of [18]; concentrations of elements below detection limit, mg/l: B, 0.01; Cd, 0.001; Pb, 0.015; Cu, 0.0015; the concentration of As in mine waters and slime waters from tailing damps varied from 0.02 to 0.60 mg/l (background value 0.002 mg/l).

Komsomolsk (mine water, pH 3.8–4.2) and Dalnegorsk regions (slime water, pH 1–4).

Analysis of hydrochemical samples from slime waters in the Komsomolsk tin-ore region in 2002–2010 (Table 1) revealed exceedence of Zn concentration over the background value by a factor of 4 to 52; Cu, 1.3 to 172; Pb, 91 to 31; Cd, 20 to 1020; Fe, 73 to 13; Mn, 152 to 2900; Al, 12 to 173; their mineralization attained 103 mg/l. Drainage waters were characterized by a Zn concentration exceeding the background value by a factor of 8 to 497; Cu, 40 to 99; Pb, 15 to 30; Cd, up to 108; Fe, 44 to 993; Mn, 167 to 5202; Al, 17 to 1375; the mineralization ranged from 58.2 to 370.7 mg/l. The corresponding ratios for mine waters from the Pereval'noe deposit (Sn–Pb–Zn ores) were as follows: Zn, 1424 to 4320; Cu, 5383 to 16100; Pb, 400 to 520; Cd, 1280 to 303000; Fe, 230 to 510; Mn, 57, to 2420; Al, 208 to 494; the mineralization varied from 155.5 to 236.4 mg/l. The concentration of Zn in mine waters from the Festivalnoe deposit (Cu–Sn ores) exceeded the background value by a factor of 568 to 1387; Cu, 15503 to 51000; Pb, up to 4; Cd, 760 to 26600; Fe, 105 to 302; Mn, 2566 to 4160; Al, 928 to 2500; mineralization, 217.1 to 405.6 mg/l. The concentration of As (see note to Table 1) was higher than the background level by a factor of 10 to 300. Highly concentrated mine, slime, and drainage water promote strong pollution of river and ground waters.

Water in Kholdami river (Komsomolsk region) contained Cd at a concentration higher than the background value by a factor of 20; Zn, 7 to 8; Cu, 14 to 28; Pb, 1.3 to 9.6. Excess Cd over background level in water of Silinka river was estimated at 20 times; Zn, 16 to 23; Cu, 8 to 17; Fe, 11; Mn, 11 to 39. It should be noted that drinking water is taken from Silinka river in Gornyi settlement. Mineralization of river waters in the region ranges from 11.8 to 20.7 mg/l. The concentrations of some elements in Silinka and Kholdami rivers (Table 1) considerably exceeded the maximum allowable concentrations set for fishery standards, respectively, by factors of 23 to 51 and 43 to 86 for Cu, 14 and 30 to 43 for Zn, 2 and 5 to 19 for Mn, up to 5 for Pb, and up to 2 for Al.

The following exceedence values were found for slime waters in five tailing dumps in the Kavalerovskii region (2001–2011; Table 2): Zn, by a factor of 1.2 to 1130; Cu, 3 to 3395; Pb, up to 25; Cd, 2 to 7220; Fe, 3.6 to 194; Mn, 3 to 943; Al, 1.2 to 351. Their mineralization reached 320.6 mg/l, the highest concentration of mineral substances being determined in slime water from the second tailing dump. The Zn content of drainage water was higher than the background by a factor of 78 to 177; Cu, 28 to 6250; Pb, up to 32; Cd, 40 to 60; Fe, 8 to 2186; Mn, 356 to 624; Al, 2 to 721; mineralization 133 mg/l. Analogous parameters of mine water from Khrustal'noe deposit were as follows: Zn, 8 to 56; Cu, 2.5 to 9; Pb, up to 2; Cd, 20 to 130; Fe, 3.8 to 137; Mn, 82 to 546; Al, 12 to 23; mineralization 167 to 282.5 mg/l. Mine water from Dubrovskoe deposit was characterized by the following exceedence factors: Zn, 4.4 to 3414; Cu, 2 to 111; Pb, 2 to 20; Cd, 10 to 1600; Fe, 7 to 207; Mn, 7 to 2422; Al, 1.2 to 8.4; mineralization, 253.6 to 632.7 mg/l. Somewhat different metal concentrations were determined for mine water from Vysokogorskoe deposit. Here, the concentration of Zn exceeded the background level by a factor of 1.3 to 59; Cu, 3.5 to 21; Pb, up to 3; Cd, 10 to 54; Fe, 3.3 to 70; Mn, 44 to 383; Al, up to 35; the mineralization varied from 12 to 51.9 mg/l. Mine water from Dubrovskoe deposit was most mineralized. It contained the highest concentrations of Zn, Cd, Mn, Cu, and Pb. The concentration of As in the examined hydrochemical samples (see note to Table 2) exceeded the background value by a factor of 10 to 310. River waters in the Kavalerovskii region revealed the following exceedence values: Zn, 1.1 to 568 times; Cu, 5.5 to 46; Cd, 2 to 12; Fe, 3.3 to 65; Mn, 20 to 103; Al, 3.3 to 4.4; the mineralization ranged from 8.7 to 502.8 mg/l. Water from Silinskii spring was most polluted with Zn and Cd, and water from Vetvistyi spring, with Fe, Mn, Al, and Cu.

The concentrations of some chemical elements in river water of the Kavalerovskii region (Table 2) within mining plant boundaries exceeded the maximum allowable concentrations (fishery standards) by a factor of 4 to 80 for Cu, 6 to 26 for Mn, up to 8 for Zn, up to 2 for Fe, and 3 to 4 for sulfates.

Tin sulfide (KODP) and polymetallic ores (CODP) were processed in the Dalnegorsk region. Analysis of hydrochemical samples of slime water withdrawn from the old tailing dump of KODP (2001–2011) showed 3266 to 23 587-fold excess of Zn content, 1675 to 8225-fold excess of Cu, 39 766 to 287 400-fold excess of Fe, 44 465 to 389 000-fold excess of Mn, 508 to 4173-fold excess of Al, and 455 to 2530-fold excess of As over the background values; no lead was found in the background water. Comparison of these results with the corresponding parameters found for the Kavalerovskii region indicates 5 to 55-fold elevation, and with reference freshwater, 3 to 36-fold. The mineralization was estimated at 775 to 4484 mg/l. Slime water from the new tailing dump of KODP contained increased amounts of Zn (by a factor of 173 to 1132), Cu (37), Fe (266 to 8723), Mn (1060 to 4077), Al (4 to 154), and As (up to 21). The concentration of Pb exceeded the background level for the Kavalerovskii region by a factor of 412 (17 with respect to reference freshwater level). The mineralization was estimated at 42 to 553 mg/l. Increased concentrations of Zn (by a factor of 53), Cu (up to 42), Fe (57 to 61), Mn (25 to 30), Al (11 to 14), and As (up to 64) were determined in hydrochemical samples of slime water from the old tailing dump of CODP, the mineralization being within 70 to 416 mg/l. The concentration of Pb attained 0.064 mg/l. The corresponding parameters of slime water from the new tailing dump (CODP) were as follows: Zn, 2.7 to 15; Cu, 47 to 69; Fe, 10 to 299; Mn, 79 to 240; Al, up to 57; As, 17 to 410; mineralization, 41 to 94 mg/l; Pb content 0.04 mg/l. Mine water from Sovetskii mine was enriched in Zn by a factor of 1.2 to 198; Cu, 7 to 50; Fe, 33 to 3103; Mn, 8 to 203; Al, 4.6 to 37; As, 9 to 57; the mineralization ranged from 30 to 78 mg/l, the concentration of Pb being up to 1.21 relative to the background level (no Pb was detected in reference samples).

Table 2. Concentration of chemical elements (mg/l) in industrial wastewaters in the Kavalerovskii region[a]

Sampling site	pH	Zn	Cd	Li	Sr	Fe	Mn	Al	Cu	Pb	Ca	Mg
Background values[b]	7.3	0.009	0.00005	–	–	0.011	0.003	0.010	0.002	0.001	7.000	0.120
2001												
Slime water, 1st TD	7.0	0.012	<DL	0.051	0.478	0.099	0.582	0.052	<DL	<DL	127.00	13.90
Slime water, 2nd TD	6.5	0.093	<DL	0.015	0.110	1.190	0.034	0.822	<DL	<DL	22.70	4.67
Slime water, 3rd TD	7.0	0.011	<DL	0.002	0.068	0.355	0.014	0.142	<DL	<DL	12.20	2.47
Spring water downstream of TD	6.0	0.036	<DL	0.022	0.241	0.198	0.102	0.171	<DL	<DL	26.70	7.10
Lake water below galleries	6.0	0.692	<DL	0.025	0.495	0.277	0.195	0.594	<DL	<DL	65.40	25.70
Mine water, Khrustal'noe deposit	7.0	0.251	<DL	0.283	2.410	0.824	0.851	1.090	<DL	<DL	165.00	60.00
2003												
Slime water, 1st TD	6.0	0.078	<DL	–	0.096	1.094	0.255	0.383	0.223	<DL	14.90	2.71
Slime water, 2nd TD	5.0	5.160	0.031	–	1.010	0.072	1.190	0.535	6.790	0.025	270.00	35.50
Slime water, 3rd TD	6.5	0.398	<DL	–	0.094	1.490	0.110	1.072	0.045	<DL	18.60	3.52
Mine water, Khrustal'noe deposit	6.5	0.072	<DL	–	1.030	0.042	0.247	0.123	0.014	<DL	126.00	41.30
2006												
Slime water, 2nd TD	5.0	0.059	<DL	0.014	0.324	0.856	0.052	0.176	0.110	0.008	46.57	12.28
Slime water, 3rd TD	5.0	0.650	0.004	0.015	0.118	0.250	0.683	0.126	1.000	<DL	16.53	3.31
Mine water, Khrustal'noe deposit	5.0	0.287	<DL	0.157	2.164	1.513	1.296	0.146	0.005	<DL	131.00	30.32
2007 (December)												
Drainage water, Vysokogorskoe deposit	5.0	0.698	0.003	0.006	0.074	0.097	1.874	0.023	0.056	<DL	9.80	4.46
Mine water, Vysokogorskoe deposit	5.0	0.178	<DL	0.013	0.189	0.037	0.382	0.004	0.001	<DL	11.64	3.22
Silinskii spring, left tributary	5.0	0.963	0.001	0.036	0.496	0.129	0.0009	0.009	0.0008	<DL	28.18	17.69
Silinskii spring	4.5	0.135	0,0001	0.011	<DL	0.037	0.0008	0.033	0.0005	<DL	9.51	5.79
Mine water, Dubrovskoe deposit	5.0	0.129	0,0005	0.030	0.598	0.436	0.714	0.012	0.004	<DL	230.34	27.80
Kavalerovka river, downstream of TD	4.5	0.045	0,0001	0.018	<DL	0.167	0.0006	0.001	0.001	<DL	39.32	22.36
Vysokogorka river, Kavalerovo settlement	5.0	0.001	<DL	0.003	0.049	0.023	0.003	0.008	0.0006	<DL	6.56	2.00
2008 (Apil)												
Drainage water, TD, Vysokogorskoe deposit	5.0	1.579	0.002	0.004	0.059	24.050	1.070	7.520	12.500	0.032	84.46	2.05
Mine water, Vysokogorskoe deposit	5.0	0.175	0.0007	0.010	0.164	0.410	0.132	0.350	0.032	0.003	49.18	1.36
Silinskii spring, left tributary	5.0	0.615	0.0003	0.011	0.141	0.010	0.001	0.030	0.0002	<DL	526.20	2.85
Silinskii spring	5.0	5116	0.001	0.034	0.036	0.001	0.002	0.030	0.0001	<DL	440.00	4.80
Mine water, Dubrovskoe deposit	5.5	30730	0.004	0.206	1.981	2.280	7.265	0.840	0.073	0.002	561.15	28.18
Kavalerovka river, downstream of TD	4.5	0.014	0.0001	0.016	0.261	0.040	0.012	0.030	0.0006	<DL	292.70	6.00
Vysokogorka river, Kavalerovo settlement	5.0	0.0002	<DL	0.002	0.040	0.040	0.003	0.060	0.0004	<DL	501.50	1.12

Table 2. (Contd.)

Sampling site	pH	Zn	Cd	Li	Sr	Fe	Mn	Al	Cu	Pb	Ca	Mg
Background values[b]	7.3	0.009	0.00005	–	–	0.011	0.003	0.010	0.002	0.001	7.00	0.12
2008 (July)												
Vetvistyi spring, downstream of TD	5.0	0.099	0.001	0.005	0.060	0.660	0.310	0.370	0.092	0.001	8.36	2.20
Mine water, Vysokogorskoe depposit	5.0	0.075	0.0005	0.009	0.080	0.080	0.130	0.040	0.007	0.001	9.59	2.01
Mine water, Khrustal'noe deposit	5.5	0.078	0.0003	0.358	2.120	0.050	1.130	<DL	0.004	0.001	145.20	50.15
Slime water, 3rd TD	5.5	1.009	0.007	0046	0.014	0.090	1.430	0.530	2.681	0.001	24.38	8.14
Slime water, 2nd TD	5.5	10.170	0.041	0.072	0.430	0.100	2.830	3.510	0.221	0.001	95.51	23.93
Mine water, Dubrovskoe deposit	5.5	4.314	0.011	0.166	1.600	0.080	5.990	0.490	0.222	0.001	228.00	34.00
Partizanka river, downstream of TD	5.0	0.086	0.0006	0.016	0.270	0.060	0.060	0.020	0.011	0.001	42.60	6.87
Vysokogorka river, Kavalerovo settlement	5.0	0.014	0.0003	0.004	0.040	0.060	0.060	0.010	0.004	<DL	7.53	1.86
Slime water, TD, Dubrovskoe deposit	5.0	0.043	0.0005	0.006	0.040	1.060	0.020	0.510	0.019	0.005	6.72	2.44
Slime water, TD, Vysokogorskoe deposit	5.0	0.015	0.0003	0.003	0.050	0.050	0.030	0.010	0.022	<DL	9.15	2.41
Drainage water, TD, Vysokogorskoe deposit	5.0	1.297	0.008	0.034	0.240	0.060	2.220	1.230	0.234	0.001	37.24	7.02
2009 (July)												
Vetvistyi spring, downstream of TD	5.5	0.070	0.0006	0.002	0.050	0.720	0.260	0.490	0.080	0.001	7.46	1.37
Mine water, Vysokogorskoe deposit	5.0	0.120	0.0006	0.010	0.110	0.230	0.160	0.140	0.012	0.001	11.45	1.41
Mine water, Khrustal'noe deposit	5.5	0.040	0.0001	0.450	2.220	0.030	0.600	0.060	0.002	<DL	153.70	48.78
Slime water, 3rd TD	5.0	0.450	0.0030	0.020	0.140	0.330	0.650	0.770	1.910	0.001	21.45	5.08
Slime water, 2nd TD	6.0	4.850	0.0236	0.060	0.420	0.190	1.940	0.620	0.220	0.003	85.11	25.61
Mine water, Dubrovskoe deposit	6.0	2.290	0.0800	0.340	1.650	0.830	5.730	0.620	0.110	0.002	244.50	28.76
Vysokogorka river, Kavalerovo settlement	5.0	0.003	0.0001	0.002	0.040	0.260	0.010	0.160	0.002	<DL	7.23	1.10
Slime water, TD, Dubrovskoe deposit	5.5	0.040	0.0014	0.010	0.050	0.410	0.010	0.190	0.037	0.006	6.73	1.97
Slime water, TD, Vysokogorskoe deposit	5.5	0.050	0.0006	0.004	0.050	0.190	0.110	0.170	0.230	0.001	8.93	1.58
2009 (October)												
Mine water, Dubrovskoe deposit	5.5	2.070	0.0058	0.185	1.480	0.130	4.910	0.360	0.107	0.001	239.90	29.50
Slime water, TD, Dubrovskoe deposit	6.0	0.070	0.0006	0.005	0.070	1.100	0.020	0.520	0.026	0.009	12.99	2.42
Mine water, Khrustal'noe deposit	5.5	0.510	0.0010	0.321	2.500	0.210	1.640	0.210	0.018	0.002	205.00	72.05
Slime water, 2nd TD	6.5	0.020	0.0001	0.002	0.100	0.750	0.020	0.430	0.022	0.005	26.02	3.31
Slime water, 3rd TD	5.0	<DL	<DL	0.001	0.060	0.060	0.001	0.020	0.006	<DL	10.40	2.07
Mine water, Vysokogorskoe deposit	5.0	0.080	0.0004	0.008	0.110	0.110	0.090	0.100	0.010	0.001	13.12	8.75
Vysokogorka river, Kavalerovo settlement	5.0	<DL	0.0001	0.003	0.050	0.050	0.001	0.030	<DL	0.002	8.75	1.38

[a] Dash denotes that the concentration was not determined; TD stands for tailing dump; DL stands for detection limit. [b] Data of [12]; concentrations of elements below detection limit, mg/l: Cd, 0.001; Pb, 0.015; Cu, 0.0015; the concentration of As in mine waters and slime waters from tailing damps varied from 0.02 to 0.62 mg/l (2003–2011; background value 0.002 mg/l).

Water in Rudnaya river (Dalnegorsk region; Table 3) contained the following amounts of chemical elements (relative to the background values): Zn, 6.2 to 23.5; Cu, up to 10; Fe, 3 to 23; Mn, 15 to 40; Al, up to 7; As, 11 to 55; the mineralization was 30 to 85 mg/l, and the concentration of Pb reached 0.011 mg/l. Taking into account author's data on the concentration of boron in Rudnaya river (in the vicinity of *Bor* joint-stock company), which attains 30 mg/l, and of sulfate ions (59.4 and 73.3 mg/l), the overall mineralization is 168 mg/l, i.e., it is higher than the mineralization of mine waters in the same region.

Table 3. Concentration of chemical elements (mg/l) in industrial wastewaters in the Dalnegorsk region[a]

Sampling site	pH	Zn	Fe	Mn	Al	Cu	Pb	As	Ca	Mg
Background values[b]	7.3	0.008	0.003	0.002	0.030	0.0004	ND	0.001	7.00	0.12
2001										
Slime water, new TD, CODP	6.0	0.036	0.276	0.279	0.158	<DL	<DL	-	62.90	2.63
Slime water, old TD, CODP	6.0	0.003	0.183	0.060	0.043	<DL	<DL	-	65.10	4.44
Mine water, Sovetskii mine	6.0	0.216	0.593	0.044	0.138	<DL	0.123	-	25.50	2.56
Rudnaya river, mouth	6.0	0.078	0.155	0.030	0.066	<DL	<DL	-	28.70	2.75
2003										
Slime water, new TD, CODP	6.5	0.060	0.694	0.159	1.720	0.275	0.013	0.213	69.30	1.42
Slime water, old TD, CODP	6.0	0.424	0.171	0.050	0.331	0.017	0.017	0.064	376.00	38.90
Mine water, Sovetskii mine	6.5	0.614	0.918	0.111	0.412	0.015	0.200	0.018	39.60	4.32
2006 (July)										
Mine water, Sovetskii mine	5.8	1.281	2.895	0.406	0.694	0.011	0.584	0.056	67.82	4.79
Slime water, old TD, KODP	4.0	53.490	446.600	>10	24.790	0.723	0.026	1.531	166.50	72.04
Slime water, new TD, KODP	5.8	9.061	26.170	8.154	4.640	0.015	0.053	0.021	48.10	14.63
Rudnaya river, 26 km	5.8	0.135	0.800	0.078	0.035	0.002	0.004	0.040	57.02	4.98
2006 (September)										
Mine water, Sovetskii mine	6.0	0.687	1.252	0.256	0.251	0.003	0.262	0.029	39.36	2.96
Slime water, new TD, CODP	5.0	0.053	0.898	0.246	0.269	0.201	0.021	0.410	38.14	0.88
Slime water, TD, KODP	4.0	51.740	524.100	>10	19.900	0.507	0.009	1.042	135.30	79.95
Rudnaya river, 26 km	6.0	0.198	0.643	0.064	0.020	<DL	0.002	0.037	53.02	3.64
Mine water, Sovetskii mine	5.8	0.937	9.309	0.267	0.978	0.008	1.033	0.033	61.68	7.29
Slime water, new TD, CODP	6.0	0.642	257.400	4.006	6.851	0.307	0.825	0.273	84.96	11.14
Slime water, TD, KODP	4.0	89.110	119.300	491.500	238.50	0.752	0.015	1.935	292.70	274.40
Rudnaya river, 26 km	6.0	0.189	0.549	0.041	0.073	0.005	0.011	0.016	49.18	13.00
2008 (July)										
Mine water, Sovetskii mine	5.0	0.217	0.100	0.100	<DL	0.003	0.011	0.010	42.16	4.12
Slime water, new TD, CODP	5.5	0.022	0.060	0.220	0.060	0.155	0.002	0.031	65.69	3.28
Slime water, TD, KODP	4.0	26.130	187.500	88.930	15.240	0.385	0.047	0.544	94.99	58.48
Rudnaya river, 26 km	5.5	0.155	0.030	<DL	<DL	0.004	0.001	0.011	39.99	5.29
2009 (July)										
Mine water, Sovetskii mine	5.0	0.010	0.520	0.030	0.640	<DL	0.003	0.018	27.17	1.79
Slime water, new TD, CODP	5.0	0.040	0.040	0.240	0.050	0.220	0.023	0.018	50.69	3.05
Slime water, TD, KODP	3.5	44.220	480.80	505.80	24.480	0.670	0.010	0.455	159.60	147.50
Rudnaya river, 26 km	5.0	0.140	0.370	0.070	0.210	0.001	0.010	0.011	58.12	3.87
2010 (July)										
Mine water, Sovetskii mine	6.7	0.390	0.330	0.160	0.180	0.003	0.121	0.015	43.64	4.21
Slime water, new TD, CODP	6.3	0.050	0.030	0.260	0.060	0.190	0.016	0.019	73.47	4.53

Table 3. (Contd.)

Sampling site	pH	Zn	Fe	Mn	Al	Cu	Pb	As	Ca	Mg
Background values[b]	7.3	0.008	0.003	0.002	0.030	0.0004	ND	0.001	7.00	0.12
2010 (July)										
Slime water, TD, KODP	2.7	169.00	2079.0	688.30	69.300	1.260	0.009	1.610	381.80	356.40
Rudnaya river, 26 km	6.4	0.120	0.060	0.030	0.030	<DL	0.002	0.009	49.49	4.53
Water supply point, Dalnegorsk city	5.8	0.080	0.200	0.080	0.140	0.010	0.002	0.002	12.80	1.54
Mine water, Sovetskii mine	5.0	0.080	<DL	0.050	<DL	<DL	0.010	0.009	26.28	2.10
Slime water, new TD, CODP	5.5	0.030	<DL	0.360	0.010	0.070	<DL	0.578	56.48	1.83
Rudnaya river, 26 km	5.0	0.050	<DL	<DL	0.010	<DL	<DL	0.055	51.64	4.96
2011 (August)										
Mine water, Sovetskii mine	5.0	1.590	4.670	0.490	1.120	0.020	1.210	0.057	49.93	3.98
Slime water, new TD, CODP	5.0	0.120	0.250	0.480	0.070	0.220	0.040	0.017	89.20	3.52
Slime water, old TD, KODP	1.0	188.70	2874.0	778.00	125.20	3.290	0.110	2.530	550.90	361.80
Slime water, new TD, KODP	5.5	1.390	0.800	2.120	0.110	<DL	<DL	0.001	29.48	8.06
Rudnaya river, 26 km	6.5	0.090	0.070	0.030	0.030	<DL	<DL	0.020	78.24	6.53

[a] Dash denotes that the concentration was not determined; TD stands for tailing dump; ND stands for not detected; DL stands for detection limit. [b] Data of [13]; concentrations of elements below detection limit, mg/l: Mn, Al, 0.01; Pb, 0.015; Cu – 0.0015.

Owing to the impact of mining technological system the concentration of most elements in water of Rudnaya river (Table 3) exceeds the maximum permissible concentrations defined by fishery regulations by a factor of 5 to 19 for Zn, 2 to 11 for B, up to 5 for Fe, 2 for Mn and Pb, 5 for Al and Cu, and 6 to 7 for sulfate ions. The most mineralized were drainage water in the Komsomolsk region (371 mg/l), slime water from the old tailing dump of KODP in the Dalnegorsk region (4484 mg/l), mine water in the Kavalerovskii region (up to 406 mg/l in Pereval'noe deposit and up to 633 mg/l in Dubrovskoe deposit), and river water in the Kavalerovskii region (Vysokogorka river, up to 503 mg/l).

On the basis of the results of this study, the following measures have been proposed to ensure environmental safety and reduce the impact of industrial wastewaters: (1) urgent reprocessing of mine wastes impounded in tailing dumps; (2) restoration of the natural environment, including the surface of tailing dumps; (3) improvement of the regulatory and legal framework; (4) and development of a Strategy for environmental safety of technological facilities in the Far East.

CONCLUSIONS

The study has shown that industrial mining complexes with strongly expressed negative effect on the environment have been generated in the Komsomolsk, Kavalerovskii, and Dalnegorsk regions of the Far East. These regions are characterized by tense and critical ecological situation. In 2001–2011 the concentrations of Zn, Cu, Pb, Cd, Fe, Mn, As, Al, and other elements in mine, drainage, slime, and river waters in the examined regions exceeded the background values and those typical of "reference" freshwaters by one, two, and even three and more orders of magnitude. These waters should be diluted by a factor of hundreds, thousands, and even tens of thousands, which is practically impossible. Because of degradation of aquatic biocoenoses natural purification of water bodies is slower than the intake of contaminated mine and drainage waters. This leads to degradation of aquatic ecosystems and deterioration of the hydrochemical background and natural water quality.

Anthropogenic pollution also damages environmental compartments from the economic viewpoint.

Therefore, a number of environmental measures, including reclamation, must be undertaken in the nearest future. It is necessary to treat mine waters that have been wasted to rivers over centuries and reclamate tailing dumps. Prior to reclamation, the tailings should be reprocessed to extract a number of recoverable components before complete oxidation of finely ground sulfide ores as a result of large-scale supergene processes. Otherwise, 10–15 years after it will be too late, for the available technologies do not ensure processing of oxidized ores.

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