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Review

Lead and Cadmium Levels in the Atmosphere in Mainland China: A review

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Abstract: Lead and Cadmium Levels in the Atmosphere in Mainland China: Zuo-Wen ZHANG, *et al.* Department of Public Health, Kyoto University Faculty of Medicine—The 1984–1997 retrieval of Chinese papers yielded 16 reports on the lead (Pb) and cadmium (Cd) levels in air of the general environment in Mainland China, in which Pb and Cd levels were reported in 29 and 10 cases, respectively. The reported values are scattered over a wide range of 0.08 to 2.69 μg/m^3 for Pb and 0.001 to 0.07 μg/m^3 for Cd. The combination of high-volume air sampling and atomic absorption spectrometry (either graphite furnace or flame) was the common method. Difference in sampling sites within the same study region and seasonal changes are among the factors identified to induce variation. No substantial difference was detected among regions with various degrees of urbanization, and trends over recent years were not remarkable both in Pb and in Cd levels. The grand geometric mean for Mainland China was thus estimated to be 0.25 μg/m^3 for Pb and 0.01 μg/m^3 for Cd. These values appear to be several times higher than those reported for Japan (i.e., 0.01 to 0.08 μg/m^3 for Pb and 0.001 to 0.003 μg/m^3 for Cd).
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Key words: Air in general environment, Cadmium, Lead, Mainland China

Workers in a factory may be exposed to various toxic chemicals in workroom air when they are inside a plant, but they are exposed to pollutants by breathing the air in the general environment for an even longer period once they are outside of the plant, e.g. at home or in the community. In addition, they are exposed to hazardous compounds via food so that non-occupational background exposure of people to toxic chemicals is basic information necessary for the evaluation of occupational exposure.

Lead (Pb) and cadmium (Cd) are two toxic metals widely used in industry and also ubiquitous in the general environment[1–5]. The discharge of these metals into the general environment in association with industrial activities or through the use of leaded fuel often results in the pollution of surrounding communities[2, 4–6]. Both metals are persistent not only in the environment but in the human body once absorbed, and have half-lives in the order of years or even longer[2, 4].

China is among rapidly industrializing countries, especially since economic reform started in 1979. Accordingly, it is quite conceivable that pollution of air in the general environment (or the atmosphere) by metals, and Pb in particular, should be the focus of public health attention. Whereas information on metal exposure via foods (e.g., Zhang *et al.*[7]) has been coming out, counterpart information on the levels in the atmosphere is less easily obtained partly because of the language barrier.

Recently we had the opportunity to obtain and review Chinese articles which report Pb and Cd concentrations in the atmosphere in Mainland China. In this communication, we summarize the available information on Pb and Cd levels in the atmosphere in the years around 1990, expecting that the summary will be a basis for comparison with the levels in the years to come and will form a reference point for the evaluation of the impact of industrial development on the environment in Mainland China.

Materials and Methods

Information sources

By means of the Chinese Medico-biological Article Database, literature retrieval was carried out for scientific articles reporting Pb and Cd levels in the atmosphere during a period from of 1984 to 1997. Altogether, 16 reports[8–23] were sorted out. Because these articles usually describe the method only briefly, the descriptions were supplemented by three methodology reports[24–26] for details of the methods employed.

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Statistical analysis

The arithmetic mean (AM) and arithmetic standard deviation (ASD) were calculated when normal distribution was assumed, whereas the geometric mean (GM) and geometric standard deviation (GSD) were obtained when it was more appropriate to consider log-normal distribution. One way analysis of variance (ANOVA) was employed to detect differences among means, and regression analysis to examine trends over years.

Results

Lead and cadmium levels in the atmosphere

The major findings in the reports on Pb[8–22] are summarized in Table 1 in terms of the year of sample collection, collection times within a year, methods used for Pb determination, and the metal concentrations observed etc., in addition to the references. Information on some items (e.g., the year of sample collection) was however not always available. When two or more reports were available for one region, they were arranged in the order of year of publication. A similar summary on Cd[9, 13, 15, 23] is presented in Table 2. The results are classified in both tables by the degree of urbanization such as two metropolises of Beijing (the national capital) and Shanghai (the largest city in Mainland China), capitals of Provinces, and others. Pb and Cd levels in the atmosphere in Japan[24, 25] are also given in Tables 1 and 2 for comparison.

The styles of the presentation of the concentrations were various; some authors reported the results just in values or a range, whereas others gave AM ± ASD or GM (GSD). Nevertheless the overall distribution of the reported values is in the range of 0.03 to 2.8 μg/m^3 for Pb (Table 1) and 0.001 to 0.07 μg/m^3 for Cd (Table 2).

Methods used in reports for determination of lead and cadmium

It appears likely that collection by high volume air sampling was the commonest method, and it was described explicitly in some papers but not in others. The methods for metal analysis varied. As early as 1979, a study group (most probably a national team), recommended graphite furnace atomic absorption spectrometry (GFAA) both for Pb and for Cd analysis together with the colorimetry with the dithizone method for Pb[26]. In an agreement with this recommendation, atomic absorption spectrometry (AA) has been identified as a national standard method for metal analysis since 1990[27]. In a recent publication, Cui *et al.*[28] introduced AA methods (both flame and graphite furnace) as the first item in the description of various methods for Pb and Cd determination.

In practice, some researchers (e.g., Song *et al.*[10]) used graphite furnace AA (abbreviated as GFAA in Table 1) and others (e.g., Qiu *et al.*[13] and Li *et al.*[8]) used flame AA (or FlAA), whereas the remaining stated only the use of AA without specifying the type of the AA instrument (e.g. Cao *et al.*[9]). In exceptional cases, use of colorimetry by the dithizone method[18] or voltammetry[12] was also reported.

Factors to be considered in evaluating the reported values

In evaluating the results reported, variations in the sampling location and the sampling time of year are among the factors to be considered. Thus, Tong *et al.*[14], Li *et al.*[17], and Gao and Deng[20] described that Pb levels in the atmosphere of a single city can vary (with a 6 or more times difference) depending on the air sampling site (Table 3). The levels were highest in the industrial area of the city or the area with heavy traffic as expected, followed by that in the residential area and were lowest in the surrounding suburbs. It is quite conceivable that Pb emissions from industries and due to the use of leaded automobile gasoline should be substantial sources. No data were available however on sampling location-dependent variation in Cd levels in the atmosphere.

Another point worthy of attention is the seasonal variation. According to Qiu *et al.*[13] and Yang and Ma[17], the Pb levels in Harbin and Taiyuan, respectively, were more than two times higher in winter than in summer, especially in the center of the city. The seasonal variation was substantially less in the case of Cd[13]. Cao *et al.*[9] reported that they measured Pb and Cd in the atmosphere in Beijing and Shanghai in each of the four seasons. Unfortunately, no data for each season but only annual averages were given in their paper.

Possible variation in lead and cadmium levels by degree of urbanization

In order to compare the Pb and Cd levels in the atmosphere of metropolises, provincial capitals and others, representative values were identified in each report. Subsequently, the arithmetic means were calculated when values were given for different seasons of the year. In cases a range of values was given in which the lower value was for residential or 'clean' areas and the higher value was for the areas with possible industry-attributable pollution, the lower value was taken. The values thus selected for individual reports were subjected to statistical evaluation.

Calculation of AM ± ASD (Table 5) showed that ASD was often larger than AM, suggesting that the assumption of normal distribution was not applicable. Accordingly, GM and GSD were also calculated with an assumption of log-normal distribution.

Possible longitudinal trends in Pb and Cd levels

It would be informative if the long-term trends over recent years in Pb and Cd levels could be analyzed. Unfortunately, however, the number of reports available for any one region is quite limited, e.g., in the case of Pb in the atmosphere, three reports for Beijing[8–10] and two reports for Shanghai[9, 11], Harbin[11, 13], Hefei[11, 14],

Table 1. Lead levels in the atmosphere

Study region (Prov.[a])	Study year	Method[b]	Sampling time	Pb (μg/m³) Reported	Repr.[c]	Reference
Metropolises						
Beijing	-	FlAA	NS	0.06-0.98[d]	0.06	8
Beijing	-	AA	4 seasons[e]	0.54 (0.51)[f]	0.54	9
Beijing	-	GFAA	NS[g]	0.11-0.36	0.24	10
Shanghai	-	AA	4 seasons	0.23 (0.18)[f]	0.23	9
Shanghai	-	NS	NS	0.2-0.4	0.3	11
Provincial capitals						
Fuzhou (Fujian)	-	VOLT[h]	NS	0.9	0.9	12
Hangzhou (Zhejiang)	-	AA	Heat-Nonh[i]	0.51 (0.48)[f]	0.51	9
Harbin (Heilongjiang)	-	NS	NS	0.13-0.36	0.25	11
Harbin (Heilongjiang)	’90	FlAA	4 seasons	1.77-3.60	2.69	13
Hefei (Anhui)	-	GFAA	NS	0.03-0.24[j]	0.03	14
Hefei (Anhui)	-	NS	NS	0.24	0.24	11
Jinan (Shandong)	-	NSTD[k]	NS	0.22	0.22	15
Nanjing (Jiangsu)	-	NSTD	NS	1.59	1.59	15
Nanjing (Jiangsu)	’83-4	NSTD	NS	0.1-1.7[d]	0.1	16
Shenyang (Liaoning)	’83	NSTD	NS	0.6-13.7[d]	0.6	16
Shenyang (Liaoning)	’84	NSTD	NS	0.6-8.3[d]	0.6	16
Taiyuan (Shanxi)	-	AA	Heat-Nonh	0.21 (0.19)[g]	0.21	9
Taiyuan (Shanxi)	’91	AA	S-W[k]	0.113	0.113	17
Xian (Shaanxi)	-	NSTD	S-W	0.11-0.25[l]	0.18	15
Others						
Antu (Jilin)	-	COL[m]	NS	0.16 ± 0.01	0.16	18
Baoding (Hebei)	-	AA	NS	0.0078	0.0078	19
Baoji (Shaanxi)	-	GFAA	NS	0.03-0.14	0.09	20
Guichi (Anhui)	’88	NS	NS	1.14	1.14	21
Taiyuan, suburbs of (Shanxi)	’91	AA	NS	0.11-0.13	0.12	17
Shaoguan (Hunan)	-	NS	NS	0.10-0.39[d]	0.10	11
Unknown village (Hubei)	-	GFAA	NS	2.80 ± 0.60	2.80	22
Yimeng (Shandong)	’83-4	NSTD	NS	0.4-11.2[d]	0.4	16
Yulin (Guangxi)	-	NS	NS	0.11	0.11	11
Zibo (Shandong)	-	AA	Heat-Nonh	0.36 (0.23)[f]	0.36	9
Japan	’93	RAA[n]	Ann Av[o]	0.010-0.081		24
Japan	’96	RAA	Ann Av	0.013-0.081		25

[a] Province; Beijing and Shanghai are administratively at the level of Provinces.
[b] Sampling was by means of high volume air sampling. AA: Atomic absorption spectrometry (graphite furnace or flame not identified). GFAA: Graphite furnace atomic absorption spectrometry. FlAA: Flame atomic absorption spectrometry.
[c] Repr.: Representative value. For selection procedures, see the Major Findings section.
[d] Concentrations in control areas - those in polluted areas.
[e] Once in each of four seasons; the average is given.
[f] The concentration in total suspended particles [that in suspended particulate matter (ϕ<10 μm) in parenthesis].
[g] Analytical method or sampling time of the year not stated.
[h] Volt.: Voltammetry.
[i] Once each in the seasons with room-heating and in the seasons without room-heating; the average is given.
[j] Concentrations in clean areas - that at heavy traffic intersections.
[k] NSTD: National Standard Method for Air Quality Monitoring[26].
[l] Summer - winter.
[m] COL: Colorimetry by the dithizone method.
[n] RAA: Radioactivation analysis.
[o] Annual average.

Table 2. Cadmium levels in the atmosphere

Study region (Prov.[a])	Study year	Method[b]	Sampling time	Cd (μg/m³) Reported	Repr.[c]	Reference
Metropolises						
Beijing	-	AA	4 seasons[d]	0.031 (0.026)[e]	0.031	9
Shanghai	-	AA	4 seasons	0.071 (0.057)[e]	0.071	9
Provincial capitals						
Harbin (Heilongjiang)	’90	FlAA	4 seasons	0.065-0.085	0.075	13
Jinan (Shandong)	-	NSTD[f]	NS[g]	0.0035	0.0035	15
Jinan (Shandong)	-	NS	NS	0.0035	0.0035	23
Nanjing (Jiangsu)	-	NSTD	NS	0.0096	0.0096	15
Nanning (Guangxi)	-	NS	NS	0.0037	0.0037	23
Taiyuan (Shanxi)	-	AA	Heat-Nonh[h]	0.037 (0.033)[e]	0.037	9
Xian (Shaanxi)	-	NSTD	S-W[i]	0.0008-0.0017[i]	0.0013	15
Xian (Shaanxi)	-	NS	NS	0.0013	0.0013	23
Other						
Zibo (Shandong)	-	AA	Heat-Nonh	0.059 (0.053)[e]	0.059	9
Japan	’93	RAA[j]	Ann Av[k]	<0.0005-0.0026		24
Japan	’97	RAA	Ann Av	<0.0005-0.0029		25

[a] Province; Beijing and Shanghai are administratively at the level of Provinces.
[b] Sampling was by means of high volume air sampling. AA: Atomic absorption spectrometry (graphite furnace or flame not identified). GFAA: Graphite furnace atomic absorption spectrometry. FlAA: Flame atomic absorption spectrometry.
[c] Repr.: Representative value. For selection procedures, see the Major Findings section.
[d] Once in each of four seasons; the average is given.
[e] The concentration in total suspended particles [that in suspended particulate matter (ø<10 μm) in parenthesis].
[f] NSTD: National Standard Method for Air Quality Monitoring[26].
[g] Analytical method or sampling time of the year not stated.
[h] Once each in the seasons with room-heating and in the seasons without room-heating; the average is given.
[i] Summer - winter.
[j] RAA: Radioactivation analysis.
[k] Annual average.

Table 3. Atmospheric lead levels by various parts in cities

City	Lead in air (μg/m³) in Suburbs	Residential area	Ind./Heavy traf. area[a]	Reference
Baoji	0.025	0.048	0.074–0.144	20
Fuzhou	0.21–0.23		0.9–1.2	12
Unknown[b]		0.025	0.236	14

[a] Industrial or heavy traffic areas.
[b] An unknown town in Anhui Province.

Nanjing[15, 16], Shenyang[16] (two year data in one report) and Taiyuan[9, 17]. It should be noted that the sampling as well as analytical conditions may not be comparable in all the reports. Nevertheless, simple comparison of the representative values shows that the values for the later year was lower than those for earlier year in Beijing (excluding the report by Li *et al.*[8]), Nanjing and Taiyuan, and that the reverse was the case in Shanghai, Harbin and Hefei, whereas there was no change in Shenyang (possibly because the lapse of time between the two measurements is only one year). It may be plausible therefore to assume that no substantial changes took place in the years covered by the reports.

Further trials to detect long-term trend in Pb levels in the atmosphere were made with provincial capital data (14 points) by regression analysis taking the years of

Table 4. Seasonal variation in atmospheric lead and cadmium concentrations

Metal	Location	Metal in air (μg/m^3) in				Reference
		Winter	Spring	Summer	Autumn	
Lead	Taiyuan					
	Center	0.49–1.13		0.12–0.50		17
	Suburbs	0.13		0.11		17
	Harbin					
	Roadside	3.60	3.48	1.77	2.01	13
Cadmium	Harbin					
	Roadside	0.078	0.065	0.066	0.085	13

Table 5. Average atmospheric levels of lead and cadmium by the extent of urbanization

Element	Metro-polises	Provincial capitals	Others	P by ANOVA	Total[b]
Lead (μg/m^3)					
n	5	14	10		29
AM ± ASD	0.274 ± 0.155	0.588 ± 0.706	0.529 ± 0.819	0.711	0.513 ± 0.711
GM (GSD)	0.222 (2.057)	0.326 (3.238)	0.192 (4.574)	0.622	0.252 (3.570)
Cadmium (μg/m^3)					
n	2[a]	8	1[a]		11
AM ± ASD	0.031, 0.071	0.013 ± 0.024	0.059	0.182	0.027 ± 0.029
GM (GSD)	0.031, 0.071	0.006 (4.004)	0.059	0.146	0.011 (4.934)

AMs or GMs do not differ significantly (p>0.10) among three groups when examined by multiple comparison test. It should be noted that GSDs are dimensionless.

[a] Individual values are shown.

[b] The combination of the all cases.

publication and the reported Pb levels as two parameters, with no other factors taken into account. The calculated regression line of Y=−108 + 0.055X, r=0.356, p>0.10) suggests that no trend can be detected by this analysis. A similar analysis with 10 data on 'other regions' also did not show a clear-cut trend with a regression line of Y= − 15 + 0.008X, r=0.035, p>0.10).

Reports on Cd levels in the atmosphere were more limited, i.e., repeated (in twice) measurements reported for Jinan and Xian both by Environmental Quality Monitoring Station[15] and Cheng *et al.*[23]. Values were identical for two occasions. Application of regression analysis was considered inappropriate because the years of publication were clustered in the 5 year period of 1984 to 1988, except for one case in 1997.

Comments

In the present review work of 16 available reports on the Pb and Cd levels in the atmosphere in Mainland China, Pb and Cd levels were obtained in 29 and 10 cases, respectively (Tables 1 and 2). It was made clear that the reported values are scattered in a wide range, i.e., 0.08 to 2.69 μg/m^3 for Pb (Table 1) and 0.001 to 0.07 μg/m^3 for Cd (Table 2), even when representative values were estimated for each report. Possible causes of variation included differences in sampling sites in each study region (Table 3) and season of the year-related factors (Table 4). No report discussed the quality assurance issue, and therefore the problems associated with analytical quality could not be ruled out, although a majority of the reports utilized the combination of high volume air sampling and atomic absorption spectrometry (Tables 1 and 2).

Overall, the average (GM) concentrations would be 0.25 μg Pb and 0.01 μg Cd/m^3 with no substantial difference among metropolises (such as Beijing and Shanghai), provincial capitals and other regions. Longitudinal trends were not remarkable in either of Pb or Cd levels. The grand GMs for Mainland China (0.25 μg Pb/m^3 and 0.01 μg Cd/m^3) appear to be several times higher when, for example, compared with the values reported for Japan [0.01 to 0.08 μg/m^3 for Pb[24, 25] (Table 1) and 0.001 to 0.003 μg/m^3 for Cd[24, 25] (Table 2)]. It should be taken into account, however, that the values for Mainland China were obtained primarily by atomic absorption spectrometry, whereas those for Japan were by the radioactivation method[24, 25].

Sources for air pollution with Pb[7] include the emission from industries[29, 30] and the exhaust from automobiles driven by leaded gasoline[31–33], as everywhere in the world including China[34, 35]. Action has been taken in China to cope with this problem. For example, the mass media reported that the supply of unleaded gasoline was initiated in Beijing in June 1997, and that this was followed by a ban on the sale and use of leaded gasoline in the city effective on and after January 1st, 1998[36]. A possible additional source is the use of coal for domestic purpose, e.g. for cooking and especially for room heating in cold seasons[15]. Zheng *et al.*[34] in fact observed among women in Beijing that those who depended on coal for cooking had significantly higher blood Pb levels (7.21 μg Pb/100 m*l* blood) than those who used liquid gas (5.76 μg Pb/100 m*l* blood). Similarly, Shen *et al.*[37] found that higher Pb levels in umbilical cord blood of newborn babies were associated with maternal exposure to household or neighborhood coal combustion in addition to proximity to major traffic roads, etc. The observation that Pb in the atmosphere used to be higher in winter than in summer[13, 17] as summarized in Table 4 is in line with these findings.

No discussion is possible on the non-industrial source of Cd at the moment. Nevertheless, lack of marked seasonal variation in Cd levels (Table 4) suggests that the contribution of home use of coal may be small, in contrast to the case of Pb.

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