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The Microelement Composition of the Soil-Plant Cover in the Basin of Lake Kotokel'

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Abstract

The content of microelements (Mn, Zn, Cu, Co, Ni, Cr, Pb, and Cd) and Fe is determined in the soils and plants of the Lake Kotokel' basin. Their content in the soils is proved not to exceed the regional background and the existing MPC and APC. The content of Cd is revealed to exceed its clarke value for the world soils, which is related to the natural origin of this element. The concentrations of Mn, Co, and Pb are close to their clarke values, and those of Zn, Cu, Ni, and Cr are lower than their clarkes. The studied soils are specified by the maximal amount of the mobile forms of microelements. The profile distribution of the microelements differs depending on the genetic soil type. For Mn, Zn, and Cu, a significant biogenic accumulation is pronounced in the organic soil horizons. The content of microelements in the aboveground phytomass exceeds the maximal permissible levels for Mn, Co, Cr, and Fe. The intensity of the microelements absorption by the plants varies widely, being specified by the high coefficient of the biological adsorption (except for Fe). Mn, Zn, and Cu are accumulated in the grass phytomass the most intensely.

Keywords: soils, vegetation, microelements, ecosystems, basin of Lake Kotokel'

1. Introduction

The necessity to analyze the microelement composition of the soil-plant cover in the basin of Lake Kotokel' included in the central ecological zone of the Baikal natural territory (Boundaries of the Baikal…, 2006) and to assess its present-day state is very important for the preservation of the natural complex and pure water of Lake Baikal as a part of our world heritage.

Lake Kotokel' is located 2 km to the east of Lake Baikal in its middle part (52°50' north latitude, 108°10' east longitude, and 460 m above the sea level). The lake is nearly 15 km long and about 5 km wide with its average depth being equal to 5-6 m with a maximal depth of 14 m. The lake's water runs off to Lake Baikal in the north via the Istok and Turka rivers. The climate is continental with a cold winter and a moderately warm summer (Bezrukova et al., 2008).

The soil-forming deposits in the investigated region are represented by the products of acidic rock weathering (Quaternary colluvial, colluvial-rubble loam, and sandy loam), layers of sands and rubble-sandy proluvium filling the intermountain depressions, and alluvial and alluvial-lacustrine sands of the low terraces (Baikal, 1996).

Larch and grass-shrub pine forests with birch prevail in the plant cover of the Lake Kotokel' basin. The dark coniferous taiga consisting of cedar, fir, and spruce occupies the middle-mountain taiga belt of ridges facing Lake Baikal. The low banks of the lake are often swamped and occupied by biocenoses with *Carex, Equisetum,* and *Typha* genera representatives.

The specifics of their accumulation and distribution in the soil-plant cover of the Lake Kotokel' basin have not been investigated.

The main aim was to estimate the present-day ecological and biogeochemical status of the soil-plant cover in the basin of Lake Kotokel'.

2. Objects and Methods

The soil-plant cover in the basin of Lake Kotokel' was the subject of our study. Samples for the physicochemical and chemical analyses and their subsequent treatment were taken according to the recommendations in (Agrochemical Methods…, 1975; Methods for Studying, 2002). The humus content was determined by the Tyurin method, the total nitrogen content was analyzed according to the Kjeldahl method, the exchangeable bases were determined by the complexometric method, the total (hydrolytic) acidity was determined by the Kappen method, and the content of mobile forms of potassium and phosphorus was analyzed according to the Kirsanov method.

The total content of microelements and iron in the soils was measured by atomic-absorption spectroscopy using an AAS Analyst 400 device produced by PerkinElmer after the preliminary decomposition of the samples by hydrofluoric acid (HF) in the presence of sulfuric acid with the subsequent decomposition of the precipitate with hydrochloric acid (HCl). The content of the mobile forms of the microelements was measured in an acetate-ammonium buffer extract (pH 4.8), and their content in the aboveground and underground phytomass of the herbs was analyzed after dry ignition. The data were treated statistically using Microsoft Excel 2000 software. The soils were classified according to (Classification & Diagnostics, 1977).The soil cover in the area is represented by various types of automorphic soils (soddy taiga, soddy forest, and gray forest soils), as well as by boggy and alluvial soils (Figure 1). Automorphic soils are formed under various arboreal and herb associations on the sandy loamy and loamy deposits.

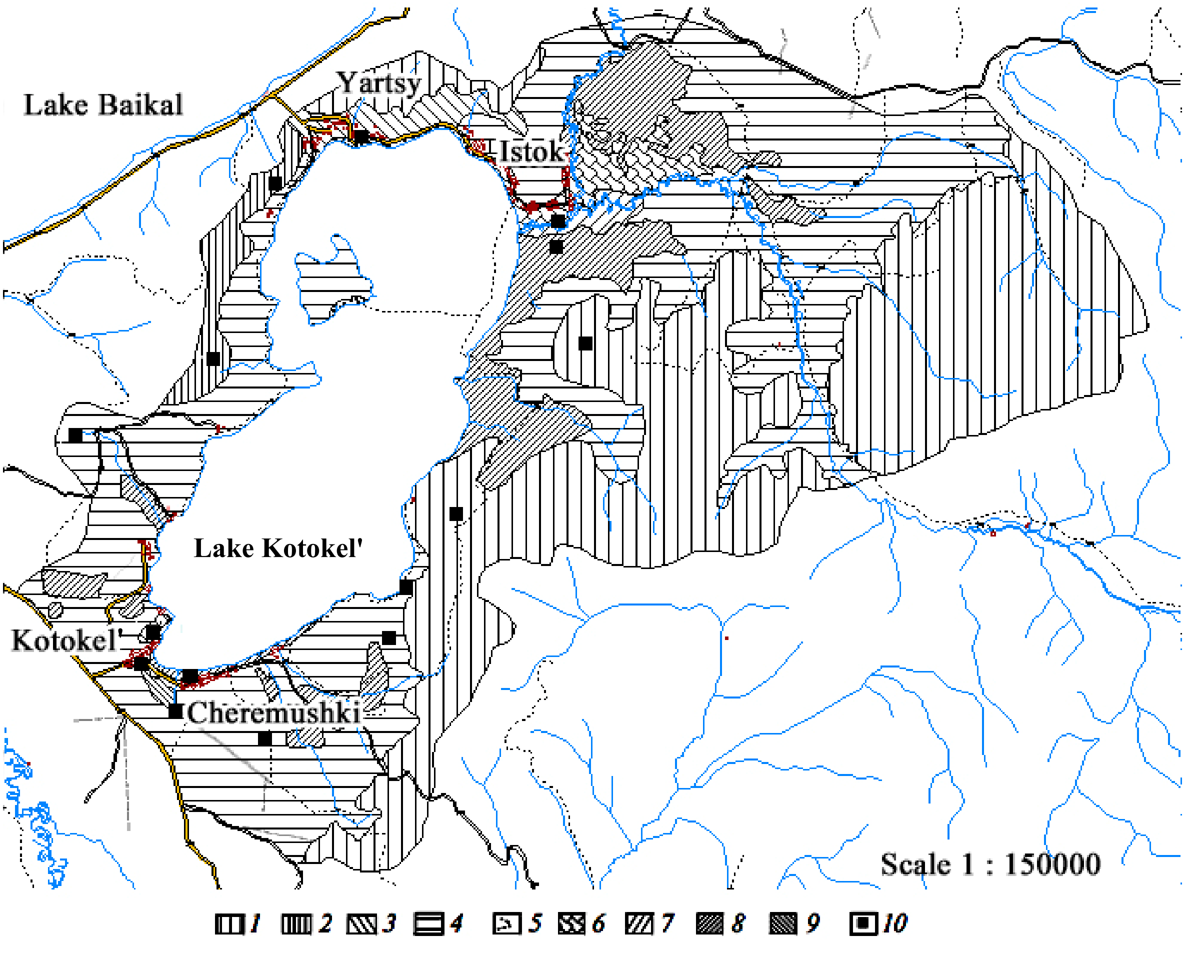

Figure 1. The soil map of the basin of Lake Kotokel' (authors: Gyninova, Tsybikdorzhiev, Balsanova, Gonchikov, & Beshentsev). Soils: (1) soddy-taiga unsaturated (raw-humus burozem); (2) soddy-taiga postcryogenic (dark burozem); (3) soddy forest; (4) gray forest; (5) soddy-gley; (6) alluvial meadow acid; (7) alluvial boggy clay-peat; (8) peat boggy low-moor; (9) peat boggy low-moor reclaimed; (10) position of the profiles

2.1 Forest Ecosystems

The profile of the soddy taiga unsaturated soils consists of the Ao–A1A2–AB–Bf–Bm–C horizons (profile 3). The zone of biogenic accumulation includes a thick weakly decomposed litter with fungal mycelium (3-12 cm) and a thin (4 cm) eluvial-accumulative A1A2 horizon. It is specified by the crumb structure, light-gray color, and the presence of lightened and *bleached* aggregates. The AB horizon is of grayish light brown color. All these features point to the eluvial processes with the insignificant accumulation of substances. The Bf horizon is stony, and the rock fragments have ferruginous ocherous coatings and fine weathering products of ocher color. The amount of stony fragments is lower in the Bm horizon with its color being reddish.

The soddy taiga unsaturated soils are characterized by their light loamy texture in the surface horizons and by their heavy loamy texture in the middle part of the profile (Table 1). The content of the clay fraction is insignificant in the upper horizons and in the soil-forming deposits; however, it reaches 12-16% in the middle part of the profile, which testifies to the metamorphism developed in the AB and Bf horizons. The soil's reaction is acidic, the humus content is low, the content of mobile forms of P_2O_5 is low, and that of K_2O is medium.

The profile of the gray forest soils is represented by the AO–A1–B1m–B2m–BCg–Cg horizons. The soils of this type are specified by the thick forest litter (6 cm) and the thick humus horizon (11 cm). The humus horizon is of dark gray and brownish color, it is underlain by a light brown horizon, and then by a brown one. The dove gray and ocherous mottles and bands in the lower part of the profile testify to the recurrent gleying. In the gray forest soils, the sandy loamy surface horizons are replaced by sandy horizons with the depth; the content of the clay fraction is maximal in the surface horizons (8.7–10.4%) while gradually decreasing to 3.6% down the profile. No signs of metamorphism and vertical migration of clay are revealed in these soils.

The soddy forest soils with the profile A0–A1–Bf–BC–C–D (profile 12) and A0–A1–AB–B1f–B2–BC (profile 7) are formed on the slopes of low hills up to 100 m high and on the northern part of the ridge spurs separating the basins of Lakes Kotokel' and Baikal. The thin humus horizon is replaced by the brown mineral Bf horizon in these soils. The soddy-forest soils are characterized by their sandy loamy texture with the maximal content of clay (3.5 and 6.2%) being found in the accumulative horizon and in the soil-forming rock, respectively. The soil's reaction is weakly acidic. The humus content is low. The upper organic horizons are characterized by a high amount of mobile K_2O.

Table 1. Physicochemical properties of forest soils in the basin of Lake Kotokel'

Horizon, depth, cm	Content of particles <0.01 mm, %	pH_{water}	Humus	N_{tot}	P_2O_5	K_2O	Exchangeable bases		Hydrolytic acidity
			%		mg/100 g of soil		Ca^{2+}	Mg^{2+}	
							mg-equiv./100 g of soil		
Profile 2. Gray forest soil under birch rhododendron – herb-green moss forest									
A0, 0–6	–	5.2	–	0.54	12.4	27.8	4.5	3.2	11.0
A1, 6–17	18.97	5.2	2.6	0.17	10.3	16.5	3.0	0.7	7.0
A1B, 17–36	18.33	5.5	1.2	0.12	11.8	4.7	1.0	0.7	3.3
B, 36–66	9.03	5.7	0.7	0.11	12.1	4.1	0.5	0.6	1.9
BCg, 66–108	4.50	6.0	0.2	0.00	19.1	3.5	0.6	0.6	1.3
Cg, 108–130	5.66	6.0	0.2	0.00	20.8	3.5	0.4	0.2	1.1
Profile 3. Soddy taiga unsaturated soil under herb–bilberry–green moss mixed forest									
Ao, 0–4	20.82	4.2	5.2	0.36	3.0	30.0	2.5	2.7	15.5
A1A2, 4–8	27.20	4.5	3.0	0.22	10.4	11.4	1.2	1.6	11.0
AB, 8–18	28.88	5.1	1.4	0.15	3.5	8.0	1.2	2.0	5.6
Bf, 18–32	19.57	5.5	1.2	0.11	2.3	10.7	1.4	0.6	3.7
Bm, 32–68	37.80	5.9	1.2	–	1.3	7.8	5.6	3.7	3.3
C, 68–118	12.36	6.2	0.7	–	39.6	3.5	6.9	4.0	2.2
Profile 7. Soddy forest soil under pine herb forest									
A1, 1.5–6	15.57	5.7	2.1	0.18	12.2	10.0	3.7	1.9	4.7
AB, 6–10	15.98	5.6	1.0	0.09	12.2	6.1	2.5	1.9	4.2
B1, 10–38	14.30	5.8	0.9	0.09	7.4	6.6	1.6	0.9	2.5
B2, 38–80	19.43	6.1	0.9	–	8.1	6.5	3.4	2.5	2.0
BC, 80–115	18.02	6.5	0.2	–	14.4	4.7	5.6	3.0	1.7
Profile 12. Soddy forest soil under pine rhododendron–cowberry forest									
Ao, 0–6	19.20	5.2	–	0.93	15.8	27.2	6.0	4.8	15.2
B1, 6–10	15.53	5.3	2.5	0.46	20.8	13.7	3.5	0.7	9.2
B, 10–16 (22)	12.86	5.8	1.0	0.26	19.3	4.0	1.7	0.3	3.7
BC, 16 (22)–32	11.07	5.9	0.9	–	9.4	4.2	2.6	0.6	2.7
C, 32–47	16.46	6.2	0.7	–	17.7	5.0	6.4	1.9	1.6
D, 47–100	8.71	6.6	0.2	–	35.4	2.5	4.6	0.9	1.2
Profile 17-07. Soddy gley soil under an herb association									
A_1 0–15	6.93	5.6	5.7	0.84	13.3	6.0	–	–	3.0
Bg 15(24)–57	1.92	6.9	0.3	–	10.3	2.4	7.1	2.4	0.5
Cg 57–75	3.36	6.9	0.4	–	9.0	2.4	6.0	2.0	0.7

2.2 Alluvial Ecosystems

Alluvial meadow soils are formed on the river floodplains in the basin of Lake Kotokel' (Table 2). The alluvial meadow soils are formed in the central flood-plain of the Kotochek River under the herb-cereal-sedge associations (Profile 13). The profile is represented by the following horizons: Ad–A1–Bg–BG–CG. The humus horizon's thickness does not exceed 18 cm. The illuvial horizons show gley features. The texture of the surface horizons is loamy sandy merging to loose sandy. The content of clay is 1.3-2.4%. The soil's reaction is acidic or weakly acidic. The humus content is high in the A1 horizon and it is much lower in the underlying horizons. The amount of mobile phosphorus is low in the organic horizons, and it is high and very high in the mineral horizons.

Table 2. Physicochemical properties of alluvial soils in the basin of Lake Kotokel'

Horizon, depth, cm	Content of particles < 0.01 mm, %	pH_{water}	Humus	N_{tot}	P_2O_5	K_2O	Exchangeable bases		Hydrolytic acidity
							Ca^{2+}	Mg^{2+}	
			%		mg/100 g of soil		mg-equiv./100 g of soil		
Profile 13. Alluvial meadow soil under herb–cereal association									
Asod, 1–2	14.38	5.5	–	0.77	2.3	15.5	7.6	1.4	16.6
A_1 2–18	15.31	5.2	7.1	0.80	2.8	5.4	4.7	0.9	11.2
Bg 18–29(33)	4.22	5.6	1.2	0.22	26.5	2.8	2.0	0.7	3.8
BG 29(33)–68(70)	7.27	5.8	1.4	–	15.5	0.6	2.5	0.5	2.9
CG 68(70) –95	1.78	6.0	0.2	–	26.1	0.6	0.5	0.6	1.6
Profile 14. Alluvial bog soil under cereal–horsetail association									
T_1d 0–7	–	5.7	14.8*	2.47	5.6	44.0	12.8	0.9	–
T2 7–14	–	5.6	13.6*	2.24	4.0	17.2	12.4	2.4	22.5
T3 14–74	–	5.7	16.5*	2.06	6.4	5.2	20.0	10.8	22.1
TG >74	–	5.8	14.9*	1.14	9.6	5.2	16.4	3.2	15.8

* Carbon content (according to Anstett).

Note: Hereinafter, dashes denote "not determined."

In the low floodplain, alluvial boggy soils are formed with a peat thickness of 74 cm (profile 14) and a T1d–T2–T3–TG profile. The soils manifest a weakly acidic reaction and a high adsorption capacity. The content of mobile phosphorus is medium, and that of potassium is very high in the surface horizons and low in the remaining part of profile.

2.3 Bog Ecosystems

The boggy low-moor peat soils are formed on sandy and loamy sandy deposits; they manifest an acidic soil reaction, are base-unsaturated, and have a high content of organic matter (Table 3). The clay content ranges from 1.7 (Profile 1) to 2.8-6.7% (Profile 10). The amount of mobile phosphorus changes from medium to elevated (7-27.5 mg/100 g of soil) in the surface horizons. The content of mobile K_2O is high in the organic horizons.

Table 3. Physicochemical properties of bog soils in the basin of Lake Kotokel'

Horizon, depth, cm	Content of particles <0.01 mm, %	pH_{water}	Humus	N_{tot}	P_2O_5	K_2O	Exchangeable bases		Hydrolytic acidity
							Ca^{2+}	Mg^{2+}	
			%		mg/100 g of soil		mg-equiv./100 g of soil		
Profile 1. Bog low-moor peat low-thickness soil under herb–sedge–moss association									
Td 0–4	–	5.5	16.1*	1.17	7.0	45.4	–	–	–
T_1 4–9	–	5.4	15.1*	1.28	8.0	66.5	–	–	22.7
T_2 9–48	–	5.4	16.6*	2.76	1.2	28.0	9.2	36.0	28.0
CG > 48	3.80	4.9	2.2	–	27.5	8.0	0.7	1.2	1.23
Profile 8. Bog low-moor peat soil under herb–cereal–orsetail–sphagnum association									
To 0–10	–	5.2	19.0*	1.17	21.8	14.0	–	–	–
T_1 10–24	–	5.1	14.2*	1.63	0.5	34.0	–	–	28.0
T_2 24–80	–	5.2	–	1.95	3.6	20.8	–	–	28.0
Profile 10. Bog lowland peaty–gley soil under sedge–shrubbery–sphagnum association									
T_1 0–9	–	5.2	15.3*	2.00	14.0	94.0	8.8	12.4	26.2
T_2 9–28	–	5.1	17.2*	3.79	1.6	28.0	20.0	8.8	28.6
G 28–32	11.44	5.0	9.5	0.14	6.8	0.9	1.2	2.6	5.0

* Carbon content (according to Anstett)

3. Results and Discussion

The soil-forming deposits in the basin of Lake Kotokel' are depleted in microelements as compared to the lithospheric clarke (Vinogradov, 1962) except for Cd, the content of which exceeds the clarke value. However, as compared to the clarke value for felsic rocks, the studied soil-forming deposits are depleted in Zn and Cu; however, the content of Mn, Co, and Pb is close to their clarkes and that of Ni, Cr, and Cd exceeds the clarke values.

The total content of microelements in the soils does not exceed the regional background value and the available maximal permissible concentration (MPC) and approximate permissible concentration (APC) (Table 4). The clarke value for the world soils is found to be exceeded for Cd, which is explained by its natural origin.

Table 4. Average total content of microelements in the soils (0–20 cm) in the basin of Lake Kotokel', mg/kg

Indices	Mn	Zn	Cu	Co	Ni	Pb	Cr	Cd
Forest ecosystems								
M±m, (n=7)	771±84.9	47.8±5.3	5.2±1.8	13.8±2.6	16.1±2.6	19.3±1.4	31.2±1.9	1.2±0.1
Lim	558-1156	33.0-75.7	2.6-15.6	9.3-27.8	10.9-30.7	15.4-25.4	5.5-38.3	0.9-1.7
V, %	29	29	89	49	43	19	16	25
Floodplain ecosystems								
M±m, (n=2)	203±3.2	24.9±2.7	3.9±0.2	7.8±2.2	10.1±1.9	16.3±1.4	19.5±3.3	1.05±0.05
Lim	200-207	22.2-27.6	3.7-4.1	5.5-10.0	8.3-12.0	14.9-17.6	16.2-22.8	1.0-1.1
V, %	2	15	7	41	26	12	24	7
Bog ecosystems								
M±m, (n=3)	239±11.6	25.7±3.9	6.0±2.5	3.7±0.9	6.5±2.5	7.5±0.8	8.8±2.3	0.9±0.03
Lim	218-258	20.1-33.4	1.0-9.1	2.5-5.4	3.6-11.5	5.9-8.5	5.9-13.4	0.8-0.9
V, %	8	27	73	40	67	19	45	7
MPC, APC (Ivanov, 1996)	1500	100*	55*	50	85*	32	100**	2.0*
Clarke in soils of the world (Requirements, 2002)	1000	90	30	8	50	12	70	0,35
Clarke in felsic rocks (Requirements, 2002)	540	58	25	10	8	20	14	0.17
Clarke in the lithosphere (Vinogradov, 1962)	1000	85	47	18	58	16	83	0.13
Southwestern Transbaikalia (Ubugunov & Kashin, 2004)	684***	76	23	–	27	34	54	–

Note: *M* is the mean content, *m* is the error of the mean, *n* is the replicate, *Lim* is the fluctuation limits, and *V* is the variation coefficients.

*Approximately permissible concentrations.

**According to (Mineev, 1988).

***Calculated by (Senichkina & Abasheeva, 1986).

The contents of Mn, Co, and Pb are close to their clarke values, and that of Zn, Cu, Ni, and the content of Cr is lower than the clarke.

According to the schedule of ecological standardization of heavy metals suggested in (Obukhov & Efremova, 1988), the soils are characterized by a low total content of Cu and Ni, by a medium content of Zn and Pb, and a very high content of Cd. The decreased concentrations of Zn, Cu, Ni, and Cr in the soils result from the removal of elements upon the acidic leaching prevailing over their biogenic accumulation.

The light-textured soils (profiles 1, 8, 10, and 16) are specified by the lower content of microelements than the relatively heavy-textured soils (profiles 3, 4, 5, 7, and 12).

According to their total content in the soils of the basin, the microelements form the following succession (in decreasing order): Mn > Zn > Cr > Pb > Ni > Co > Cu > Cd. This sequence corresponds to the distribution of the microelement clarkes in the regional soils. However, if compared to the distribution in the world soils (Mn > Zn > Cr > Ni > Cu > Pb > Co > Cd), an elevated concentration is noted for Pb (unlike Ni and Cu).

The soils of the different ecosystems form the following succession according to the decreasing content of microelements: forest > floodplain > boggy soils, which is related to the soil properties and the ecological conditions of their formation and functioning. The contents of Mn and Zn form another succession: forest > boggy > floodplain soils.

The mobile compounds of chemical elements is the most important group of chemical substances in the soil, which provide the main ecological function of soils as natural-historical bodies, the source of fertility, and contamination control for the environment (Motuzova, 2009). The content of the mobile forms of microelements in soil permits the determination of the soil's supply with chemical elements necessary for the normal growth and development of plants, as well as the levels of their tolerant and toxic concentrations.

The contents of mobile microelements in the upper layers (0-20 cm) of the investigated soils does not exceed 96 for Mn, 60 for Zn, 22 for Cu, 54 for Co, 23 for Ni, 23 for Pb, 51 for Cr, and 30% of the total content for Cd (Table 5, 6, 7). In the underlying horizons, the mobility of the microelements decreases and does not exceed the following (% of the total content): Mn–22, Zn–23, Cu–11, Co–17, Ni–20, Pb–165.7, Cr–4, Cd–24.

The mobility of heavy metals is higher in the low-moor boggy peat soils as compared to the other soils (Table 7). This is explained by the lower moisture of the automorphic soils, which limits the mobility of the chemical elements. According to schedule (Field Survey…, 1980), the studied soils are specified by the low and very low content of mobile forms of microelements except for Mn, the amount of which reaches average values in the boggy and soddy taiga soils.

The profile distribution of the total content of microelements in the soils depends on the soil's genetic type. The reason is the difference in the soil-forming processes developing in the soils. In the soils of the boggy soil-formation type (profiles 1, 8, 10, and 14) and in the soddy taiga unsaturated soils (profile 3), the total content of microelements increases with the depth. In the profile of the soddy forest (profile 2, 7, and 12) and soddy taiga post-cryogenic soil (profiles 4 and 5), no significant redistribution of the microelements is revealed as compared to the soil-forming deposits except for the biogenic accumulation of Mn and Zn and the distribution of Cu in the soddy forest soil, the content of which increases with the depth. In the soddy gley soil (profile 17-07), the accumulation of microelements is registered in the illuvial gley horizon, which is related to the soil's reaction varying from weakly acidic to neutral.

Table 5. Content of heavy metals (mobile form) in the soils of forest herb ecosystems (mg/kg of air-dry substance, AAB with pH 4.8 (% of the total content)

Horizon, depth, cm	Mn	Zn	Cu	Co	Ni	Pb	Cr	Cd
Profile 2. Gray forest soil under birch rhododendron-herb-green moss forest								
Ao, 0–6	193.6/31.1	2.89/5.9	0.19/6.3	0.37/3.9	0.40/3.2	1.20/5.8	0.34/1.3	0.06/4.6
A1, 6–17	113.6/23.0	0.85/1.6	0.18/7.2	0.33/2.7	0.23/1.7	0.77/3.1	0.64/2.3	0.08/8.0
A1B, 17–36	14.6/5.3	0.15/0.4	0.18/6.2	0.14/1.1	0.06/0.4	0.56/2.5	0.51/1.7	0.07/6.4
B, 36–66	4.0/1.2	2.60/8.0	0.14/4.4	0.04/0.3	0.13/0.9	0.26/1.1	0.41/1.4	0.06/5.5
BCg, 66–108	2.6/1.1	0.87/4.0	0.16/9.4	0.01/0.1	0.07/0.7	0.10/0.5	0.20/0.9	0.06/7.5
Cg, 108–130	1.7/0.7	0.79/4.2	0.13/5.6	0.02/0.2	0.04/0.4	0.02/0.1	0.23/1.1	0.06/8.6
Profile 3. Soddy taiga unsaturated soil under herb-bilberry-green moss mixed forest								
Ao, 0–4	400.2/43.6	6.43/17.6	0.21/4.5	0.50/4.8	0.32/3.2	1.05/4.2	0.77/3.3	0.11/12.2
A1A2, 4–8	128.3/20.6	1.76/4.7	0.17/3.7	0.47/4.2	0.19/1.7	0.62/2.3	0.73/2.3	0.09/12.9
AB, 8–18	50.0/18.7	1.05/2.0	0.18/3.8	0.40/3.5	0.15/1.3	0.57/2.3	0.45/1.5	0.07/7.8
Bf, 18–32	11.8/6.6	0.4/1.0	0.18/2.6	0.15/1.2	0.07/0.4	0.42/1.6	0.57/1.7	0.07/6.4
Bm, 32–68	3.8/1.2	0.54/0.9	0.21/2.4	0.21/1.5	0.17/1.0	0.69/2.8	0.14/0.3	0.07/7.0
C, 68–118	2.0/0.4	3.68/5.3	0.23/0.9	0.11/0.5	0.18/0.6	0.30/1.7	0.37/1.1	0.08/7.3
Profile 4. Soddy taiga postcryogenic soil under an herb pine forest								
Ao, 0–5	270.9/39.8	13.92/38.4	0.30/11.5	0.03/0.5	0.45/5.1	2.91/19.1	0.63/2.6	0.15/12.5
A1, 5–14	162.8/10.0	4.30/6.2	0.15/4.7	0.08/0.6	0.22/1.0	0.29/1.6	0.34/0.7	0.08/8.0
BF, 14–44	8.6/2.2	0.22/0.7	0.18/10.6	0.07/0.7	0.15/0.9	0.14/1.0	0.43/1.2	0.07/10.0
BC, 44–65	3.5/0.8	0.68/2.7	0.12/9.2	0.04/0.4	0.10/0.6	0.07/0.5	0.13/0.4	0.06/10.0
C, 65–95	2.4/0.5	0.31/1.4	0.09/4.3	0.01/0.1	0.08/0.5	0.04/0.3	0.21/0.6	0.06/6.0
Profile 5. Soddy taiga postcryogenic soil under an herb pine forest								
Ao, 0–10	505.5/80.4	15.12/49.7	0.30/6.7	0.03/0.3	0.54/4.7	1.59/8.6	0.75/2.3	0.12/10.0
A1, 10–19	118.8/18.8	1.12/3.1	0.16/6.9	0.16/1.7	0.05/0.4	0.36/2.4	0.42/1.3	0.08/8.9
BF, 19–39 (56)	7.70/2.2	0.36/1.0	0.47/10.7	0.24/2.0	0.21/1.1	0.24/1.6	0.16/0.4	0.06/5.5
BG, 39(56)–73	0.60/0.2	1.11/3.6	0.37/10.0	0.04/0.4	0.04/0.2	0.38/2.1	0.16/0.4	0.07/7.0
C, 73–120	1.00/0.4	0.38/1.3	0.18/7.5	0.01/0.1	0.04/0.3	0.15/1.0	0.25/0.8	0.06/6.7
Profile 7. Soddy forest soil under a pine herb forest								
A1, 1.5–6	61.5/6.6	0.70/1.5	0.06/2.1	0.03/0.3	0.19/1.5	0.22/1.1	0.16/0.6	0.04/4.0
AB, 6–10	33.5/5.1	0.43/1.2	0.08/3.2	0.16/1.7	0.09/0.7	0.12/0.6	0.17/0.7	0.01/1.0
B1, 10–38	10.5/3.0	0.38/1.3	0.12/4.6	0.02/6.7	0.12/1.1	0.15/1.5	0.20/0.8	0.01/1.0
B2, 38–80	6.70/2.0	0.13/0.5	0.19/4.5	0.05/0.5	0.10/0.8	0.35/1.7	0.59/2.0	0.01/1.1
BC, 80–115	4.20/1.2	0.45/1.6	0.17/3.8	0.01/0.1	0.26/1.5	0.31/1.6	0.46/1.5	0.02/2.0
Profile 12. Soddy forest soil under pine rhododendron-cowberry forest								
Ao, 0–6	218.1/26.2	6.98/9.3	0.15/1.2	0.40/1.5	0.18/0.6	1.17/16.4	0.39/0.9	0.07/4.7
A1, 6–10	61.0/5.7	27.40/34.7	0.10/0.9	0.30/1.0	0.13/0.4	0.88/6.2	0.33/0.8	0.05/3.3
B, 10–16(22)	11.7/1.1	0.19/0.3	0.25/1.1	0.06/0.2	0.09/0.3	0.30/1.9	0.31/0.9	0.02/1.3
BC, 16(22)–32	4.6/0.2	0.16/0.2	0.18/0.7	0.09/0.3	0.12/0.4	0.23/1.6	0.30/0.9	0.01/0.7
C, 32–47	3.6/0.1	0.14/0.3	0.45/1.6	0.21/0.9	0.16/3.9	0.42/3.8	0.19/0.9	0.02/1.7
D, 47–100	2.2/0.1	0.14/0.2	0.39/0.9	0.06/0.2	0.16/0.6	0.26/1.9	0.23/1.1	0.01/0.8
Profile 17–07. Soddy gley soil under herb association								
A1, 0–15	54.4/6.6	3.35/7.5	0.15/3.1	0.19/1.1	0.27/1.4	0.06/0.3	0.10/0.3	0.16/9.4
Bg, 15(24)–57	1.6/0.2	13.25/23.2	0.05/1.6	0.04/0.2	0.12/0.4	0.58/2.1	0.19/0.5	0.03/1.9
Cg, 57–75	2.1/0.4	3.14/9.0	0.10/1.9	0.06/0.4	0.11/0.6	0.06/0.3	0.16/0.4	0.02/1.4

Table 6. Content of heavy metals (mobile form) in the soils of alluvial ecosystems (mg/kg of air-dry substance, AAB with pH 4.8 (% of the total content)

Horizon, depth, cm	Mn	Zn	Cu	Co	Ni	Pb	Cr	Cd
Profile 13. Alluvial meadow soil under herb-cereal association								
Asod, 1–2	42.8/17.8	2.54/39.8	0.11/2.8.	0.36/3.8	0.25/2.1	0.89/5.1	0.65/2.9	0.05/5.0
A1, 2–18	7.1/4.1	0.78/3.8	0.07/1.9	0.34/3.2	0.23/1.8	0.51/2.9	1.03/4.4	0.05/5.0
Bg, 18–29(33)	0.9/0.4	0.29/0.7	0.07/3.7	0.02/0.1	0.01/0.1	0.07/0.3	0.19/0.8	0.03/2.7
BG, 29(33)–68(70)	0.6/0.1	0.15/0.4	0.17/6.5	0.10/0.6	0.15/1.0	0.17/1.0	0.35/1.3	0.03/3.0
CG, 68(70)–95	0.6/0.1	0.18/0.5	0.23/9.2	0.09/0.4	0.02/0.1	0.04/0.3	0.20/0.7	0.03/3.0
Profile 14. Alluvial boggy soil under cereal-horsetail association								
T1d, 0–7	146.0/82.5	9.54/28.8	0.18/4.6	0.84/18.3	0.69/9.8	3.06/21.0	0.30/2.3	0.21/17.5
T2, 7–14	64.3/28.7	2.31/10.4	0.24/5.6	0.90/14.3	0.66/7.0	1.50/9.8	0.54/2.8	0.24/21.8
T3, 14–74	100.1/47.9	1.35/6.1	0.27/5.4	0.39/7.5	0.24/2.7	0.45/3.7	1.11/5.6	0.18/16.4
TG, >74	92.6/34.5	2.37/6.5	0.18/2.9	0.30/3.8	0.39/3.3	0.69/4.9	1.50/5.9	0.06/5.4

Table 7. Content of heavy metals (mobile form) in the soils of bog ecosystems (mg/kg of air-dry substance, AAB with pH 4.8 (% of the total content)

Horizon, depth, cm	Mn	Zn	Cu	Co	Ni	Pb	Cr	Cd
Profile 1. Bog low-moor peat low-thickness soil under herb-sedge-moss association								
T2, 9–48	124.2/82.8	1.59/14.6	0.42/22.1	0.27/54.0	0.33/10.3	0.51/13.8	0.72/7.5	0.18/25.7
CG, >48	3.8/0.6	11.65/24.7	0.12/8.0	0.13/1.0	0.04/0.4	0.17/0.8	0.40/1.6	0.07/6.4
Profile 8. Bog low-moor peat soil under herb-cereal-horsetail-sphagnum association								
To, 0–10	304.5/95.8	13.56/37.3	0.69/11.9	2.19/43.8	2.58/23.2	1.56/2.4	1.47/26.3	0.27/30.0
T1, 10–24	82.9/70.0	6.75/22.1	0.75/6.0	1.32/22.4	2.73/22.9	2.25/21.6	1.80/8.4	0.21/23.3
T2, 24–80	57.3/64.4	9.57/23.3	1.26/6.1	0.90/16.7	2.70/19.7	1.95/15.7	0.42/1.6	0.24/24.0
Profile 10. Bog lowland peaty-gley soil under sedge-shrubbery-sphagnum association								
T1, 0–9	200.2/63.7	18.90/59.8	0.33/5.1	0.48/16.5	0.54/16.4	1.80/22.8	2.10/51.2	No data
T2, 9–28	104/62.3	5.19/33.9	0.18/1.9	0.39/10.5	0.27/6.7	0.39/4.5	0.33/3.2	0.18/22.5
G, 28–32	12.50/21.9	0.63/7.7	0.06/6.7	0.03/0.4	0.14/1.9	0.24/1.3	0.54/3.5	0.01/0.9
B_{other}, 32–59	9.10/11.4	0.23/2.2	0.08/8.0	0.07/0.9	0.23/2.8	0.33/1.7	0.65/4.0	0.01/0.8
BCG, 59–80	7.60/11.9	0.22/0.8	0.21/11.0	0.08/0.8	0.20/2.0	0.42/1.9	0.87/3.9	0.01/0.8
MPC (Hygienic Norms, 2006)	80	23	3.0	5.0	4.0	6.0	6.0	No data

The profile distribution of the mobile forms of the microelements does not always repeat the distribution of their total content by the soil profile. For the bulk of the microelements, it follows a certain regularity. In general, the content of mobile Mn, Co, Cr, and Cd decreases down the soil profile. Two maximums are revealed in the profile distribution of the mobile forms of Cu, Ni, and Pb: the first is caused by the biogenic accumulation, and the second is related to the adsorption accumulation in the illuvial soil horizons. An insignificant concentration of the mobile Zn forms is noted in the illuvial gley horizons. Zn's solubility grows noticeably in the neutral environment. This is caused by the amphoteric nature of this metal and its capacity to form hydrocomplexes. The substantial accumulation of the mobile forms of the microelements is typical for the upper organogenic soil layers.

Plants are the most important intermediate links for chemical elements passing from the soil, water, and air into humans and animals (Steblevskaya et al., 2006), and they represent a powerful biogeochemical barrier removing the excessive masses of elements from the migration flows to depositing media (Karel'skaya, 2008). The content of chemical elements in plants is mainly inherited from the soils on which they grow; however, it is not identical, as plants selectively consume the necessary elements according to their physiological and biochemical needs (El'chininova, 2009). As proceeds from the analysis of the microelement amount in the plants, despite the low content of mobile forms in the soil in the studied territory, the plants do not suffer from a physiological deficit in these elements, and the concentration of Mn, Co, Cr, and Fe in the aboveground phytomass exceeds their maximal permissible levels (Table 8). This is explained by the more intense consumption of the microelements by the plants in the acidic media as compared to neutral and alkaline media.

The coefficient of biological consumption is a quantitative measure of the intensity of the chemical elements accumulation by plants; it is calculated as the ratio of an element's content in the plant ash to its content in the soil

(Perel'man, 1975). Note that the intensity of the microelements accumulation in the aboveground phytomass in the investigated area varies widely and manifests high values of the biological consumption coefficient. The coefficient of the Mn consumption by the aboveground phytomass ranges from 1.7 to 53.4; Zn, 7.3-98.5; Cu, 3.5-37.4; Co, 1.2-16.6; Ni, 0.8-14.2; Cr, 1.2-24.0; Fe, 0.07-0.62; Pb, 1.5-15.3, and Cd, 0.9-7.3. The underground phytomass accumulates microelements less intensely. For example, the coefficient of the Mn consumption is equal to 3.910.7; Zn, 0.7-24.0; Cu, 2.5-15.1; Co, 0.7-16.1; Ni, 0.2-5.5; Cr, 0.4-6.5, Fe, 0.04-0.37; Pb, 0.7-21.0; and Cd, 0.5-4.5.

Table 8. Content of microelements in the phytomass (aboveground, above the dash; underground, below the dash) in the Lake Kotokel' basin, mg/kg of air-dry mass/coefficient of the biological consumption

Biocenosis; profile	Mn	Zn	Cu	Co	Ni	Pb	Cr	Cd	Fe
Forest ecosystems									
Herb, profile 2	355/10.7	24.1/8.1	3.6/21.0	1.6/2.5	2.2/2.8	2.5/1.9	4.8/3.1	0.14/2.1	204/0.22
	728/5.2	29.5/2.2	3.9/5.3	3.8/1.3	4.1/1.2	5.1/0.9	6.7/1.0	0.19/0.7	646/0.16
profile 3	1071/43.8	24.7/14.5	5.3/27.8	1.3/3.0	1.7/3.8	1.6/1.6	6.1/5.2	0.15/4.1	83/0.13
	732/10.7	35.8/7.5	4.5/8.5	4.5/3.6	2.2/1.8	4.6/1.6	5.7/1.8	0.24/2.3	648/0.37
profile 7	576/23.1	21.3/14.6	3.8/37.4	1.5/3.9	1.5/3.3	1.0/1.6	4.9/5.0	0.13/3.3	120/0.20
	2527/8.1	29.2/1.6	3.3/2.6	5.3/1.1	3.4/0.6	5.9/0.7	5.2/0.4	0.23/0.5	670/0.09
profile 12	1491/23.0	19.2/7.6	3.4/6.5	1.4/1.5	2.1/2.0	2.1/3.6	3.6/1.2	0.10/3.0	112/0.07
	1585/4.2	20.7/0.7	15.0/2.5	7.0/0.7	2.9/0.2	6.9/1.2	8.9/0.6	0.3/0.5	706/0.04
Cereal-herb, profile 17-	133/1.7	30.8/7.3	7.3/16.2	2.1/1.2	1.5/0.8	2.0/1.0	3.9/1.3	0.15/0.9	348/0.13
07	889/3.9	88.9/7.1	20.3/15.1	11.4/7.7	4.4/1.8	11.3/2.0	7.8/0.9	0.51/1.1	755/0.10
Floodplain ecosystems									
Herb-cereal, profile 13	260/23.1	32.8/27.3	6.5/14.6	1.6/2.7	2.2/3.2	2.5/2.6	4.3/3.3	0.14/2.6	145/0.18
	568/9.8	45.8/7.4	14.2/13.5	3.8/1.3	6.1/1.7	5.3/1.1	12.9/1.9	0.28/1.0	637/0.15
Herb-cereal-horsetail, profile 14	166/15.2	21.9/15.8	1.3/5.4	1.2/3.7	0.4/0.8	1.1/1.2	2.9/2.8	0.08/1.0	72/0.07
	157/7.1	13.4/4.8	4.1/8.5	3.1/5.3	0.9/0.9	4.8/2.9	5.7/3.0	0.26/1.7	674/0.37
Bog ecosystems									
Herb-sedge, profile 1	366/33.9	29.4/33.9	1.6/23.6	1.6/16.6	1.8/9.0	3.7/15.3	7.8/21.5	0.17/4.2	270/0.21
	190/105	35.0/24.0	1.1/10.1	2.6/16.1	1.0/2.8	8.6/21.0	4.0/6.5	0.31/4.5	811/0.37
Herb-cereal-horsetail, profile 8	233/11.6	26.6/7.5	3.4/3.5	2.0/3.4	1.0/2.0	1.2/1.5	5.5/3.4	0.17/1.8	173/0.15
	181/8.7	23.6/6.4	12.9/12.9	3.1/5.2	5.2/4.1	4.6/5.3	7.0/4.1	0.27/2.7	704/0.40
Herb-cereal, profile 10	477/53.4	98.9/98.5	4.6/13.3	1.8/12.6	2.2/14.2	2.6/7.3	7.4/24.0	0.25/7.3	213/0.62
	213/14.8	22.6/14.0	3.5/6.4	2.2/9.5	1.4/5.5	4.7/8.2	3.0/6.1	0.23/4.2	648/0.37
Limits of normal concentrations (Mineev, 1988)	no data	15-150	2.0-12.0	0.3-0.5	0.4-3.0	0.1-5.0	0.2-1.0	0.05-0.2	no data
Maximal permissible level in forage (Sanitary Rules …, 1996)	100	50	30	1.0	3.0	5.0	0.5	0.3	100
Rate of forage provision	40-50	30-50	6.0-10.0	0.8-1.0	0.4-3.0	0.1-5.0	0.4-0.6	no data	
Intensity of the biological consumption (Dobrovol'skii, 1997)	6.9	11.8	2.3	1.4	1.5	1.5	1.0	4.4	0.1
Mean content in the vegetation of the continents (Dobrovol'skii, 1997)	205	30	8.0	0.5	2.0	1.25	1.8	0.035	200

Note: The underground phytomass is determined in the soil layer of 0-20 cm, and the forest herb mowing consists of the following: profile 2 – *Rubus saxatilis*, *Pyrola asarifolia*, *Maianthemum bifolium*, *Galium boreale*, *Aegopodium alpastre*, *Diphasiastrum complanatum*, and sporadically *Calamagrostis sp.*, *Festuca ovina*; profile 3 –*Diphasiastrum complanatum*, *Vicia nervata*, *Maianthemum bifolium*, *Lathyrus humilis*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Carex sp.*; profile 7 – *Festuca ovina*, *Pulsatilla flavescens*, *Orthilia secunda*, *Aegopodium alpastre*, *Galium boreale*, *Lathyrus humilis*, *Rubus saxatilis*, *Maianthemum bifolium*, *Hieracium ganeschinii*; profile 12 –*Aegopodium alpastre*, *Platanthera bifolia*, *Rubus saxatilis*, *Pyrola asarifolia*, *Festuca ovina*, *Maianthemum bifolium*, *Galium boreale*, *Geranium krylovii*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*; and profile 17-07 – *Poa supine*, *Carex ovalis*, *Plantago major*, *Trifolium repens*, *Prunella vulgaris*.

Mn, Zn, and Cu are accumulated in the phytomass most intensely, which is caused by their important biochemical function and points to the cationphilic character of the biogeochemical specialization of the forest landscape plants. The vegetation of bog ecosystems adsorbs microelements more intensely as compared to that of the forest ecosystems. The difference in the degree of the microelement consumption is caused both by the properties of the plant species and by the ecological conditions of their growth. For instance, in the boggy low-moor soils, the excessive moisture favors the low oxidation degree and the easily-soluble forms of chemical elements. The anaerobic conditions make the microelements more available to plants (Sadovnikova et al., 2006). In addition, the light texture of the boggy soils increases the mobility of the microelements.

4. Conclusions

Thus, the content of microelements in the soils of the Lake Kotokel' basin does not exceed the regional background as well as the existing MPC and APC. The profile distribution of the microelements is different and depends on the genetic type of the soils. The significant biogenic accumulation in the organic soil horizons is markedly pronounced for Mn, Zn, and Cu.

The amounts of microelements in the aboveground phytomass of the studied associations exceed the maximal permissible levels for Mn, Co, Cr, and Fe. The intensity of the microelements' consumption varies widely, being specified by the high values of the biological consumption coefficients, except for Fe.

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