Spatiotemporal distribution and elemental composition of atmospheric aerosol along Moscow–Khabarovsk railway

A.V. Andronova, I.G. Granberg, D.P. Gubanova, B.V. Zudin, M.A. Iordanskii, V.A. Lebedev, V.M. Minashkin, I.A. Nevskii, and Yu.I. Obvintsev

Karpov Scientific Research Physical Chemical Institute, Moscow

Received July 11, 2006

The data of elemental analysis of the railway soil and atmospheric aerosols, correlations between elements and particle sizes, enrichment coefficients of aerosols and soil of railroad bed are presented. The results were obtained in two expeditions "TROICA" along Moscow–Khabarovsk–Moscow rout: in February–March 1998 and June–July 2000. The measurements were conducted along 8000 km long route in five natural-territorial complexes. The differences of elemental composition of the atmospheric aerosol in winter and summer periods are identified.

Introduction

Among important parameters of atmospheric aerosols, characterizing aerosol physical-chemical properties and ecologic effect on environment are mass concentration, elemental composition, and size distribution function. Knowledge of these parameters makes it possible to model the air-disperse system, processes of formation, transformation, and transport of aerosols in the atmosphere; also, it provides the possibility to determine the pollution sources.[1–4]

The railway is an operating industrial enterprise ensuring transportation of different goods, including oil, polymetallic ore, coil, etc. The transportation of goods leads to pollution of atmospheric air, soil of railroad bed, ballast section, and soils of granted lands during pouring out, dusting, and evaporating. Yearly transportation losses[5] include about 3.3 mln t of ore, 0.15 mln t of salts, and 0.36 mln tons of fertilizers. In addition, as a result of wearing of movable vehicles, railing, and contact wires, the railway soil is polluted by the lubricating oil and heavy metals. The objects of railway transport emit yearly to the atmospheric air about 5 mln t of adverse substances, about 1.6 mln t of which from the movable sources. These are emissions of the chimneys of diesel locomotives and trains.

In the winter period, the pollution increases due to use of the stove heating of the carriages. The stationary objects of the railway transportation yearly emit to the atmosphere 80 thousand t of solid particles, 70 thousand t of sulfuric anhydride, 20 thousand t of nitrogen dioxide, 4 thousand t of soot, 90 thousand t of vanadium pentoxide, 5 thousand t of lead, and tens of tons of other adverse substances.

A significant contribution to pollution of the atmospheric air over the railway territory is maid by foreign objects, namely by big cities and industrial centers, neighboring mining enterprises, gas, oil, and product pipe lines passing nearby the railway, etc. A significant contribution to change of atmospheric gas and aerosol composition is made by different natural processes and events. The bogged territories are generators of the natural methane and carbon oxide; forest fires, in addition to carbon oxides and dioxides, emit into the atmosphere a considerable amount of aerosol particles including soot.

The results of the studies of spatiotemporal variations of aerosol mass and number concentration, obtained using carriage-laboratory in the expeditions "TROICA" along Moscow–Khabarovsk–Moscow route are presented in Ref. 6.

This paper presents the data of elemental analysis of the railroad bed soil and atmospheric aerosols, correlations between elements and particle sizes, enrichment coefficients of aerosols and railroad bed soil. The data are obtained in the expeditions TROICA-4 (February–March 1998) and TROICA-7 (June–July 2000). In analogy to Ref. 6, the results of analysis of the obtained data are presented for five natural-territorial complexes (NTC): East European Plain (rout segment 0–1500 km); Middle Urals (1500–2100 km); West Siberian Plain (2100–4200 km); mountains of the South Siberia (4200–7500 km), as well as Near- and Far-Baikal; and Amur-Zeisk Plain (7500–8550 km). The parameters of NTCs and description of the measurement complex are presented in Ref. 6.

The sampling method and analysis of the obtained data

At present, the monitoring of atmospheric air, as well as the study of different atmospheric processes, including the spatiotemporal distribution of substance, are widely conducted. However, the analysis of atmospheric air is very difficult primarily for two reasons. First, the atmosphere is an unstable system because its physical and chemical characteristics constantly change. Second, numerous chemical compounds to be analyzed are contained in

0235-6880/07/10 831-06 $02.00

air in concentrations between 10^{-12} and 10^{-3} g/m^3. The latter imposes certain conditions on the sampling procedure and the methods of analysis.

Most applied methods imply concentrating simultaneously with sampling; which is made by pumping of large air amounts (1 to 30 m^3). Therefore, the result of subsequent analysis is a quantity integrated over pumping time (from a few minutes to a few days). The samples are usually taken either during pumping of air through special filters or through the cascade impactors, when the aerosols from the atmosphere are deposited on special substrates.

Because of smallness of the substance amount in the collected sample (0.1–1 mg/cm^2), the choice of the proper physical analytical method is of importance. When relatively clean filters of AFA-KhA, FPA, and FPAR types are used for sampling in neutron-activation analysis, sufficient (threshold) amount of the pumped air can be estimated between 0.5 and 1 m^3; for other methods this amount is about 3–10 m^3. These estimates depend on the clearness of the atmospheric air, the matter to be determined; as well as on the interrelation between amounts of the given matter in the sample and on the filter. If the air amount is less than indicated above, the samples cannot be analyzed by the known methods.

Samples were taken from the railway bed, representing surface layer down to a depth about of 5 cm, (no less than five samples in each NTC). Approximately in the same regions, samples for the chemical analysis have been also taken with the use of the aspiration device from a height of 4 m above the railroad bed on the AFA-KhA filters with a flow rate of 12 m^3/h during 1 h. The elemental composition of aerosol and soil samples was determined by the roentgen-fluorescent analysis (RFA), atomic-absorption analysis, and mass spectrometry.

We calculated the enrichment coefficients of elements in the aerosols EF (Refs. 2, 7, 8) relative to clarkes (mean elemental composition in the earth's crust) by the Vinogradov method[9] and average elemental composition in the soil of railroad bed. For the soil, the enrichment coefficient was determined relative to the clarkes.

Simultaneously with aerosol sampling, measurements of the mass and number concentrations of aerosol particles were conducted using nephelometer and analyzers of particle size (diameter) spectrum in the interval between 0.15 and 15 μm.[6]

Measurement results

The elemental composition of the railroad bed is determined by two components: (1) lithogenic component, which reflects the elemental composition of the soil where it was taken for embanking of railroad, and (2) anthropogenic, associated with activity of railway and surrounding industrial enterprises.

A general insight into the mean percentage of the chemical elements in the soil of the railroad bed over different NTCs, obtained by the RFA method, is reflected in Table 1.

Table 1. Mean relative elemental composition of the soil of the railroad bed over different NTCs, %

Chemical element	Natural-territorial complex				
	1st	2nd	3rd	4th	5th
Si	24.8240	16.8728	21.8710	25.7967	22.4405
Al	2.2588	4.0445	2.6810	6.8448	7.2928
Ca	1.9620	1.3688	1.4069	2.2496	2.3092
Mg	6.9735	10.2088	12.7885	3.5184	1.0527
K	0.5975	0.4653	0.6215	1.2019	1.6152
Fe	16.8868	23.2258	14.7483	11.5816	15.0847
Mn	0.2178	0.2385	0.1759	0.2076	0.2310
Ba	0.2533	0.0615	0.0610	0.1714	0.1170
Sr	0.2557	0.4455	0.5721	0.7058	0.8258
Cs	0.0870	0.0795	0.0694	0.1032	0.1175
P	0.3868	0.3332	0.3434	0.4601	0.3987
S	0.2868	0.3445	0.2760	0.4839	0.3532
Cl	0.0433	0.0935	0.0688	0.0277	0.0598
Br	0.2683	0.1432	0.2828	0.1782	0.2217
I	0.0473	0.0692	0.0509	0.1266	0.1950
V	0.0268	0.0263	0.0215	0.0492	0.0375
Ti	0.1278	0.1513	0.1101	0.3030	0.3500
Ni	0.1408	0.1883	0.2198	0.1262	0.0400
Cu	0.1048	0.1308	0.0540	0.0319	0.0218
Zn	0.0780	0.0795	0.0611	0.1000	0.3640
Sc	0.0009	0.0008	0.0007	0.0006	0.0008
Pb	0.2910	0.3886	0.4648	0.2982	0.3700
Cd	0.0235	0.0490	0.1627	0.0577	0.0722
Se	0.2230	0.1400	0.0667	0.1583	0.1238
Co	0.0555	0.0450	0.0355	0.0450	0.0525
Cr	0.1175	0.1155	0.0735	0.0350	0.0100
Hg	0.8515	0.5990	1.0190	0.5760	0.8220
Mo	1.0915	0.9055	1.8335	0.7375	0.9035
Sn	0.5660	0.2985	0.1435	0.1950	0.1330

Table 2 presents the enrichment coefficients EF_{S-C} of the chemical elements in the railroad bed soil relative to the clarkes (the reference element is aluminum).

It follows from Table 2 that for most elements including Si, Ca, Man, K, Ti, and Sc, each being the lithogenic basis of the soil composition, the enrichment coefficients $EF_{S-C} \le 10$, and even in a number of cases $EF_{S-C} \le 1$. The enrichment coefficient $EF_{S-C} \le 1$ in all NTCs for K, as well as in four NTCs for Ti, and in three NTCs for Ca. In certain NTCs, the coefficients of soil enrichment $EF_{S-C} \le 10$ for Mg, Fe, Bad, S, Cu, P, Cl, Ni, V, and Cr, and even significantly exceed 10 in some cases, indicating that the soil in certain NTCs can be anthropogenic ally polluted by these elements. The coefficients of soil enrichment with Sir, Cs, Br, I, Zn, Pub, Cod, Se, Co, Hg, Mo, and Son considerably exceed 10 practically in all NTCs, possibly because of their anthropogenic pollution and accumulation in the soil. The soil in the railroad bed of the 1st NTC is most polluted, where 21 elements have a high enrichment coefficient; and the most clean soil is in the 5th NTC, where only 12 elements have a high enrichment coefficient.

Table 2. The enrichment coefficient of the elements EF_{S-C} in the railroad bed soil over NTCs relative to clarkes (the reference element is aluminum)

Chemical element	Natural-territorial complex				
	1st	2nd	3rd	4th	5th
	EF				
Si	3.00	1.15	2.25	1.00	0.85
Ca	2.35	0.95	1.45	0.87	0.85
Mg	**13**	**11**	**21**	2.00	0.64
K	0.85	0.37	0.75	0.57	0.71
Fe	**13**	10	10	3.00	4.00
Mn	8.00	5.00	5.00	2.00	3.00
Ba	**14**	2.00	3.00	3.00	2.00
Sr	**27**	**26**	**51**	**24**	**27**
Cs	**838**	**428**	**563**	**328**	**351**
P	**15**	7.00	**11**	6.00	5.00
S	**22**	**15**	**18**	**12**	8.00
Cl	9.00	**11**	**12**	2.00	4.00
Br	**4550**	**1358**	**4044**	**999**	**1166**
I	**4208**	**3445**	**3820**	**3724**	**5383**
V	**11**	6.00	7.00	6.00	5.00
Ti	1.00	0.67	0.71	0.83	0.89
Ni	**86**	**65**	**114**	**26**	8.00
Cu	**79**	**55**	**35**	8.00	5.00
Zn	**33**	**19**	**22**	**14**	**46**
Sc	3.00	1.61	2.12	0.71	0.92
Pb	**648**	**484**	**873**	**219**	**255**
Cd	**6801**	**7510**	**37585**	**5221**	6130
Se	**167800**	**55792**	**40050**	**37269**	**27349**
Co	**116**	**56**	**48**	**26**	**33**
Cr	**130**	**76**	**53**	**11**	3.00
Hg	**385980**	**161171**	**301893**	**74653**	**112961**
Mo	**37333**	**18384**	**40987**	**7212**	**9369**
Sn	**8518**	**1863**	**1411**	**839**	**607**

Table 3 presents the mean mass concentration of the chemical elements in the composition of the atmospheric aerosol for each of the studied NTCs in the summer and winter periods. The data are obtained by averaging over no less than five samples in each NTC (symbol "***" means that the element was not determined).

Following approach, suggested in Ref. 7, we divide the chemical elements, contained in the atmospheric aerosol, into two groups:

– macro components (Si, Al, Ca, Mg, K, and Fe), which are most often considered as the group of the natural lithogenic elements; and

– micro components (Mn, Ba, Sr, Cs, P, S, Cl, Br, I, V, Ti, Ni, Cu, Zn, Sc, Pb, Cd, Se, As, Be, Co, Cr, Hg, Li, Mo, Na, and Sn).

The second group contains elements which may come to the atmospheric aerosol both from natural and anthropogenic sources; hence the border between the elements is conditional.

Analysis of Table 3 shows that the total mass concentration of the macro components is considerably higher in summer than in winter, possibly, because of stronger blow-off from the surface layers of the soil of the region and railroad bed.

The total mass concentration of the micro components is larger in winter than in summer in practically all NTCs with exception of the 5th NTC. This fact may point to additional (and in particular anthropogenic) sources emitting aerosols to the atmosphere in this period.

Table 3. Mean mass content (μg/m^3) of the chemical elements in the composition of the atmospheric aerosol

Chemical element	Natural-territorial complex									
	1st		2nd		3rd		4th		5th	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1	2	3	4	5	6	7	8	9	10	11
Si	0.2547	1.1244	0.0709	1.1008	0.2044	0.1117	0.3081	0.7129	0.5773	0.5620
Al	13.2366	2.3072	8.1638	0.8428	13.0238	0.9772	25.4083	2.2989	23.6452	1.8579
Ca	5.0802	3.0430	2.5325	1.5643	3.4845	1.7206	5.5919	3.4088	5.0027	3.0979
Mg	2.6873	0.4623	1.8398	0.3321	2.3504	0.8333	4.1415	0.8150	3.6672	0.6722
K	1.4312	2.8809	1.1458	2.0916	1.7821	0.7708	3.6917	1.7489	3.3929	3.1511
Fe	8.7283	6.2486	16.8686	6.3818	9.0828	4.7085	16.8537	16.1898	11.2473	24.6080
Mn	0.1005	0.1734	0.1151	0.0841	0.0938	0.0605	0.1966	0.2092	0.1629	0.2232
Ba	0.0056	***	0.0147	***	0.0158	***	0.0178	***	0.0274	***
Sr	0.0037	0.0490	0.0853	0.0153	0.1396	0.0334	0.2002	0.0373	0.2942	0.0279
Cs	0.0110	***	0.0216	***	0.0166	***	0.0231	***	***	***
P	0.1909	1.0002	0.0539	0.7177	0.1349	0.1454	0.1550	0.5122	0.2296	0.4727
S	0.0334	***	0.0458	***	0.0337	***	0.0385	***	0.0893	***
Cl	0.2689	***	0.3645	***	0.2695	***	0.0617	***	0.5378	***
Br	0.0336	0.0050	0.0349	0.0038	0.0616	0.0026	0.0229	0.0071	0.0638	0.0165
I	0.0088	***	0.0171	***	0.0077	***	0.0037	***	0.0204	***
V	0.0043	1.4196	0.0028	0.0354	0.0030	0.0321	0.0036	0.0208	0.0033	0.0189
Ti	0.0166	0.1037	0.0119	0.0348	0.0138	0.0260	0.0228	0.0858	0.0145	0.0663
Ni	0.4436	0.8934	0.2231	0.1510	0.1905	0.0580	0.5604	0.0831	0.5575	0.1070
Cu	0.4893	0.1678	2.9764	0.3153	1.6707	0.2735	1.3014	0.4440	2.4415	0.2796
Zn	0.1346	0.4572	0.1760	0.5319	0.0630	0.1729	0.1398	1.1147	0.0643	0.4614

Table 3 continued

1	2	3	4	5	6	7	8	9	10	11
Sc	0.0009	0.0017	0.0002	0.0002	0.0001	0.0002	0.0003	0.0004	0.0002	0.0007
Pb	0.0281	0.3324	0.0496	0.2356	0.0460	0.0654	0.0363	0.2752	0.0518	0.2754
Cd	0.0008	0.0420	0.0005	0.0092	0.0007	0.0026	0.0011	0.0094	0.0008	0.0104
Se	0.0006	0.0066	0.0004	0.0055	0.0003	0.0022	0.0003	0.0027	0.0005	0.0032
As	0.0021	0.0144	0.0019	0.0099	0.0015	0.0112	0.0033	0.0115	0.0026	0.0198
Be	0.0000	0.0003	0.0000	0.0001	0.0002	0.0001	0.0001	0.0002	0.0001	0.0001
Co	0.0027	0.0158	0.0029	0.0177	0.0023	0.0015	0.0048	0.0056	0.0043	0.0050
Cr	0.0415	0.1510	0.0388	0.0890	0.0423	0.0450	0.0768	0.0681	0.0838	0.0861
Hg	0.0012	0.0032	0.0003	0.0042	0.0003	0.0018	0.0008	0.0031	0.0008	0.0020
Li	0.0033	0.0035	0.0024	0.0030	0.0040	0.0011	0.0073	0.0029	0.0081	0.0023
Mo	0.0014	0.0248	0.0020	0.0182	0.0014	0.0016	0.0025	0.0135	0.0028	0.0139
Na	0.7730	5.0143	0.4097	2.6984	0.6626	2.9193	1.0494	2.3536	1.7988	2.5573
Sn	0.0030	0.0218	0.0028	0.0640	0.0011	0.0226	0.0024	0.0329	0.0053	0.0408
Σ	34.0217	25.9675	35.276	17.3577	33.405	13.0011	59.9281	30.4676	53.999	38.6396

Table 4. The enrichment coefficient of elements EF_{A-C} in aerosols relative to the clarkes (reference element is aluminum)

Chemical element	Natural-territorial complex									
	1st		2nd		3rd		4th		5th	
	EF									
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1	2	3	4	5	6	7	8	9	10	11
Si	0.005	0.13	0.002	0.36	0.004	0.03	0.003	0.08	0.007	0.08
Ca	1.0	4.0	0.81	5.0	0.72	5.0	0.6	4.0	0.63	5.0
Mg	0.89	0.91	1.0	1.7	0.82	3.7	0.71	1.5	0.67	1.6
K	0.32	4.0	0.52	8.0	0.43	3.0	0.49	2.0	0.52	5.0
Fe	1.15	5.0	4.0	**13**	1.2	8.0	1.1	**12**	0.78	**23**
Mn	0.61	6.0	1.1	8.0	0.58	5.0	0.62	7.0	0.59	9.0
Ba	0.05	***	0.21	***	0.15	***	0.09	***	0.15	***
Sr	0.07	5.0	2.5	4.0	2.5	8.0	1.9	4.0	2.9	4.0
Cs	**18**	***	**58**	***	**28**	***	**20**	***	***	***
P	1.25	**38**	0.55	**74**	0.91	**13**	0.52	**19**	0.85	**22**
S	0.39	***	0.95	***	0.45	***	0.25	***	0.65	***
Cl	9.6	***	**21.1**	***	9.8	***	1.1	***	9.8	***
Br	**97**	**84**	**164**	**171**	**181**	**102**	**35**	**118**	**103**	**341**
I	**134**	***	**422**	***	**119**	***	**29**	***	**174**	***
V	0.29	**86**	0.30	**38**	0.21	**29**	0.13	8	0.13	9.0
Ti	0.02	0.78	0.03	0.69	0.02	0.52	0.02	0.71	0.01	0.59
Ni	**47**	**537**	**38**	**249**	**20**	**82**	**31**	**50**	**33**	**80**
Cu	**63**	**125**	**624**	**641**	**220**	**479**	**88**	**331**	**177**	**258**
Zn	9.0	**192**	21	**612**	5.0	**172**	5.0	**470**	3.0	**241**
Sc	0.54	0.31	0.19	0.89	0.04	0.21	0.11	0.61	0.07	0.69
Pb	**11**	**725**	**31**	**1406**	**18**	**337**	**11**	**602**	**11**	**746**
Cd	**37**	**11263**	**38**	**6728**	**32**	**1635**	**27**	**2541**	**20**	**3481**
Se	**72**	**4624**	**74**	**10414**	**37**	**3693**	**19**	**1865**	**32**	**2763**
As	9.0	**359**	**14**	**677**	7.0	**661**	7.0	**288**	6.0	**614**
Be	0.05	3.0	0.12	3.0	0.25	2.0	0.11	2.0	0.12	2.0
Co	0.89	**31**	1.6	**94**	0.81	7	0.78	**11**	0.82	**12**
Cr	7.0	**155**	**11**	**250**	8.0	**109**	7.0	**70**	8.0	**110**
Hg	**86**	**1352**	**34**	**4843**	**24**	**1809**	**29**	**1295**	**32**	**1065**
Li	0.62	4.0	0.75	9.0	0.78	3.0	0.72	3.0	0.89	3.0
Mo	8.0	**786**	**18**	**1582**	8.0	**118**	7.0	**428**	9.0	**547**
Na	0.23	7.0	0.15	9.0	0.15	9.0	0.12	3.0	0.25	4.0
Sn	7.0	**304**	**11**	**2445**	3.0	**746**	3.0	**461**	7.0	**708**

Table 5. The enrichment coefficient of elements EF_{A-S} in the aerosol with respect to the soil of railway bed (reference element is aluminum)

Chemical element	Natural-territorial complex									
	1st		2nd		3rd		4th		5th	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Si	0.002	0.04	0.002	0.31	0.002	0.01	0.003	0.08	0.008	0.10
Ca	0.38	**1.5**	0.89	**5.5**	0.51	**3.35**	0.67	**5.0**	0.67	**5.25**
Mg	0.07	0.06	0.09	0.16	0.04	0.18	0.32	0.71	**1.1**	**2.5**
K	0.39	**4.7**	**1.2**	**21.55**	0.58	**3.4**	0.78	**4.0**	0.62	**7.65**
Fe	0.09	0.36	0.39	**1.3**	0.10	0.88	0.42	**4.0**	0.29	**6.4**
Mn	0.08	0.78	0.22	**1.7**	0.13	0.94	0.32	**3.0**	0.21	**3.8**
Ba	0.004	***	0.12	***	0.05	***	0.03	***	0.07	***
Sr	0.002	0.19	0.09	0.16	0.05	0.16	0.08	0.16	0.09	0.13
Cs	0.02	***	0.09	***	0.05	***	0.06	***	***	***
P	0.08	**2.5**	0.08	**10.3**	0.08	**1.2**	0.09	**3.3**	0.21	**4.65**
S	0.02	***	0.07	***	0.03	***	0.02	***	0.08	***
Cl	**1.1**	***	**1.9**	***	0.78	***	0.62	***	**2.8**	***
Br	0.02	0.02	0.11	0.13	0.04	0.03	0.03	0.12	0.09	0.29
I	0.03	***	0.12	***	0.03	***	0.01	***	0.03	***
V	0.03	**52**	0.05	**6.45**	0.03	**4.1**	0.02	**1.0**	0.03	**2.0**
Ti	0.02	0.79	0.04	**1.1**	0.03	0.65	0.02	**1.0**	0.01	0.74
Ni	0.51	**6.2**	0.62	**3.85**	0.18	0.72	**1.2**	**2.0**	**4.3**	**10.5**
Cu	0.78	**1.6**	**11**	**11.55**	**6.0**	**13.9**	**11**	**41**	**34**	**50**
Zn	0.29	**5.75**	**1.1**	**32**	0.21	**17.8**	0.42	**33**	0.06	**5.25**
Sc	0.23	0.11	0.11	0.58	0.02	0.11	0.19	0.89	0.53	0.76
Pb	0.02	**1.1**	0.06	**2.9**	0.02	0.39	0.03	**2.7**	0.04	**2.9**
Cd	0.01	**1.65**	0.01	0.90	0.001	0.04	0.005	0.49	0.003	0.57
Se	0.0004	0.03	0.001	0.19	0.001	0.09	0.0001	0.05	0.001	0.10
Co	0.01	0.26	0.029	**1.7**	0.02	0.14	0.031	0.40	0.025	0.36
Cr	0.06	**1.2**	0.15	**3.3**	0.145	**2.0**	0.65	**6.3**	**2.5**	**32.7**
Hg	0.0002	0.004	0.0002	0.03	0.0001	0.01	0.0004	0.02	0.0003	0.01
Mo	0.0002	0.02	0.001	0.09	0.0002	0.003	0.001	0.06	0.001	0.06
Sn	0.001	0.04	0.006	**1.3**	0.002	0.53	0.004	0.55	0.012	**1.2**

Table 4 presents the enrichment coefficients EF_{A-C} of the chemical elements in aerosols relative to clarkes (reference element is aluminum), showing quantitative deviation of each element content from its mean abundance in the earth's crust. Vinogradova et al.[10,11] suggest that the chemical elements in aerosol composition, for which $EF_{A-C} \le 10$, have a natural and, primarily, lithogenic origin. Chemical elements, for which $EF_{A-C} > 10$, may have natural (volcanic eruption, marine aerosol, etc.) or anthropogenic origins.

We analyzed the coefficients of aerosol enrichment EF_{A-S} with respect to the elemental composition of the underlying surface (the soil of the railroad bed in our case). This was motivated by the fact that, during motion of the carriage-laboratory, and especially during passage of trains of the opposite direction, the emission of aerosols from the soil surface sharply increases.

The coefficients of aerosol enrichment EF_{A-S} relative to the railway bed soil are given in Table 5.

Both in summer and winter periods, the largest amount of the chemical elements for which $EF_{A-C} > 10$ was observed in the 2nd NTC (Urals), obviously because of the specific character of this industrial region, having mineral deposits and industrial enterprises, being additional sources of emission of these elements to the atmosphere.

The presence of different sources of emission of the chemical elements to the atmosphere is confirmed by the correlation between mass content of the chemical elements and particle size (Table 6).

The data were obtained in the summer period during synchronous aerosol sampling and measurement of the number density throughout the path by using analyzers of particle size spectrum in the size interval from 0.15 to 15 μm. The results of the measurements of the aerosol particle number density were averaged over the time interval corresponding to sampling of each particle fraction.

From Table 6 it follows that Si, Al, Ca, Mg, K, Mn, Ba, Sr, Cl, Br, and I have a significant coefficient of correlation $K_{cor} > 0.7$ mainly with large particles $d = 0.5$–10.0 μm; Fe, V, Se, Li, Hg, and Sn are correlated with small particles $d = 0.15$–0.5 μm, and Cs, P, S, Ti, Ni, Cd, Co, Cr, Mo, and Na are correlated both with small and large particles.

Table 6. Correlation between disperse and elemental composition of aerosols

Chemical element	Size fraction, μm	Correlation coefficient
Si	0.4–0.5 and 3.0–5.0	0.8–0.9
	0.5–1.0	0.6–0.7
Al	0.2–3.0	0.8–1.0
	3.0–5.0	0.7–0.8
Ca	0.15–0.25	0.8–0.9
	0.25–0.4 and 0.5–1.0	0.74
Mg	0.2–2.0	0.8–0.9
	2.0–3.0	0.73
K	0.25–3.0	0.8–1.0
	0.2–0.25 and 3.0–5.0	0.7–0.8
Fe	0.25–0.3	0.5
Mn	0.2–1.0 and 2.0–3.0	0.8–1.0
	1.0–2.0	0.77
Ba	2.0–5.0	0.8–0.9
	0.4–0.5	0.79
Sr	0.4–5.0	0.8–0.95
Cs	2.0–5.0	0.8–0.9
	0.25–1.0	0.5–0.6
P	0.4–0.5 and 3.0–5.0	0.64
	0.15–0.25 and 0.5–2.0	0.5–0.6
S	0.4–0.5	0.8
	3.0–5.0	0.68
Cl	10.0–15.0	0.77
Br	3.0–5.0	0.66
I	10.0–15.0	0.68
V	0.15–0.2	0.83
	0.2–0.3	0.58
Ti	0.2–1.0	0.9–0.95
	0.15–0.2 and 1.0–2.0	0.7–0.8
Ni	0.15–0.7	0.8–0.95
	0.7–1.0	0.78
Cu	–	–
Zn	–	–
Sc	0.15–0.2	0.8
Pb	–	–
Cd	0.2–0.4	0.8–0.85
	0.5–2.0	0.7–0.8
Se	0.15–0.2	0.53
As	0.2–0.4 and 0.5–1.0	0.9–1.0
	0.15–0.2 and 0.5–1.0	0.6–0.8
Be	1.0–3.0	0.8–0.9
	0.5–1.0	0.5–0.55
Co	0.2–1.0	0.9–1.0
	0.15–0.2 and 2.0–3.0	0.6–0.8
Cr	0.25–3.0	0.8–1.0
	0.2–0.25 and 3.0–5.0	0.7–0.8
Hg	0.15–0.2	0.89
	0.2–0.25	0.65
Li	0.25–5.0	0.8–1.0
	0.2–0.25	0.72
Mo	0.4–1.0	0.8–0.9
	0.2–0.4 and 1.0–5.0	0.6–0.8
Na	0.4–0.5 and 3.0–5.0	0.8–0.9
	0.2–0.4 and 0.5–3.0	0.6–0.8
Sn	0.4–0.5	0.77

Conclusion

Soil of the railroad bed in all NTCs considerably accumulates Sr, Cs, Br, I, Zn, Ni, Pb, Cd, and Se. In summer period, the soil enriches the atmospheric aerosols at least with seven elements (Cs, Br, I, Pb, Cd, Se, and Hg) in all NTCs; additionally enrichment with Ni proceeds in the 1st, 2nd, and 3rd NTCs, with Cu in the 1st NTC, and with Cr, Mo, and Sn in 2nd NTC. In summer period, four elements Br, Se, Hg, and Mo enrich all NTCs; Cd – the 2nd, 3rd, 4th, and 5th NTCs, Ni and Pb – the 1st NTC, and Co – the 4th and 5th NTCs.

Both in soil and in aerosols, the microcomponents have enrichment coefficients pointing to their significant excess there relative to their mean content in earth's crust.

For Fe, Cl, Ni, Cu, Zn, Pb, As, Co, Cr, Mo, and Sn, the degree of aerosol enrichment depends on the NTC. Both in the summer and winter periods, the largest amount of enriched elements is observed in the 2nd NTC (Urals).

Significant correlation dependences are characteristic for the chemical elements, which might arrive to the atmosphere from common sources and are contained in the particles with similar dispersivity.

The presence of different sources of emission of the chemical elements to the atmosphere is also confirmed by the correlation dependence between the mass content of the chemical elements and particle size.

Acknowledgments

This work is performed as part of the ISTC Projects, Nos. 1235, 2773, and 2770.

References

1. L.S. Ivlev, *Chemical Composition and Structure of Atmospheric Aerosols* (Publishing House of Leningrad State University, 1982), 382 pp.
2. V.I. Kudryashov, in: *Problems of Atmospheric Physics, Collected papers of Joint Higher-Education Institutions*, Issue 20, *Physics and Chemistry of Atmospheric Aerosols* (Publishing House of St. Petersburg State University, St. Petersburg, 1997), pp. 97–130.
3. B.I. Ogorodnikov, A.K. Budyka, V.I. Skitovich, and I.V. Borodovoi, Izv. Ros. Akad. Nauk. Ser. Fiz. Atmos. Okeana **36**, No. 2, 163–171 (1996).
4. L.S. Ivlev, V.M. Zhukov, V.I. Kudryashov, and S.N. Pogorskii, Izv. Ros. Akad. Nauk. Ser. Fiz. Atmos. Okeana **25**, No. 4, 128–136 (1989).
5. L.K. Isaev, ed., *Monitoring of Chemical and Biological Environmental Parameters* (Saint Petersburg, 1998).
6. A.V. Andronova, I.G. Granberg, A.M. Grisenko, D.P. Gubanova, B.V. Zudin, M.A. Iordanskii, V.A. Lebedev, I.A. Nevskii, and Yu.I. Obvintsev, Izv. Atmos. Ocean. Phys. **39**, Suppl. 1. P. S27–S34 (2003).
7. L.S. Ivlev, V.I. Kudryashov, and E.M. Arias Vilnueva, *Proceedings of III International Conference "Natural and Anthropogenic Aerosols"* (Publishing House of St. Petersburg State University, St. Petersburg, 2001), pp. 54–67.
8. V.K. Donchenko and L.S. Ivlev, in: *Proceedings of III International Conference "Natural and Anthropogenic Aerosols"* (Publishing House of St. Petersburg State University, St. Petersburg, 2001), pp. 41–52.
9. P.I. Perelman, Geochemistry (Vysshaya Shkola, 1979).
10. A.A. Vinogradova, I.P. Malkov, A.V. Polissar, and N.N. Khramov, Izv. Ros. Akad. Nauk. Ser. Fiz. Atmos. Okeana **29**, No. 2, 164–172 (1993).
11. G.N. Tolmachev, in: *Proceedings of III International Conference "Natural and Anthropogenic Aerosols"* (Publishing House of St. Petersburg State University, St. Petersburg, 1999), pp. 142–151.