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The effect of the tramway track construction on the aerosol pollution in Debrecen, Hungary

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ABSTRACT

In this study the effect of a new tramway track construction on the atmospheric aerosol concentration and composition in Debrecen, Hungary, was investigated. The tramway track construction started in 2011 and it was finished in 2013.

$PM_{2.5}$ and PM_{10} daily samples were collected with a Gent type filter unit in an urban background site 2 times a week. In addition, a sampling campaign direct next to the construction site was performed with 2-stage personal samplers between the 21st and 30th of September, 2011 – four hours a day, during working hours.

We studied the change in concentration and composition of fine and coarse fraction aerosol in comparison with the average of the past 5 years. An additional goal was to investigate the personal aerosol exposure near to the construction sites.

In the urban background site a significant increase could be observed both for the $PM_{2.5}$ and PM_{10} concentrations for 2012 and 2013. In the elemental composition the concentration of Fe, Mn, Ni, and Cr increased significantly for the construction period.

The PM_{10} concentrations measured direct next to the construction site were 10–20 higher than those measured at our urban background site or the data provided by the Hungarian Air Quality monitoring network. Days with very high Pb pollution level (~3000 ng/m^3) was also recorded.

1. Introduction

Atmospheric aerosol pollution is one of the most concerned environmental problems in densely populated urban environments [1]. Atmospheric aerosol particles influence the climate, cause several environmental problems, such as air pollution, acidification of ecosystems, damage to buildings and in addition, they have negative effects on human health [2–7]. In order to regulate the particulate matter (PM) level the EU2008/50/EC directive "On ambient air quality and clean air for Europe" is in force in the member states of Europe, including Hungary, since 2008. However, detailed quantitative information is needed on the sources of PM pollution in order to work out effective mitigation strategies.

The main sources of urban air pollution across Europe were reported as traffic, mineral dust, sea salt and regional scale pollution (e. g. sulphate) [8,9]. However, large and medium scale construction and reconstruction works can have significant influence on the air quality level locally, for months or for years.

In this work we study the effect of a new tramline construction in the city of Debrecen, Hungary which took place between 2011 and 2013.

Debrecen is a second largest city in Hungary with about 200,000 inhabitants. It is situated in the Eastern part of the country 230 km from the capital, Budapest. The city is located between two landscapes Hajdúhát and Nyírség. The main activity is agriculture in the surrounding areas. Debrecen had 6 tramlines from 1884 to 1970, but due to the policy of the communist era these were all destroyed but one. From 1970 to 2014 only one tramline was operating. In 2010 the construction of the second tramline was started which was delivered in 2014. The new tramline construction was started with a press conference in March 2010. The ceremony of the kick-off meeting was in September 2010. Thereafter the construction begun with the excavations. The works were paused in 2012. During the pause plants were growing on the excavated track. The abandoned building debris (sand dunes) was exposed to the changing of the weather (wind and rain). After nearly a year of stagnation the building started again in 2013. The test operation of the new trams started in July 2013. Finally the new track was handed over in February 2014 and the new and modern tramcars

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started their works as well. Parallel to the development of the new track the old tram track was also renewed. The map on Fig. 1 shows the old and new tram tracks. Our urban background station is situated 500 m away from the new tramline, so we had a unique possibility to study the effect of the construction work on the concentration and composition of fine and coarse fraction aerosols in comparison with the average of the past 5 years. With the help of a personal sampler we also investigated the personal aerosol exposure near to the construction sites.

2. Sampling

The aerosol sampling was carried out at two locations. One was the garden of the Atomki which is situated about 500 m from the new tramline (see station no 1 on Fig. 1). Here we collect aerosol samples two times a week since 1988. The samplings were executed with a 2 stage Gent type samplers [10] equipped with Nuclepore polycarbonate filters of 8 μm and 0.4 μm pore diameters. This way two size fractions were separated: the fine fraction

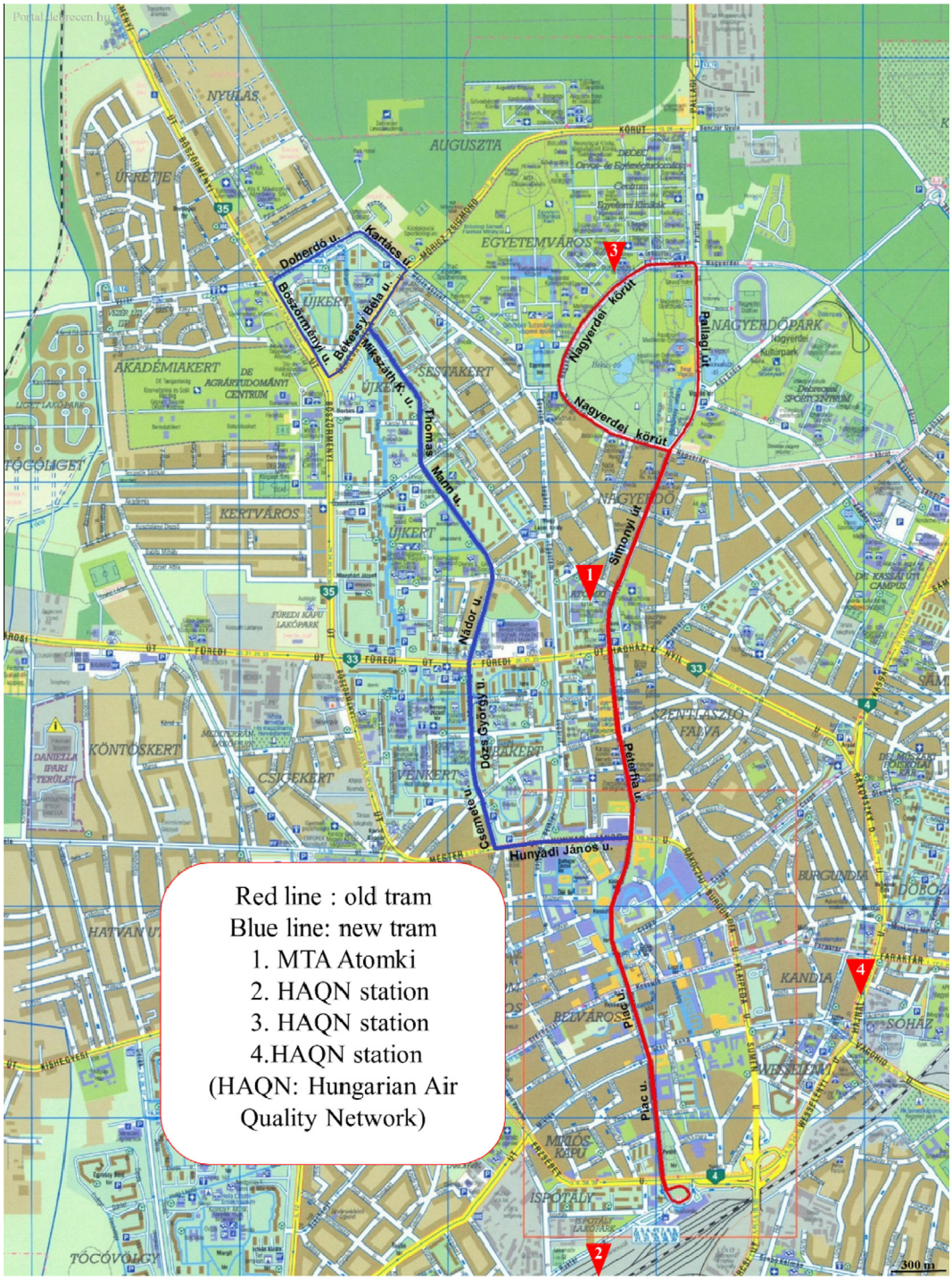

Fig. 1. Map of the track of the old and the new tramlines, and the locations of the sampling sites. Red line: old tramline; blue line: new tramline, (1) sampling station at Atomki (urban background site), (2–4) sampling stations of the Hungarian Air Quality network (2 and 3 are urban background, 4 is a traffic site). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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Table 1
Yearly average PM_{10} concentrations (in $\mu g/m^3$) measured at the 3 stations of the Hungarian Air Quality Network, PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$ annual mean concentrations (in $\mu g/m^3$) measured at the Atomki station, $PM_{2.5}/PM_{10}$ ratios and the annual precipitation (mm) for the years 2006–2014.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
4.HAQN – PM_{10}	34	30	33	28	32	35	29	30	34
2.HAQN – PM_{10}	32	28	30	28	26	33	28	26	26
3.HAQN – PM_{10}	36	28	28	29	30	34	29	27	29
Atomki – PM_{10}	26	24	25	25	16	25	37	21	22
Atomki – $PM_{10-2.5}$	11	11	11	10	7	9	13	7	7
Atomki – $PM_{2.5}$	15	13	14	15	9	15	24	14	14
Atomki – $PM_{2.5}/PM_{10}$	0.59	0.56	0.57	0.58	0.58	0.62	0.65	0.67	0.66
Precipitation	633	551	551	485	845	442	427	545	456

Fig. 2. Monthly average concentrations of $PM_{2.5}$ (a) and $PM_{10-2.5}$ (b) for the years 2006–2014. The dotted line corresponds to the moving average of 3 months.

($PM_{2.5}$: particles with aerodynamic diameter smaller than 2.5 μm) and the coarse fraction (PM_{10}–$PM_{2.5}$: particles with aerodynamic diameter between 2.5 μm and 10 μm). The sampler is installed at 4 m above ground level, on the roof of the IBA Laboratory building.

Table 2
PM mass concentrations measured next to the construction by the personal sampling and the PM_{10} concentrations measured by the Hungarian Air Quality Network stations in 21–30 September, 2011.

	The construction		Hungarian Air Quality Network stations PM_{10}		
	PM_{coarse} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	2HAQN ($\mu g/m^3$)	3HAQN ($\mu g/m^3$)	4HAQN ($\mu g/m^3$)
21.09.2011	269	24	26	28	24
22.09.2011	255	36	45	63	40
23.09.2011	196	36	34	51	26
26.09.2011	283	39	33	48	33
27.09.2011	596	51	45	57	43
28.09.2011	365	43	48	49	28
29.09.2011	584	33	26	24	15
30.09.2011	519	40	28	41	21

The air was pumped through the system with 16–18 l/min flow rate. The total volume of the infiltrated air was measured with a gas-meter. There were no sampling in September and October 2012 due to the reconstruction of the roofs and buildings of Atomki. The other type of aerosol collection was personal sampling. The sample collection was made by walking on the pavement next to the construction on 21–30. September 2011 – four hours a day. The weather was dry and warm on the sampling days. The samplings were carried out with a 2-stage Nuclepore personal sampler equipped with Nuclepore polycarbonate filters with 25 mm diameter and with 8 μm and 0.4 μm pore sizes. Thus the fine ($PM_{2.5}$) and coarse (particles with aerodynamic diameter larger than 2.5 μm) particles were collected separately. For this purpose a Buck Elite personal pump was used. The air was pumped through the system with about 3 l/min flow rate.

3. Analysis

Mass concentration of the PM samples was determined by gravimetry. The polycarbonate filters were weighted before and

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Table 3
Yearly average, minimum and maximum elemental concentrations (in ng/m^3) in fine fraction from 2006 to 2014 at the Atomki.

	2006			2007			2008			2009			2010			2011			2012			2013			2014		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
Al	90	7	365	170	8	670	140	8	735	150	12	490	105	20	440	210	2	730	175	10	515	155	10	1020	140	10	470
Si	150	5	690	200	4	1505	235	9	1000	285	5	1260	95	2	560	280	4	1540	250	4	2950	230	3	3055	210	10	720
P	–	–	–	–	–	–	–	–	–	–	–	–	8	2	55	8	3	60	8	3	30	10	4	30	–	–	–
S	1180	250	3700	1010	215	2870	930	265	3410	980	120	2550	635	15	2685	1290	4	4440	1055	145	5660	830	170	2660	915	15	3020
Cl	10	1	40	10	2	35	12	1	40	7	2	45	5	3	50	8	3	75	6	3	35	10	2	115	6	1	20
K	210	45	750	210	25	745	230	25	795	210	225	460	150	1	655	300	2	1810	260	40	860	210	10	1210	260	4	1405
Ca	65	9	180	100	10	770	110	8	370	110	2	630	40	2	200	110	2	375	95	9	585	95	3	970	80	2	230
Ti	4	‹1	20	6	1	50	7	1	30	9	1	35	3	1	15	10	1	50	9	1	700	7	1	80	7	1	20
Cr	1	‹1	3	–	–	–	1	‹1	5	1	1	8	–	–	–	50	1	100	20	1	40	–	–	–	1	1	3
Mn	2	1	9	3	1	7	3	‹1	9	3	‹1	9	2	‹1	8	7	1	20	3	2	20	3	1	20	3	‹1	10
Fe	110	30	300	140	30	700	160	30	430	140	9	470	70	3	300	320	1	825	175	6	1050	120	4	980	125	1	400
Ni	1	1	3	1	‹1	2	1	1	2	–	–	–	–	–	–	15	6	50	5	1	10	–	–	–	1	1	2
Cu	8	1	65	10	1	60	4	1	40	6	‹1	70	4	‹1	30	10	‹1	60	8	1	100	4	1	30	3	‹1	10
Zn	25	4	170	20	4	110	20	4	120	15	3	65	10	1	50	20	1	160	20	3	90	16	2	80	20	1	100
Br	2	1	5	3	1	40	3	1	9	3	1	10	4	1	20	7	2	20	3	2	7	3	2	6	4	2	8
Ba	5	1	20	5	2	25	6	2	30	5	1	15	3	1	10	3	2	10	–	–	–	6	1	30	5	2	10
Pb	10	2	70	10	1	40	10	3	100	9	2	105	7	2	40	9	2	65	8	3	20	8	1	40	10	1	45

Table 4
Yearly average, minimum and maximum elemental concentrations (in ng/m^3) in the coarse fraction from 2006 to 2014 at the Atomki.

	2006			2007			2008			2009			2010			2011			2012			2013			2014		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
Al	245	20	970	325	20	1090	300	10	1060	180	15	670	290	30	750	410	150	1200	235	30	805	240	4	1090	280	60	720
Si	800	60	3245	870	30	3010	860	50	2950	685	40	2830	535	40	1990	890	7	4890	510	50	2120	490	60	4000	490	40	1530
P	10	3	35	10	2	50	10	2	40	8	2	35	10	2	50	10	5	30	10	3	70	10	‹1	50	10	2	30
S	215	35	1420	170	35	730	210	25	1130	170	35	1385	165	20	500	250	20	1210	150	35	1330	140	30	700	150	25	1370
Cl	40	2	370	45	2	320	75	2	410	55	2	410	45	2	470	35	4	170	35	2	490	30	‹1	310	20	2	120
K	140	30	560	160	30	760	160	30	515	120	20	480	110	15	325	170	15	635	95	10	310	90	15	535	110	20	610
Ca	370	75	1180	440	40	1560	460	30	2570	310	35	1230	250	25	780	360	20	1345	240	40	920	230	40	1550	230	30	760
Ti	20	3	90	20	3	80	20	1	80	20	2	70	15	1	60	25	1	90	15	1	60	10	2	110	15	2	40
Cr	1	‹1	55	1	‹1	3	1	‹1	15	1	‹1	3	1	1	3	30	5	60	15	1	40	2	1	5	1	1	4
Mn	6	1	20	7	1	25	7	1	20	5	1	25	4	0	15	9	1	30	5	2	15	4	1	25	5	‹1	15
Fe	350	80	1150	380	50	1315	380	55	1485	260	40	850	230	20	890	420	40	1440	240	7	790	190	5	1310	230	1	710
Ni	1	‹1	3	1	‹1	4	1	‹1	4	1	‹1	2	1	‹1	3	8	1	20	5	1	15	–	–	–	–	–	–
Cu	8	1	35	9	2	65	6	1	35	4	‹1	20	5	1	45	10	1	90	6	‹1	35	3	‹1	30	1	1	1
Zn	10	2	110	10	3	80	10	2	80	6	2	25	9	1	150	8	1	65	4	1	20	6	1	30	3	1	20
Ba	6	2	20	6	2	20	9	1	75	8	2	30	7	2	50	10	3	40	6	2	25	8	‹1	35	4	1	7
Pb	4	2	25	4	2	40	5	30	2	3	1	15	4	1	35	3	2	20	3	2	6	5	2	10	7	1	20

Table 5
PM coarse and $PM_{2.5}$ elemental concentrations at the construction site by the personal sampling.

	PM coarse (ng/m^3)				PM fine (ng/m^3)			
	Min	Max	Average	SD	Min	Max	Average	SD
Al	2710	9820	5360	±2270	170	460	325	±110
Si	13,600	94,800	35,360	±25,280	655	4720	1600	±1325
P	40	445	190	±120	9	100	20	±30
S	490	1240	780	±2902	440	2720	1430	±730
Cl	380	1020	645	±210	30	550	190	±180
K	2090	6530	3790	±1450	250	550	385	±90
Ca	6960	37,500	17,695	±11,860	320	1850	810	±480
Ti	305	1110	700	±265	15	50	30	±10
V	15	40	25	±10	–	–	–	–
Cr	10	190	90	±50	2	6	3	±1
Mn	105	350	210	±90	10	20	15	±3
Fe	3930	14,400	8205	±3530	310	875	470	±195
Co	15	50	30	±10	4	10	5	±3
Ni	20	50	35	±20	–	–	–	–
Cu	20	70	50	±20	6	35	20	±10
Zn	70	390	125	±110	20	40	30	±8
Br	20	30	20	±5	20	25	20	±3
Sr	50	155	90	±30	–	–	–	–
Ba	150	600	310	±145	20	25	20	±2
Pb	30	470	125	±145	8	3255	420	±1150

after the collection. The filters were conditioned for at least 24 h before weighing in the weighing box at ~25 °C temperature and ~60% relative humidity. The elemental composition of the aerosol samples were measured by particle induced X-ray emission (PIXE) analytical method in the Institute for Nuclear Research, Hungarian Academy of Sciences (ATOMKI). The measurement were performed using the PIXE chamber of the IBA Laboratory installed on the left 45° beamline of the 5 MV Van de Graff accelerator [11]. The irradiation was performed with a H^+ beam of 2 MeV energy. The beam current was usually 20–50 nA and the measurement time was approximately 15–20 min. The accumulated charge was 40 μC on each sample. The obtained X-ray spectra were evaluated with the PIXYKLM program package [12,13]. Concentration of the following elements were assigned: Al, Si, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Cu, Zn, Ba, Pb. The values of the concentration were given in ng/m^3. For calculating the elemental concentration values blank corrections were carried out. The error of the determination of the elemental concentration varied between 3% and 10%, and the detection limit was between 0.2 and 20 ng/m^3, depending on the element and its concentration.

4. Results

4.1. Mass concentration

Table 1 shows the annual average mass concentration of $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10} measured at Atomki, and the annual PM_{10} concentrations measured by the Hungarian Air Quality Network (stations No. 2–4 on Fig. 1) before and after the years of the construction from 2006 to 2014.

The data of the mass concentration and the precipitation are inverse [14–15]. 2010 was an extremely rainy year, therefore the mass concentration was reduced compared to the other years. In 2006 – 2011 we measured lower PM_{10} concentrations in the Atomki than the HAQ at their stations. In 2012, the time of the abandoned work site and of the intensive field work, this tendency was reversed. This increase could be explained by the tramline construction. In addition, the contribution of $PM_{2.5}$ to PM_{10} increased from 56–58% to 62–67% in the years of the construction works. Time series of monthly average $PM_{2.5}$ and $PM_{10-2.5}$ are shown in Fig. 2. In 2006–2011 the seasonal variation the $PM_{2.5}$ concentration shows a maximum in winter and a minimum in summer. In 2012 and 2013 this seasonal trend turned around with summer maximums. Then in 2014 it was again the normal, as before the construction. The concentration of $PM_{10-2.5}$ shows maximums in autumns and springs for the period of 2006–2011. In 2012 and 2013 summer maximums appeared too. In 2014 it was again the same, as before the construction.

In Table 2 we present the $PM_{2.5}$ and PM_{coarse} mass concentrations measured next to the construction site between 21 and 30. September 2011 by the personal sampling. The concentration of $PM_{2.5}$ varied between 24 μg/m^3 and 51 μg/m^3. Although the sampling time was only approximately 4 h, as a comparison we mention that the 24 h limit value of the WHO guideline for $PM_{2.5}$ is 25 μg/m^3 [16].

The concentration of the coarse fraction varied between 196 μg/m^3 and 596 μg/m^3. In the second week of the sampling the concentration values were nearly double as the values measured in the previous week. This can be attributed to the windy weather conditions on the second week. We compared our data with the PM_{10} values measured for the same sampling periods by the Hungarian Air Quality Network at their 3 sampling stations. The distance of these sites were about 4 km from the tramline construction. In every case our values were 8–20 times higher along the construction than the official PM_{10} data at the distant stations.

4.2. Elemental concentrations

For the period of 2006–2014 yearly average, minimum and maximum elemental concentrations are shown in Tables 3 and 4 for the coarse and fine fractions at the Atomki, respectively. Significant changes in the concentration of Cr and Ni could be observed in both size fractions. The concentration of Cr was increased about 40–50-fold in 2011 and about 20-fold in 2012 in both the coarse and the fine fractions. In case of Ni the increase of the concentration was about 8 times in 2011 and 5 times in 2012. The concentration of iron and manganese also increased, although with much less extent. Time series of Cr on the coarse fraction and Fe concentrations on the fine fraction can be seen on Fig. 3. The concentration increase appeared with the start of the field works, there was a significant decrease during the stop, and it increased again – to a lesser extent – for the finishing of the construction. The same tendency was observed in the case of coarse fraction Ni, and fine fraction Mn too. A slight increase (about

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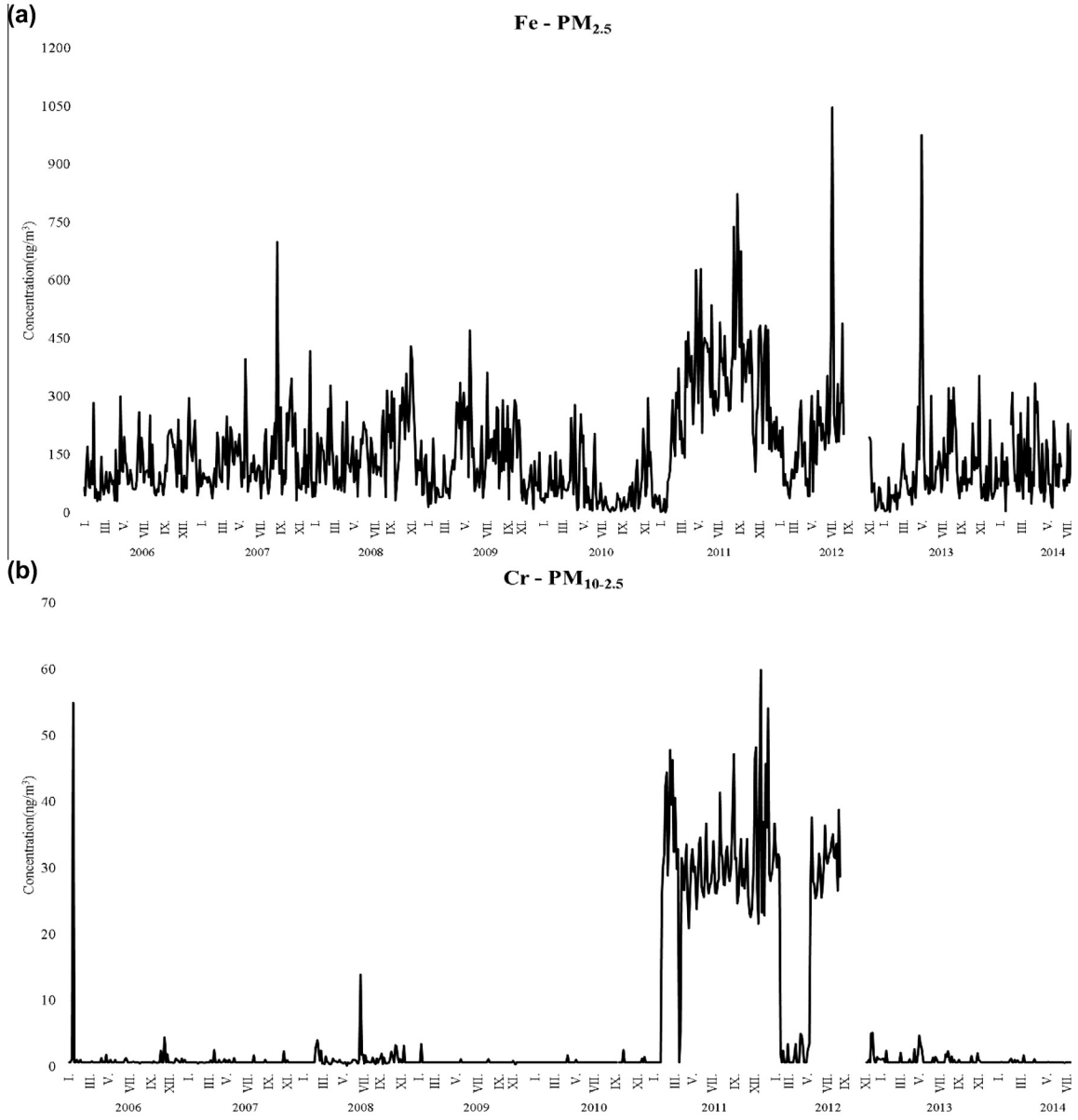

Fig. 3. Variation of Fe concentration between 2006 and 2014 on the $PM_{2.5}$ fraction (a) and variation of Cr concentration between 2006 and 2014 on the $PM_{10-2.5}$ fraction (b).

1.5–2 folds) in the concentration of Cu could be also observed for 2011–2013 in both size fractions. The variation of the other elements were not significant in this period.

Average elemental concentrations, minimum and maximum values are presented in Table 5 for the fine and coarse fractions measured next to the construction site by personal sampling.

In case of the coarse fraction Si and Ca were dominant. High concentration of Al, K, and Fe was also measured. In case of the coarse fraction we measured about 10 times higher elemental concentrations next to the construction than in the Atomki. These elemental concentration increases were 1.5–2 folds in the case of the fine fraction. The composition of the dust next to the construction was similar to the "usual" urban aerosol pollution, only it appeared in much higher concentrations. However, there were few exceptions. *P* is typically natural element but in this case it appeared in the anthropogenic fraction with higher enrichment factor. In the fine fraction the concentration of Pb was usually under detection limit. However, one day, on 26. September we measured extremely high Pb concentration: 3255 ng/m^3. The origin of this is not clear, one working phase could inject this high amount of lead into the atmosphere. In the case of the coarse fraction the Pb/Br ratio was similar to that of the leaded gasoline, thus its origin could be the resuspended dust, despite the fact that leaded gasoline was not used for 15 years.

5. Summary and conclusions

In this study we have investigated the effect of a large scale construction work on urban aerosol pollution in the city of Debrecen, Hungary. We have compared the concentration data measured at several air quality monitoring stations situated at different distances from the construction. At the nearby station we have seen increase in both PM_{10} and $PM_{2.5}$ concentrations, however, at the more distant stations no or negligible effect was detected in the PM_{10}. In addition to the increase of the mass concentration, the contribution of $PM_{2.5}$ increased significantly at the nearby sampling site for the years of the construction work. The seasonal variation of both the $PM_{2.5}$ and the $PM_{10-2.5}$ fractions changed too; it showed summer maximums during the period of the building.

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The elemental composition of atmospheric particulate matter did not change significantly, considerable increase in Mn, Cr, Fe and Ni concentrations was observed in our samples which could be attributed to the railroad building. However, at the construction site occasionally very high concentrations of heavy metals and toxic elements could be measured. In summary we can conclude that the effect of the tramline construction was local, did not expand to the whole city, only to about few streets nearby. However, those who lived or worked next to the construction were exposed to increased $PM_{2.5}$ and PM_{10} levels with high heavy metal contents continuously for years.

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