

The estimation of emission sources of heavy metals of hazardous air pollutants in Hachinohe city

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The estimation of emission sources of heavy metals of hazardous air pollutants in Hachinohe city was described. Cluster analyses and single correlation analyses revealed similar behavior of nickel and chromium and of arsenic and mercury, respectively. By the analyses of correlations between frequencies of wind directions and the concentrations of the heavy metals in air, nickel and chromium were supposed to be emitted from a ferronickel factory and sources of arsenic and mercury were estimated to be a non-ferrous metal smelter and/or a steel factory. Furthermore, by analyzing the chemical compositions of the factory dust samples, arsenic was thought to come from the non-ferrous metal smelter. It also became possible to discuss where emission sources of nickel and chromium were in the ferronickel factory.

Key words :hazardous air pollutants, heavy metals, dust

1. Introduction

In the hazardous air pollutants (HAPs) monitoring in Aomori prefecture, measurements of heavy metals including nickel, chromium, manganese, arsenic, mercury and beryllium have started since 1999 at one site in Aomori city and at two sites in Hachinohe city.

The measurements of HAPs in 1999 were frequently obliged to be carried out in rainy days. When it rains during the measurement of atmospheric heavy metals, the concentrations of atmospheric suspending dust tends to decrease and the concentrations of atmospheric heavy metals are reduced.

In the investigations in 2000, nickel, chromium, manganese, arsenic and mercury were detected at much higher levels than the lowest limits of quantification at the two sites in Hachinohe city from spring to fall. In this season, i.e. from May to September, fortunately it did not rain during investigation periods and we could obtain measurement results without influence of rainfall. From spring to fall, the yamase wind blows in the Hachinohe area. This

yamase wind, which is an east wind, blows in the direction from the seaside where factories are built to a central part of Hachinohe. Furthermore, from May to September, principal wind directions in the investigation periods changed gradually. Namely, in the investigations of HAPs in Hachinohe city from May to September in 2000, no influence of rain existed and the most frequent wind directions shifted successively, thus we were lucky enough to be able to learn of the influences of emission sources in the area. In this paper, analyses of results of the investigations of atmospheric heavy metals of HAPs in Hachinohe city in 2000 are described so as to elucidate emission source factories. Finally, we estimate where emission sources were in the factories, by using results of chemical analyses of factory dust samples which were collected when we inspected the factories.

2. Methods

2. 1 Sites of investigations

The investigations were performed at two sites in Hachinohe city, i.e. Hachinohe primary school and Negishi primary school, once a month with the sampling

1) Drainage facility section, sewerage department of Hachinohe city

period of 24 hours. Locations of the sampling sites and of three principal metal factories are depicted in Figure 1. The factory A is a non-ferrous metal smelter which produces zinc, lead and cadmium. The factory B makes steels and it possesses an electric furnace. The factory C is a ferronickel factory and it had produced stainless steel until 1999.

2. 2 Methods of investigations of HAPs

The atmospheric heavy metals were measured according to manuals for measurements of hazardous air pollutants published by the ministry of the environment in Japan. Detailed materials on the methods of chemical analyses were reported separately¹⁾.

Nickel, chromium, beryllium, manganese and arsenic in the air were collected with high-volume air samplers on quartz fiber filters. Mercury was sampled by a gold-amalgam method. Wet decompositions in the chemical analyses of nickel, chromium and manganese were made with nitric acid, hydrofluoric acid and hydrogen peroxide in pressure vessels. For the analyses of arsenic and beryllium, acid digestions with nitric acid and hydrogen peroxide were done in pressure vessels. The concentrations of nickel, chromium and beryllium in the pre-treated solutions were determined by the method of standard addition

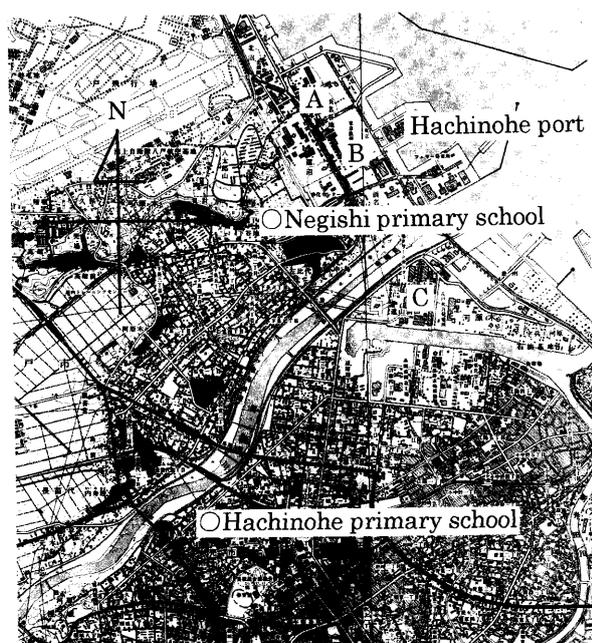


Figure 1 Locations of the sampling sites (○) and three principal metal factories (A, B and C).

of the graphite furnace atomic absorption spectrometry. The concentrations of manganese were measured by the flame atomic absorption spectrometry. The arsenic concentrations were quantified by the hydride generation atomic absorption spectrometry. Atmospheric mercury collected with gold-coated diatomaceous soil was quantified by the heat-gasification atomic absorption spectrometry.

2. 3 Methods of numerical analyses

Analyses of environmental data were carried out by using spreadsheet application add-in programs which were coded by SH and were run on a personal computer. The used add-ins were as follows: add-ins for single correlation analyses, for repeat-summing up and for making graphs on a map, and series of add-ins for statistical analyses. These spreadsheet application add-ins can be freely obtained from a web site²⁾ on the Internet.

2. 4 Methods of chemical analyses of the dust samples of the emission source factories

Dust samples collected in inspections to the metal factories were chemically analyzed with acid digestions. Table I shows the analysis methods. To ca. 50 mg of

Table 1 Methods for chemical analyses of heavy metals contained in factory dust samples.

Element	Used acids and oxidizer in pre-treatments with pressure vessels	Method of instrumental analysis
Ni	HNO ₃ /HF/H ₂ O ₂	Flame atomic absorption spectrometry
Fe		
Zn		
Cd		
Mn		
Cu		
Cr	HNO ₃ /H ₂ O ₂	Hydride generation atomic absorption spectrometry
Pb		
As		

the dust samples were added acids and oxidizer with the same amounts as used in the HAPs analyses.

If hydrofluoric acid is used in wet decomposition, evaporation of acids after the wet digestion is then needed. In some cases, lead was included in some insoluble solids produced after evaporation and these phenomena caused negative errors in the analysis results. Therefore, lead was analyzed by acid digestion without using hydrofluoric acid. Table 1 tabulates the analysis methods for the factory dust.

3. Results and discussion

3. 1 Monthly changes of concentrations of atmospheric heavy metals

(1) Weather conditions in investigation periods

Table 2 is filled with weather conditions in periods of the investigations in 2000. The principal wind directions and averaged wind velocities were calculated by the use of one-hour values of Hachinohe primary school station of the air pollution monitoring system in Aomori prefecture. Some averaged wind velocities were different between the two sites, because starting and ending times of sampling differed.

From May to September, no rains were observed in the investigation periods, thus mass concentrations of suspending dust in the air did not decrease due to rainfall. Furthermore, the principal wind direction changed from May to September just as if it gradually changed through NNE to SW.

(2) Rough trends of concentrations of atmospheric heavy metals

Firstly, in order to understand broad tendencies of concentrations of heavy metals in the air, the monthly changes from May to September when it did not rain during the periods of the investigations are shown in Figure 2.

Nickel and chromium behaved similarly to each other. These had their maximum concentrations in June at Hachinohe primary school, and in August at Negishi primary school, respectively. Furthermore, trends of arsenic and mercury were similar to each other. These concentrations were high in May and June at Hachinohe primary school, and at Negishi primary school the maximum was observed in May. Manganese behaved moderately, between the nickel-chromium group and arsenic-mercury group. Beryllium concentrations were below the lower

Table 2 Weather conditions in investigations of HAPs in 2000.

Month	Hachinohe primary school			Negishi primary school		
	Weather	Principal wind direction	Averaged wind velocity (m/s)	Weather	Principal wind direction	Averaged wind velocity (m/s)
4	Rainy	NE	2.4	Rainy	NE	2.3
5	Fine	NNE	2.1	Fine	NNE	2.1
6	Fine	NE	1.4	Fine	NE	1.4
7	Cloudy	ENE	1.8	Cloudy	ENE	1.9
8	Cloudy	ESE	2.0	Cloudy	ESE	2.1
9	Cloudy	SW	2.3	Cloudy	SW	2.3
10	Rainy	SW	1.6	Rainy	SW	1.6
11	Cloudy	W	3.2	Cloudy	W	3.3
12	Rain	W	4.5	Rain	W	4.5
1	Snowy	W	4.7	Snowy	W	4.8
2	Snowy	WNW	1.6	Snowy	WNW	1.6
3	Snowy	WSW	5.5	Snowy	WSW	5.3

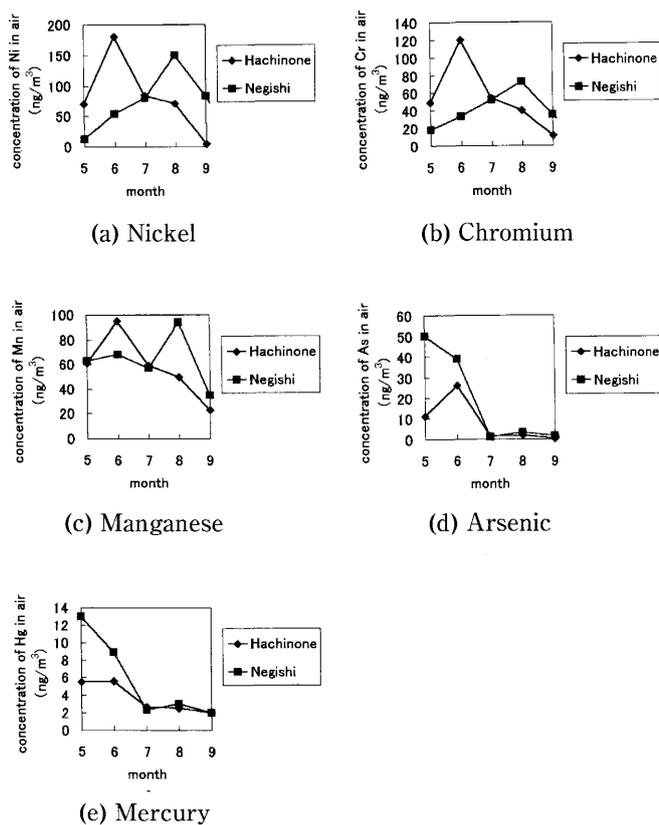


Figure 2 Monthly changes of concentrations of heavy metals in air at two sites, Hachinohe primary school and Negishi primary school.

limit of quantification in the all investigation periods at both sites.

(3) Comparisons of atmospheric heavy metal concentrations with the environmental quality standards in foreign countries

No environmental quality standards of concentrations of these atmospheric heavy metals were published in Japan, but for reference concentrations are compared with the 10^{-5} risk levels of the U. S. EPA etc. Here, breathing air containing pollutants with the concentrations of the 10^{-5} risk levels are estimated to result in not greater than a one-in-a-hundred thousand increased chance of developing cancer, by the use of mathematical models based on animal studies. Therefore, these risk levels should be compared with the annual average concentrations of heavy metals.

In table 3, comparisons of the annual average

Table 3 Comparisons of annual averages of concentrations of atmospheric heavy metals in Hachinohe city in 2000 with environmental quality standards in foreign countries (Units of the concentrations are ng/m^3)

* : Annual average of total chromium concentration
 ** : The risk level for chromium (VI) concentration

Element	Hachinohe primary school	Negishi primary school	Environmental quality standards of foreign countries
Ni	37	34	40
Cr	30*	21*	0.8**
Be	0.017	0.020	4
As	4.4	9.2	2
Mn	37	38	150
Hg	2.7	3.7	1000

concentrations of heavy metals in the air with these risk levels and the other environmental quality standard of foreign countries are made for reference.

In addition, we compare these risk levels etc. with the monthly data. The concentrations of nickel almost exceeded the risk level from May to September. The concentrations of arsenic were much greater than the risk level in May and June. For manganese and mercury, the concentrations did not exceed the WHO European secretariat guidelines. The risk level of chromium is applied to chromium (VI) and the investigations of HAPs reported here measured total chromium, so it was impossible to conclude that the chromium concentrations observed exceeded the risk level.

3. 2 Single correlation analyses

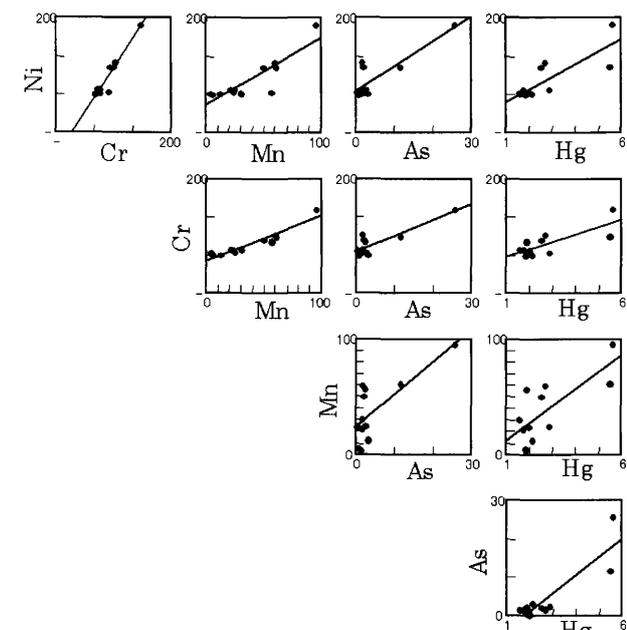
Results of single correlation analyses are

shown in Figure 3. All units used here were ng/m^3 . Here, a solid line indicates that the correlation is significant at a significant level of 5%. Points in common between observed data at Hachinohe primary school and at Negishi primary school were good correlations between nickel and chromium and between arsenic and mercury, respectively. Manganese is highly correlated with chromium in

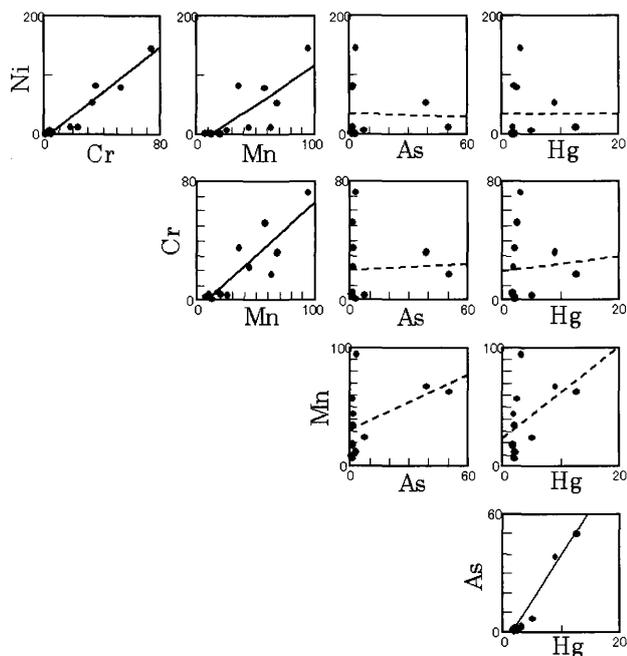
Hachinohe primary school.

3. 3 Cluster analyses

Cluster analyses are of assistance in understanding results of single correlation analyses. The results are shown in Figure 4. These cluster analyses were made on items of pollutants by taking the distance of $1 - |\text{correlation coefficient}|$ based on the Ward method. The longitudinal scales are different in the two graphs. At the both two sites of Hachinohe primary school and Negishi primary school, it turned out that nickel and chromium, and arsenic and mercury made combinations, respectively. These analysis results are equivalent to the results obtained in the single correlation analyses described in 3.2.

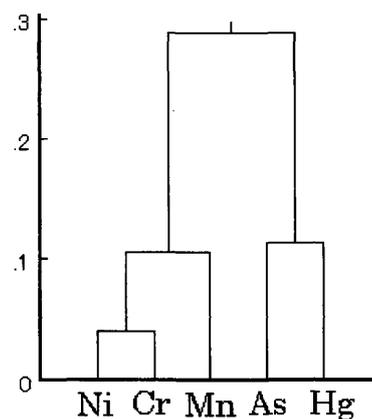


(a) Hachinohe primary school

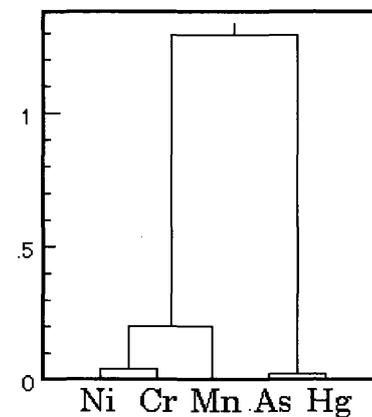


(b) Negishi primary school

Figure 3 Results of single correlation analyses



(a) Hachinohe primary school



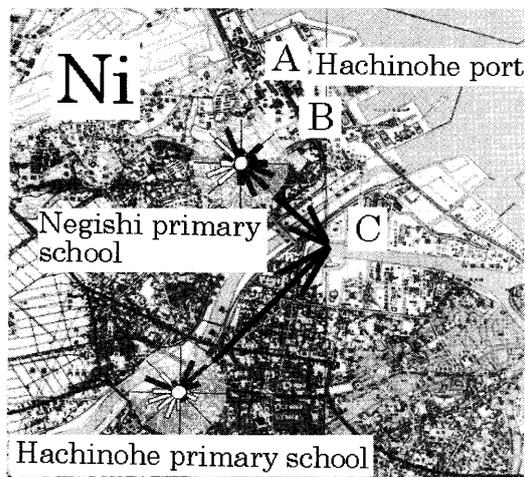
(b) Negishi primary school

Figure 4 Results of cluster analyses

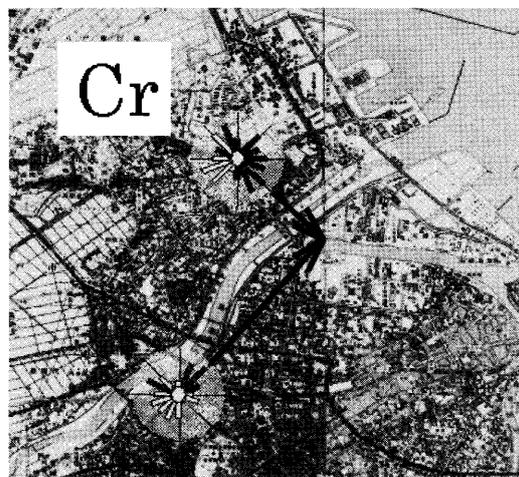
3. 4 Correlations of pollutant concentrations with frequencies of wind directions

Figure 5 shows correlations of pollutant con-

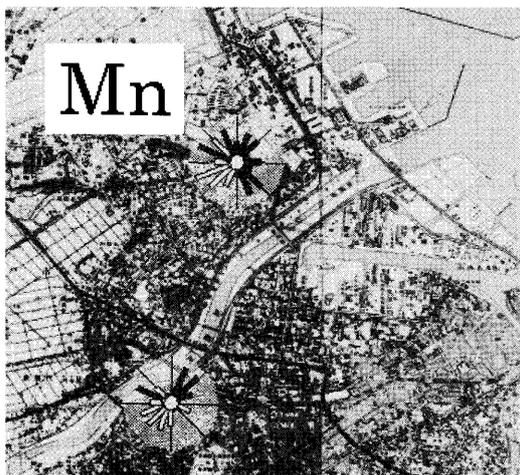
centrations with frequencies of wind directions. The used wind direction data were one-hour values observed at Hachinohe primary school station of the air pollution monitoring system in Aomori prefecture. In Figure 5, a black



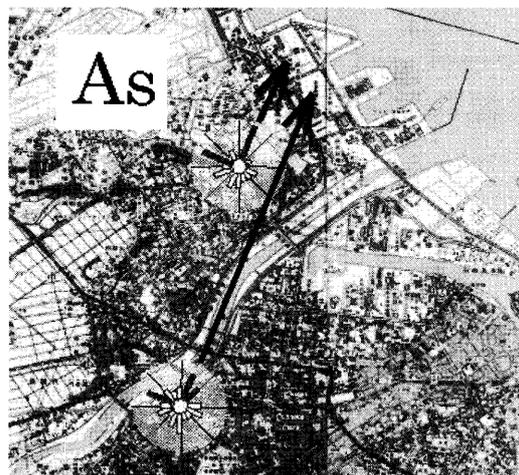
(a) Nickel



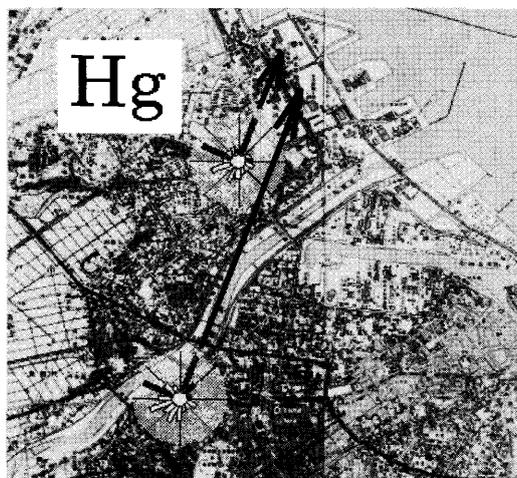
(b) Chromium



(c) Manganese



(d) Arsenic



(e) Mercury

Figure 5 Correlations of frequencies of wind directions and pollutant concentrations

stick inside the circles indicates a positive correlation, and a white stick depicts a negative correlation. The length of the stick represents the absolute values of correlation coefficient.

(1) Estimation of emission sources

In Figure 5, arrows are presented, which show major directions of black sticks indicating positive correlations of pollutants concentrations with frequencies of wind directions. For nickel and chromium, black sticks directed mainly to SW from Negishi primary school and to NE from Hachinohe primary school. These directions were indicated by arrows and these arrows crossed at a site where the ferronickel factory C is built. For arsenic and mercury, the black sticks were directed to NNE from both Hachinohe primary school and Negishi primary school. In this direction, the non-ferrous metal smelter A and the steel factory B are present. Conclusively, emission sources of nickel and chromium are estimated to be in the factory C and of arsenic and mercury in the factory A and/or factory B.

(2) Land breezes in the yamase season

In the yamase season when the yamase wind blows from the sea, the land breeze sometimes blows from the sea to the land at night. This phenomenon was sometimes observed in periods of investigations of HAPs in 2000, when in the daytime the yamase blew from the sea to the land and at night the land breeze blew in the other direction. When the yamase wind brought pollutants with the high concentrations from the seaside area in the daytime and at night the land breeze blew, an emission source would seem to exist also at the direction of the land breeze in a correlation graph of frequencies of wind directions and concentrations of pollutants. This phenomenon is, for example, presented in Figure 5 (a) where a black stick is drawn in the direction of WNW from Hachinohe primary school. If one discusses correlation of wind directions and concentrations of pollutants only by the use of principal wind direction, one cannot consider details of the wind. Thus it is necessary to discuss the problem by utilizing one-hour values of wind directions, although the phenomenon of the land and sea breeze does not always make the corre-

lation clear.

In the direction of WNW guided by the black stick in Figure 5 (a) no emission sources, e.g. metal smelters, exist. Because of the land breeze at night, one would think that some emission sources were in the direction.

3. 5 Results of chemical analyses of dust samples of factories and ensuing discussion

Table 4 tabulates results of chemical analyses of dust samples of the factories. The dust samples are as follows: dust samples on bag filters in the smelting processes, ores and slag of the factory A, dust collected by the electrostatic precipitator (EP) and dust accumulated inside a building of the factory B, and ores, slag, dust generated in the smelting processes of the factory C.

(1) Arsenic

Dust, ores and slag of the factory A contain much arsenic and zinc sulfide ores (sphalerite, ZnS) which are main raw materials in the factory include 0.075% of arsenic. The arsenic contents of dust of bag filters attached to the blast furnace and of dust of bag filters of the zinc distillation column were 0.30% and 0.48%, respectively. In the smelting process, arsenic proved to be concentrated in the dust. On the other hand, dust of the factory B contained rare arsenic. It became clear on the bases of the chemical analyses of the factory dust that the factory B was not an emission source of arsenic but the factory A was, although both the factory A and B had possibilities of their being emission sources when we interpreted only the results of correlations of frequencies of wind directions and concentrations of the pollutant as mentioned before.

If all ambient suspending dust had been consisted of dust of the zinc distillation column, 480 ng/m³ of arsenic would have been detected at the ambient site in the case where mass concentration of ambient suspending dust was 100 μg/m³. In turn, only the zinc sulfide ores had contributed to ambient suspending dust, 75ng/m³ of arsenic would have been observed in ambient air in the above case. The observed maximum concentration of arsenic in Negishi primary school was 50 ng/m³ and this observation was not

Table 4 Results of analyses of chemical compositions of the factory dust samples (%)

Factory		Ni	Fe	Pb	Zn	Cd	Mn	Cu	Cr	As
A	Dust collected by bag filters of the decopperizing furnace	0.23	3.6	48	12	0.0017	0.0015	7.7	<0.003	0.045
	Dust collected by bag filters of the crusher of the sinter plant	<0.02	7.7	32	27	0.68	0.2	0.71	0.013	0.17
	Dust collected by bag filters of the briquetting plant	0.02	2.7	17	48	0.032	0.3	0.19	0.02	0.087
	Dust collected by bag filters of the blast furnace	<0.02	0.91	26	39	0.056	0.074	0.16	0.005	0.3
	Dust collected by bag filters of the zinc distillation column	<0.02	0.26	1.8	55	2.5	0.023	0.068	<0.004	0.48
	Lead oxide ores	<0.02	0.14	63	3.2	0.091	0.0096	0.048	<0.004	0.0005
	Lead sulfide ores	<0.02	4.6	57	10	0.13	0.003	0.052	0.02	0.037
	Zinc oxide ores	<0.02	0.83	2.5	78	0.045	0.061	0.024	0.036	0.004
	Zinc sulfide ores	<0.02	12	2.1	48	0.15	0.76	0.24	<0.002	0.075
	Slag	0.04	29	0.1	6.6	0.0003	0.96	0.7	0.062	0.1
B	Dust collected by the electrostatic precipitator	0.02	23	2	33	0.048	1.2	0.21	0.21	0.0016
	Dust deposited inside the factory building	0.02	12	0.29	4	0.0056	3.6	0.098	0.056	0.0017
	Dust deposited under the EP attached on the roof of the factory	0.02	17	2.1	29	0.042	1.2	0.18	0.12	<0.0002
C	Dust generated in the kiln	2.2	18	<0.005	0.048	0.0039	0.37	0.0036	0.35	<0.0001
	Dust generated in the impact drier	2	14	0.16	1.1	0.0082	0.27	0.004	0.27	0.0007
	Dust generated in working environment	2.6	16	0.13	1.8	0.0043	0.29	0.0067	0.48	<0.0002
	Nickel ores	1.7	16	<0.007	0.014	<0.0003	0.29	0.001	0.16	<0.0002
	Slag, brown	0.04	2.8	<0.007	0.022	<0.0004	0.23	<0.001	0.36	<0.0002
	Slag, colorless	0.03	3.5	<0.006	0.033	<0.0003	0.35	<0.0008	0.63	<0.0002

unreasonable if the dust of factory A scattered. Furthermore, the arsenic contents in the factory dust increased in the course of smelting, so it will be needed to investigate the arsenic concentrations in the exhaust gasses

of the factory A.

Two kinds of dusts existed which could be emission sources of arsenic. The first kinds included the zinc sulfide ores and the second were dust generated in the

smelting processes. The formers become coarse particles, and the latter fine particles which are generated via high-energy states. In order to know where emission sources of arsenic are in the factory A, investigations will be effectively carried out using Andersen air samplers by which one can collect ambient suspending dust samples with distinctions of the particle sizes.

In a previous paper ³⁾, it was demonstrated that dust of the zinc sulfide ores of the factory A contributed significantly to dust fall around the metal factory area in Hachinohe city although the source estimation was performed on the basis of the contents of nickel, lead, zinc and cadmium. This result is adequate only near the factory A and is not always possible to apply to the case of areas around Hachinohe primary school and around Negishi primary school at which the investigations reported in this paper were made. Actually, for zinc, lead and cadmium, dust samples of fine particles contributed to some extent in areas being apart from the metal factories as reported before ⁴⁾ in which investigations were done on the metal concentrations in the air with distinctions of dust particle diameters by the use of Andersen air samplers. This result was obtained in the past, but it should be a problem whether coarse particles or fine particles contribute to the ambient air, depending on a distance from factories to the investigation area.

Additionally, measurements of arsenic were not made in investigations of dust fall because dust falls must be analyzed after ashing and also because arsenic tends to vaporize at low temperature.

However, the zinc sulfide ores of the factory A significantly contributed to the metal contents in dust fall observed in an area around the factory A, and the ores contain no less than 0.075% of arsenic. Furthermore, the concentration of ambient atmospheric arsenic was observed to be 50 ng/m³ at most at Negishi primary school and this observation was possible viewed in the light of the arsenic content of the ores. The correlation of these three facts cannot be ignored.

(2) Nickel and chromium

As describing before, emission sources of nickel and chromium were estimated to be in the factory C.

Results of chemical analyses of the factory dust samples revealed that dust of the factory C included nickel with the content of a few percent. Therefore, it can be easily said that an emission source factory of nickel is the factory C. The chromium contents in dust of the factory B were not so little, but colorless slag of the factory C had the highest content. But the slag included rare amounts of nickel.

Ratios (Ni/Cr) of concentrations of atmospheric nickel to those of chromium in ambient air were from 1.3 to 1.4. On the other hand, no dust of the factory C included amounts of nickel and chromium having the ratios within this range. The dust of the factory C which were seen to have the same chemical compositions as those of the nickel ores of the factory had ratios (Ni/Cr) being in the range from 8 to 10. On the contrary, the slag contained nickel and chromium at ratios (Ni/Cr) of 1/10 to 1/20. The nickel and chromium contents of the dust of the factory C whose chemical compositions were similar to those of the ores were 2.6% and 0.48% at most, respectively. If only these dust samples constituted ambient suspending dust, 2600 ng/m³ of nickel and 480 ng/m³ of chromium would be detected in ambient air in the case where the mass concentration of suspending dust was 100 μg/m³. On the other hand, the colorless slag of the factory C, which had the considerable content of chromium, included 0.03% of nickel and 0.63% of chromium. If the slag entirely contributed to ambient suspending dust, the nickel and chromium contents in ambient air whose suspending dust had the mass concentrations of 100 μg/m³ were 30 ng/m³ and 630 ng/m³, respectively. Although emission sources of nickel and chromium are estimated to be in the same place, i.e., in the factory C as mentioned in the before section, nickel is postulated to have come from dust of the factory C which had the similar chemical compositions to those of the nickel ores used in the factory. For chromium, ambient air includes sufficient amounts of chromium when the dust of the factory C scatter whose chemical compositions resembled to those of the nickel ores, but the observed ratios of concentrations of nickel to those of chromium in the air cannot be explained. If only these dusts were emitted, ambient atmospheric chromium had to be detected to be in smaller concentration than that of actually observed. On the contrary, the dust generated from the slag of the factory C

does not give sufficient concentrations of nickel in ambient air, but does give sufficient concentrations of atmospheric chromium to understand the observed concentrations. An emission source factory was of course the factory C, but nickel is assumed to come from the dust having similar chemical compositions to those of the nickel ores, and an emission source of chromium is postulated to be the slag. The factory C had produced stainless steel until 1999, but influences of factory dust of those days cannot be confirmed at the present time even if the dust effect now.

(3) Manganese

Dust of the factory B had considerable contents of manganese although ambient manganese is estimated to be emitted from various sources as described before by the use of the results of analyses of correlation of frequencies of wind directions and pollutant concentrations. It should be difficult to decide emission sources since manganese also comes from soil which contains this element to some extent.

4. Conclusions

Results obtained in investigations of hazardous air pollutants in Hachinohe city in 2000 were analyzed.

Firstly, at both two investigation sites, the behaviors of nickel and chromium, and of arsenic and mer-

cury turned out to be similar to each other, respectively.

Correlations of frequencies of wind directions and pollutant concentrations in ambient air revealed that nickel and chromium are estimated to come from a ferrous nickel factory C and that arsenic and mercury are considered to be emitted from a non-ferrous metal smelter A and/or a steel factory B.

By interpreting results of analyses of chemical compositions of factory dust samples, an emission factory of arsenic became the factory A. Zinc sulfide ores which were main raw materials of the factory A contained 0.075% of arsenic. Furthermore, the dust generated in the smelting processes in the factory A contained more arsenic. These arsenic contents of the dust of the factory A could explain the observed concentrations of ambient atmospheric arsenic. Emission sources of nickel and chromium were thought to be in the factory C. However, these elements could not be derived from a single kind of dust. That is, nickel was postulated to come from the dust of the factory C which had similar chemical compositions to that of the nickel ores used in this factory. An emission source of chromium was assumed to be the slag of this factory. Thus, for nickel and chromium, different kinds of sources were supposed to be in the factory C. The above results are summarized in Table 5.

Interpretations of both the results of analyses of ambient pollutant concentrations and chemical compositions of the dust samples of the emission factories enabled

Table 5 Results of the estimations of emission sources of atmospheric heavy metals in Hachinohe city

Element	From the analyses results of correlation of frequencies of wind directions with pollutant concentrations	From the results of analyses of chemical compositions of factory dust samples	Emission sources estimated by means of both of the two methods
Ni	Factory C	Dust of factory C whose compositions resemble to those of nickel ores used in factory C	Dust of factory C whose compositions resemble to those of nickel ores used in factory C
Cr	Factory C	Slag of factory C	Slag of factory C
As	Factory A and/or B	Dust and/or raw materials used in factory A	Dust and/or raw materials used in factory A
Hg	Factory A and/or B	Obscure from the results of the analyses of the factory dust	Factory A and/or B
Mn	Various emission sources influenced.		

us to estimate emission sources in detail to such an extent that emission places in the factories could be assumed.

The aforementioned analysis methods and their results are exceedingly effective in the promotion of environmental conservation measures in the future.

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(要約)

八戸市内における有害大気汚染物質（重金属類）の発生源の推定

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これまでの青森県における有害大気汚染物質モニタリング調査で明らかになった、八戸市内の重金属類の発生源推定について述べる。クラスター分析や単相関解析から、ニッケルとクロム、水銀とヒ素がそれぞれ同一挙動を示すことが分かった。また風向頻度と汚染物質濃度との相関を解析すると、ニッケルとクロムがフェロニッケル製造工場、ヒ素と水銀が非鉄金属製錬工場あるいは鉄鋼業工場が発生源と推定された。さらに、発生源と考えられる工場のダスト類の分析結果から、ヒ素は非鉄金属製錬工場に由来する可能性が濃厚になった。また、ニッケルとクロムの発生源がフェロニッケル製造工場のどこにあるのかを考察した。

- 1) 八戸市下水道部下水道施設課