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Study of atmospheric metallic elements pollution in Asia during 2000–2007

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ABSTRACT

The main purpose of this study is to observe the concentration variations for metallic elements in the atmosphere in Asian countries during 2000–2007. These metallic elements typically generated by human activities are directly or indirectly detrimental to human health. The results show that the highest average metallic elements concentrations of Fe, Cu, Zn and Mn in total suspended particles (TSP) were in China, while the lowest average concentrations were in Japan. For metallic elements Cr and Ni, the highest average concentrations in Japan. The highest average concentrations for metallic element Pb were in China while the lowest average concentrations were in Hong-Kong.

These analytical results show that the highest average metallic elements concentrations of Pb, Mn, Cr and Ni in PM_{10} occurred in Hong-Kong while the lowest average concentrations were in India. In addition, the lowest average concentrations for Zn and Fe occurred in India.

These analytical results demonstrate that the highest average concentrations of Pb in $PM_{2.5}$ occurred in Hong-Kong while the lowest average concentration was in Japan. The lowest average concentrations for Cu, Mn, Cr and Ni, the average lowest concentrations occurred in Bangladesh. Taiwan had the lowest average concentrations of Cu and Ni among all Asian countries studied during 2000–2007.

1. Introduction

Atmospheric particulate pollution has imposed a great burden on the terrestrial environment on both regional and global scales [1,2]. Many researchers have investigated the distributions of particle matter and its chemical properties in urban, suburban, rural and industrial zones. Large particles are greatly affected by gravity while fine particles are affected most by diffusion [3].

In Taiwan, for example, the concentration, composition, and size of suspended particulate matter at any given site are determined by such factors as: meteorological properties of the atmosphere, topographical influences, emission sources, and particle parameters such as density, shape, and hygroscopicity [4].

Average TSP concentrations decreased from the urban and industrial zones to residential areas. The same behavior is observed for Cd, Zn, and Pb, but not for Cu, which has a relatively short residential time [5,6].

The combustion of waste and fuel generates particulate matter consisting of inorganic elements such as metals and unburned carbon. Many investigations about heavy metals such as Pb, Cd, and Cr, have been made, as regulated by law in Taiwan [7,8]. Mn is also generated from multiple industrial, combustion and resuspension sources [9]. However, Ca, Mg and Mn indicate construction materials as sources, while Al, K, Ti and Mn indicate wind-blown soils as sources. Higher concentrations of Pb reflect the impact of vehicle emissions [10].

Metallic element concentrations of Cd, Mn, Ni and Zn were significantly higher at industrial sites and are attributed to the pyrometallurgical processes (Pb and Zn smelters, non-ferrous metal industries, etc.) taking place in the area, as well as a manganese ore treating plant. Higher traffic density at the urban sites, found Pb concentrations relatively higher [11].

A variety of sources release fine particles into the atmosphere including: automobiles, heavy-duty trucks, wood burning, and food cooking. $PM_{2.5}$ can also form in the atmosphere through chemical reactions that convert gaseous pollutants to semivolatile compounds that can partition into the particles. Emission controls applied to any of these potential $PM_{2.5}$ source categories would involve large economic and social consequences [12].

In general, airborne fine particles of 1 μm (PM_1) and 2.5 μm ($PM_{2.5}$) or less in diameter are considered to have the greatest health significance [13]. Thus, due to its potential health impact, PM_{10} (particulate matter <10 mm in diameter) has been widely studied to assess and regulate air quality [14].

Our study discusses and compares air metallic element pollutants of various particle sizes ($PM_{2.5}$, PM_{10}) in various Asian countries within the past 10 years. The concentration distribution trends, sample site characteristics, and health impacts are also investigated which may lead to environmental pollution, policy-related regulations in Taiwan.

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2. Results and discussion

Table 1 shows the effects of metallic elements on human health. Exposure to individual metallic elements can cause various conditions in humans. For example, prolonged exposure to Fe can lead to the development of pneumoconiosis, while exposure to Zn can cause arteriosclerosis, hypertension and heart disease. Notably, Cr is carcinogenic and can lead to nasal septum perforation, asthma and liver damage. Moreover, Ni can cause nasal and lung cancer. Additionally Cu can cause nasal septum perforation, pulmonary granuloma, pulmonary interstitial fibrosis and lung cancer, while exposure to Cd and Pb can lead to itai-itai disease, blood poisoning and anemia respectively.

Table 2 shows the global average concentrations of TSP in ambient air and the metallic elements that attached to them during 2000–2007. Additionally, the maximum average particulate concentration for Pb occurred in China in (average, 694 ng/m^3) [18]. This value was about 5.5, 8.8, 4.8, 2.5, 2.2, 2.7, 3.3, 1.6, 1.2, 3.2, 3.9, 5.4, 1, 1, 2.8, 12.6 and 2.8 times higher that of Japan [15], Hong-Kong [16], Vietnam [17], Bangladesh [51], China [18], Korea [19], Islamabad [54], China [18], Taiwan [22], Islamabad [52], Taiwan [24], Islamabad [53], China [18], China [18], Islamabad [50], Hong-Kong [26] and China [26], respectively. Additionally results also indicate that the maximum average particulate concentration for Cu occurred in Taiwan in (average, 235 ng/m^3) [24]. This value was about 38.6, 2.7, 43.5, 2.1, 4.3, 1.9, 1.2, 1.5, 1.3, 1.5, 16.9 and 12.4 times higher than those of Japan [15], Hong-Kong [16], Bangladesh [51], China [18], Korea [19], China (2003) [18], Taiwan (2003) [22], China [18], China [18], China [18], Hong-Kong [26] and China [26], respectively.

Notably, the maximum average particulate concentration for Zn occurred in China in (average, 1214 ng/m^3) [18]. This value was about 40.2, 8.7, 6.0, 1.5, 1.6, 5.5, 2.2, 1.5, 3.1, 2.0, 1.1, 1.3, 1.2, 1.1, 2, 23.9 and 16.4 times higher than averages for Japan [15], Hong-Kong [16], Vietnam [17], Bangladesh [51], China [18], Korea [19], Islamabad [54], China [18], Taiwan [22], Islamabad [52], China [18], Taiwan [24], Islamabad [53], China [18], Islamabad [50], Hong-Kong [26] and China [26], respectively. The maximum average particulate concentration for Cr occurred in Japan (average, 299 ng/m^3) [15]. This value was about 15.0, 9.4, 7.0, 15.0, 10.2, 15.7, 15.0, 5.1, 10.3, 13.0, 13.6, 21.5 and 15.8 times higher that in China [18], Korea [19], Islamabad [54], China [18], Taiwan [22], Islamabad [52], China [18], Islamabad [53], China [18], China [18], Islamabad [50], Hong-Kong [26] and China [26], respectively.

Table 1
Effect of metallic element to human health [10].

Element	Abbreviations	Illness
Iron	Fe	Pneumoconiosis
Zinc	Zn	Arteriosclerosis, hypertension and heart disease
Chromium	Cr	Carcinogenicity, liver damage, nasal perforation and asthma
Nickel	Ni	Nasal cancer and lung
Copper	Cu	Nasal septum perforation, pulmonary granuloma, pulmonary interstitial fibrosis and Lung
Cadmium	Cd	Itai-itai disease
Lead	Pb	Poisoning and anemia

Table 3 lists the global average concentration of PM_{10} in ambient air and the metallic elements that attached to PM_{10} during 2000–2007.

The highest and lowest average concentrations of Pb that occurred in Hong-Kong [20] and India [27], respectively.

The highest and lowest average concentrations of Zn occurred in India [27] and Taiwan [24], respectively, and the highest and lowest average concentrations of Mn occurred in China [16] and India [27] respectively. Finally, the highest and lowest average concentrations of Ni were in Hong-Kong [20] and India [27], respectively.

Table 4 shows the global average concentrations of $PM_{2.5}$ in ambient air and the metallic elements that attached to them during 2000–2007.

The maximum average particulate concentrations for Fe occurred in Vietnam (average, 1222 ng/m^3) [17], this value was about 4.9, 7.6, 2.5, 7.5, 1.6 and 8.3 times higher than that in

Table 2
Metallic elements concentrations study in TSP for Asian countries during 2000–2007.

Year	Refs.	City	Character	Mass (μg^{-3})	Fe (ng^{-3})	Pb (ng^{-3})	Cu (ng^{-3})	Zn (ng^{-3})	Mn (ng^{-3})	Cr (ng^{-3})	Ni (ng^{-3})
2000	Var et al. [15]	Tokyo (Japan)	Urban city		677	125	6.09	30.2	5.63	299	40.1
2001	Lau and Luk [16]	Hong-Kong (China)	Airborne traffic	79	1421	79	88	140	–	–	–
	Hien et al. [17]	Ho Chi Minh (Vietnam)	Urban	73.6	2904	146	–	203	–	–	–
	Salam et al. [51]	Bangladesh		–	–	280	5.4	800	–	–	–
2002	Okuda et al. [18]	Beijing (China)			5814	317	111	735	235	20	24
	Kim et al. [19]	Taejon (Korea)	Industrial	115	1839	260	54.9	220	66.1	31.8	33.6
	Jaffar et al. [54]*	Islamabad	Urban		937	209	–	544.5	56.5	42.5	8.7
2003	Okuda et al. [18]	Beijing (China)			5556	443	120	787	257	20	22
	Fang et al. [22]	Taichung (Taiwan)		113.5	1182.6	573.6	198.6	395.3	83.7	29.3	15.8
	Jaffar et al.* [52]	Islamabad	Urban		584	214	–	603	59	19	9
2004	Okuda et al. [18]	Beijing (China)			5889	694	157	1121	295	20	22
	Fang et al.* [24]	Taiwan	Traffic junction	766	1685	180	235	960	90	–	–
	Shah and Shaheen [53]	Islamabad	Urban		1761	128	–	1021	55	59	17
2005	Okuda et al. [18]	Beijing (China)			7762	690	178	1214	374	29	23
2006	Okuda et al. [18]	Beijing (China)			5869	693	157	1087	296	23	17
	Jaffar et al.* [54]	Islamabad	Urban		620	245	–	616.5	61	22	6
2007	Lee and co-workers* [26]	Hong-Kong (China)			1040	55	13.9	50.8	39.5	13.9	–
		Guangzhou (China)			2475	244	18.9	73.8	75.1	18.9	–

* Average.

Table 3
Metallic elements concentrations study in PM_{10} for Asian countries during 2000–2007.

Year	Refs.	City	Character	Mass (μg^{-3})	Fe (ng^{-3})	Pb (ng^{-3})	Cu (ng^{-3})	Zn (ng^{-3})	Mn (ng^{-3})	Cr (ng^{-3})	Ni (ng^{-3})
2001	Lau and Luk [16]	Hong-Kong (China)	Airborne traffic	84	860	98740	35380	340	23070	6850	8620
2002	Kim et al. [19]	Taejon (Korea)	Industrial	72.2	1577	195	32.4	277	41.8	39.3	42.6
2003	Ho et al. [20]	Hong-Kong (China)	Industry	73	790	100520	63530	460	26080	5750	9580
	Chen et al.* [21]	Kaoshiung (Taiwan)	Coastal industrial	168	1990	203	–	400	67	–	53
	Kim et al. [23]	Seou (Korea)	Urban	–	2321	124	50	302	94	19	48
2004	Fang et al. [24]	Taichung (Taiwan)	Inland urban	167	1730	150	–	190	50	–	30
2007	Kara and Gupta* [27]	Kolkata (India)		168.5	105	79.5	–	512.5	2	6.5	7.5

* Average.

Hong-Kong [16], Bangladesh [49], Hong-Kong [20], Taiwan [22], Korea [23] and Japan [25], respectively. The maximum average particulate concentration for Pb was in Hong-Kong (average, 91,260 ng/m^3) [20], this value was about 1.2, 1250, 1020, 322.3, 947 and 24,664 times higher than that in Hong-Kong [16], Vietnam [17], Bangladesh [49], Taiwan [22], Korea [23] and Japan [25], respectively.

The maximum particulate concentration for Cu occurred in Hong-Kong (average, 36,780 ng/m^3) [20]. This value was about 2.1, 12,260, 10,817, 3198, 1323 and 3254 times higher than that in Hong-Kong [16], Vietnam [17], Bangladesh [49], Taiwan (2003) [22], Korea [23] and Japan [25], respectively. Moreover, the maximum average particulate concentrations for Zn occurred in Japan [25], this value was about 2.3, 2.0, 4.6, 1.7, 3.7 and 4.1 times higher than that in Hong-Kong [16], Vietnam [17], Bangladesh [49], Hong-Kong [20], Taiwan [22] and Korea [23], respectively. Finally, the maximum average particulate concentrations for Cr occurred in Hong-Kong [20], this value was about 1.8, 715.8, 134.6 and 329.2 times higher than that in Hong-Kong [16], Bangladesh [49], Taiwan [22] and Korea [23], respectively.

Table 5 lists the global average concentrations of $PM_{2.5-10}$ in ambient air and the metallic elements that attached to them during 2000–2007.

The highest average concentration for Fe in Bangladesh was 1212.5 ng/m^3 [49] and lowest average concentration in Vietnam was 261 ng/m^3 [17]. The ratios for these two values were about 4.7. The highest average concentrations for Pb in Taiwan were 90.6 ng/m^3 [22] and lowest average concentration in Japan was 21 ng/m^3 [25]. The ratios for these two values were about 4.3.

The highest average concentration for Cu in Taiwan was 12.8 ng/m^3 [22] and lowest average concentration in Vietnam was 2 ng/m^3 [17]. The ratios for these two values were about 6.4. Moreover, the highest average concentration for Zn in Japan was 503.6 ng/m^3 [25] and lowest average concentration in Taiwan was 40.3 ng/m^3 [22]. The ratios for these two values were about 12.5. Finally, the highest average concentration for Mn in Bangladesh was 29.7 ng/m^3 [49] and lowest average concentration in Taiwan was 7.5 ng/m^3 [22]. The ratios for these two values were about 3.9.

Table 6 displayed source contribution for metallic elements. The major source for metallic element Mn, Zn and K was industrial processes. And the main source for metallic element Al, Fe, Si, Mn and Ti was come from construction site. In addition, the major source for metallic element Ni and V was oil combustion. As for the main source for metallic element Cr was coal combustion. Moreover, the major source for metallic element Na, Ca, Mg, and K was sea salt. However, the main source for metallic element Fe, Mn and Pb was metal industry. And the major source for metallic element Ca, Mg, Al, Si, Fe and Mn was soils and re-suspended dusts. Incinerators were the major source for metallic element of K, Zn and Pb was incinerator. Vehicle exhaust was the primary major source for metallic element of Cr, Pb, Cu, Zn, Cd, Sb, Br, Fe and Ba was vehicle exhaust.

Fig. 1 indicates that the highest average concentrations of Fe in total suspended particulate (TSP) in China were 7762 ng/m^3 [18] and lowest average concentration in Islamabad was 584 ng/m^3 [52], respectively. The ratios for these two values were about 13.3. And the highest average concentrations in China of Pb were 694 ng/m^3 [18] while the lowest average concentration in Hong-Kong was 55 ng/m^3 [26], respectively. The ratios for these two values were about 12.6. The results also indicated that the highest average concentration in China of Zn was 1214 ng/m^3 [18] and the lowest average concentration in Japan was 30.2 ng/m^3 [15], The ratios for these two values were about 40.2 for Asian countries during 2000–2007.

The order of average concentrations of Pb was China 694 ng/m^3 [18] > China 693 ng/m^3 [18] > China 690 ng/m^3 [18] > Taiwan 573.6 ng/m^3 [22] > China 443 ng/m^3 [18] > China 317 ng/m^3 [18] > Bangladesh 280 ng/m^3 [51] > Korea 260 ng/m^3 [19] > Islamabad 245 ng/m^3 [50] > China 244 ng/m^3 [26] > Islamabad 214 ng/m^3 [52] > Islamabad 209 ng/m^3 [54] > Taiwan 180 ng/m^3 [24] > Vietnam 146 ng/m^3 [17] > Islamabad 128 ng/m^3 [53] > Japan 125 ng/m^3 [15] > Hong-Kong 79 ng/m^3 [16] > Hong-Kong 55 ng/m^3 [26]. Additionally,

Table 4
Metallic elements concentrations study in $PM_{2.5}$ for Asian countries during 2000–2007.

Year	Refs.	City	Character	Mass (μg^{-3})	Fe (ng^{-3})	Pb (ng^{-3})	Cu (ng^{-3})	Zn (ng^{-3})	Mn (ng^{-3})	Cr (ng^{-3})	Ni (ng^{-3})
2001	Lau and Luk [16]	Hong-Kong (China)	Airborne traffic	51	250	76860	17320	290	9960	2430	5340
	Hien et al. [17]	Ho Chi Minh (Vietnam)	Urban	32	1222	73	3	326	52	–	–
2002	Beguma et al.* [49]	Bangladesh	Semi-urban	22.4	160.5	89.4	3.4	144.4	6.7	6.3	2.6
2003	Ho et al. [20]	Hong-Kong (China)	Industry	57	480	91260	36780	380	19720	4510	6000
	Fang et al. [22]	Taichung (Taiwan)		42.8	162.8	283.1	11.5	177.8	19.1	33.5	11.8
	Kim et al. [23]	Seou (Korea)	Urban	–	743	96.4	27.8	163	39	13.7	19.6
2006	Wang et al. [25]	Kanazawa (Japan)	Urban city	–	147.3	3.7	11.3	660.7	9.4	–	–

* Average.

Table 5
Metallic elements concentrations study in $PM_{2.5-10}$ for Asian countries during 2000–2007.

Year	Refs.	City	Character	Mass (μg^{-3})	Fe (ng^{-3})	Pb (ng^{-3})	Cu (ng^{-3})	Zn (ng^{-3})	Mn (ng^{-3})	Cr (ng^{-3})	Ni (ng^{-3})
2001	Hien et al. [17]	Ho Chi Minh (Vietnam)	Urban	16	261	79	2	245	14	–	–
2002	Beguma et al.* [49]	Bangladesh	Semi-urban	42	1212.5	70.1	7.9	201.2	29.7	17.3	3.6
2003	Fang et al. [22]	Taichung (Taiwan)		19.4	360.6	90.6	12.8	40.3	7.5	9	4.3
2006	Wang et al. [25]	Kanazawa (Japan)	Urban city	–	721.9	21	5.9	503.6	25.3	–	–

* Average.

Table 6
Source contribution for metallic elements.

Source	Predominant species	Refs.
Industrial process	Mn, Zn and K	[9,33–36]
Construction site	AI, Fe, Si, Mn and Ti	[29,30]
Oil combustion	Ni and V	[28–30]
Coal combustion	Cr	[37,38]
Sea salt	Na, Ca, Mg, and K	[36]
Metal industry	Fe, Mn and Pb	[31,32]
Soils and re-suspended dusts	Ca, Mg, Al, Si, Fe and Mn	[29–33,34,39–45]
Incinerator	K, Zn and Pb	[31,32]
Vehicle exhaust	Cr, Pb, Cu, Zn, Cd, Sb, Br, Fe and Ba	[10,30,39,41,43,46–48]

order of average concentrations of Cu was Taiwan 235 ng/m^3 [24] > Taiwan 198.6 ng/m^3 [22] > China 178 ng/m^3 [18] > China 2006, 157 ng/m^3 [18] > China 120 ng/m^3 [18] > China 111 ng/m^3 [18] > Hong-Kong 88 ng/m^3 [16] > Korea 54.9 ng/m^3 [19] > China 18.9 ng/m^3 [26] > Hong-Kong 13.9 ng/m^3 [26] > Japan 6.09 ng/m^3 [15] > Bangladesh 5.4 ng/m^3 [51] for Asian countries during 2000–2007.

Moreover, order of average concentrations of Zn was China 1214 ng/m^3 [18] > China 1121 ng/m^3 [18] > China 1087 ng/m^3 [18] > Islamabad 1021 ng/m^3 [53] > Taiwan 960 ng/m^3 [24] > Bangladesh 800 ng/m^3 [51] > China 787 ng/m^3 [18] > China 735 ng/m^3 [18] > Islamabad 616.5 ng/m^3 [50] > Islamabad 603 ng/m^3 [52] > Islamabad 544.5 ng/m^3 [54] > Taiwan 395.3 ng/m^3 [22] > Korea 220 ng/m^3 [19] > Vietnam 203 ng/m^3 [17] > Hong-Kong 140 ng/m^3 [16] > China 73.8 ng/m^3 [26] > Hong-Kong 50.8 ng/m^3 [26] > Japan 30.2 ng/m^3 [15]. Finally, order of average concentrations of Mn was China 374 ng/m^3 [18] > China 296 ng/m^3 [18] > China 295 ng/m^3 [18] > China 257 ng/m^3 [18] > China 235 ng/m^3 [18] > Taiwan 90 ng/m^3 [24] > China 75.1 ng/m^3 [26] > Korea 66.1 ng/m^3 [19] > Islamabad 1 ng/m^3 [50] > Islamabad 59 ng/m^3 [52] > Islamabad 55 ng/m^3 [53] > Islamabad 56.5 ng/m^3 [54] > Hong-Kong 39.5 ng/m^3 [26] > Japan 5.63 ng/m^3 [15] for Asian countries during 2000–2007.

To sum up, order of average concentration of Cr was Japan 299 ng/m^3 [15] > Islamabad 59 ng/m^3 [53] > Islamabad 42.5 ng/m^3 [54] > Korea 31.8 ng/m^3 [19] > Taiwan 29.3 ng/m^3 [22] > China 29 ng/m^3 [18] > China 23 ng/m^3 [18] > Islamabad 22 ng/m^3 [50] > China 20 ng/m^3 [18] > Islamabad 19 ng/m^3 [52] > China 18.9 ng/m^3 [26] > Hong-Kong 3.9 ng/m^3 [26] for Asian countries during 2000–2007.

Fig. 2 lists the average concentrations of Fe, Pb, Cr, Cu, Ni, Zn and Mn in PM_{10} in the Asian countries studied during 2000–2007. The highest average Pb concentration in Hong-Kong was 100,520 ng/m^3 [20] and the lowest average Pb concentration in India was 79.5 ng/m^3 [27] in the Asian countries studied during 2000–2007.

The highest average Cr concentration in Hong-Kong was 6850 ng/m^3 [16] and the lowest average Cr concentration in India was 6.5 ng/m^3 [27] in the Asian countries studied during 2000–2007.

Hong-Kong [20] had the highest and second highest average Cu concentrations at 63,530 ng/m^3 and 35,380 ng/m^3, respectively; Korea [19] had lowest concentration at 32.4 ng/m^3 in the Asian countries studied during 2000–2007.

Hong-Kong had the highest average concentrations. In addition, the results also reflected that the highest metallic elements of Pb, Cu, Cr, Ni and Mn were all found in Hong-Kong [16,20]. Moreover,

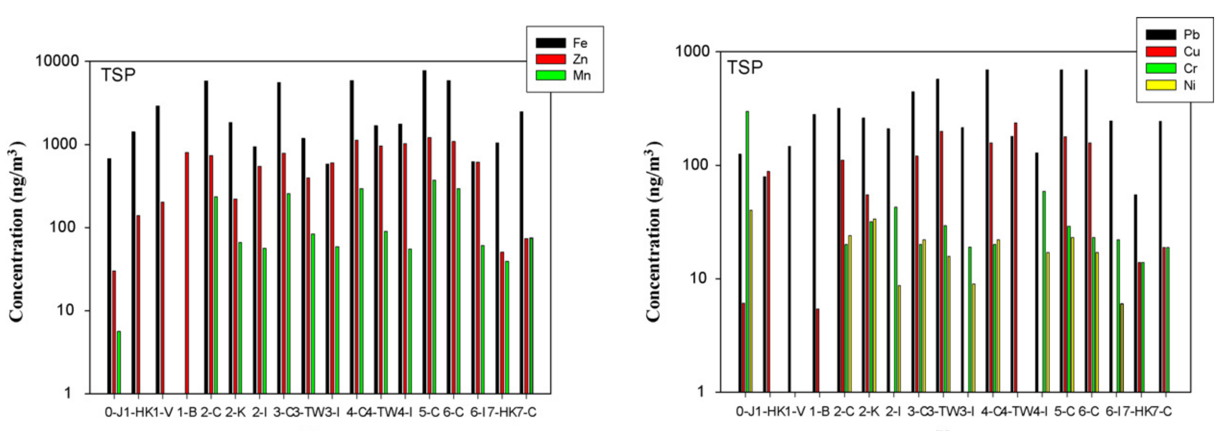

Fig. 1. Comparison of metallic elements in TSP for Asian countries during years of 2000–2007. 0-J(2000, Japan), 1, 7-HK(2001, 2007, Hong-Kong), 1-V(2001, Vietnam), 1-B(2001, Bangladesh), 2, 3, 4, 6-I(2002, 2003, 2004, 2006, Islamabad), 2, 3, 4, 5, 6, 7-C(2002–2007, China), 2-K(2002, Korea), 3, 4-TW(2003, 2004, Taiwan).

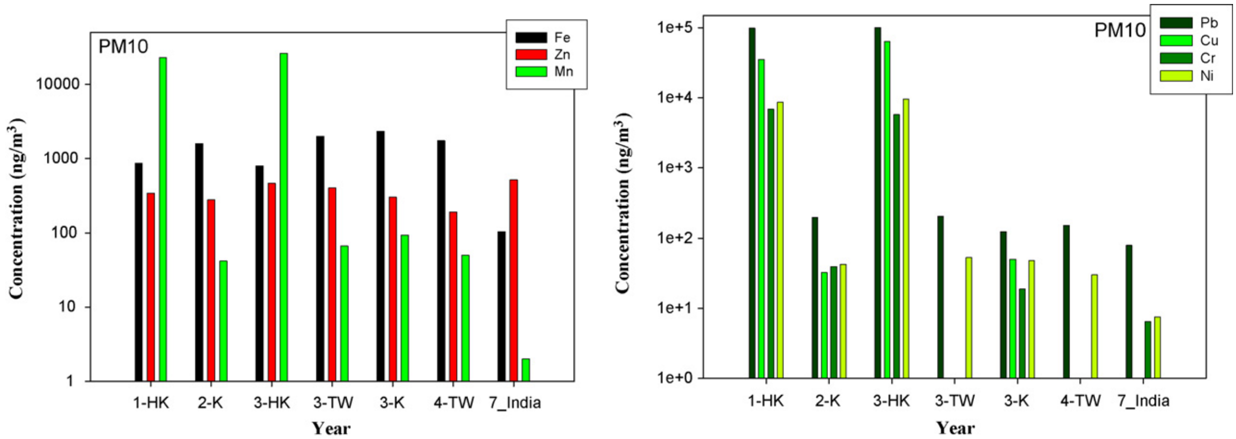

Fig. 2. Average concentration metallic element in PM_{10} at Asian countries during years of 2000–2007. 1, 3-HK (2001, 2003, Hong-Kong), 2, 3-K (2002, 2003, Korea), 3, 4-TW (2003, 2004, Taiwan), 7-India (2007, India).

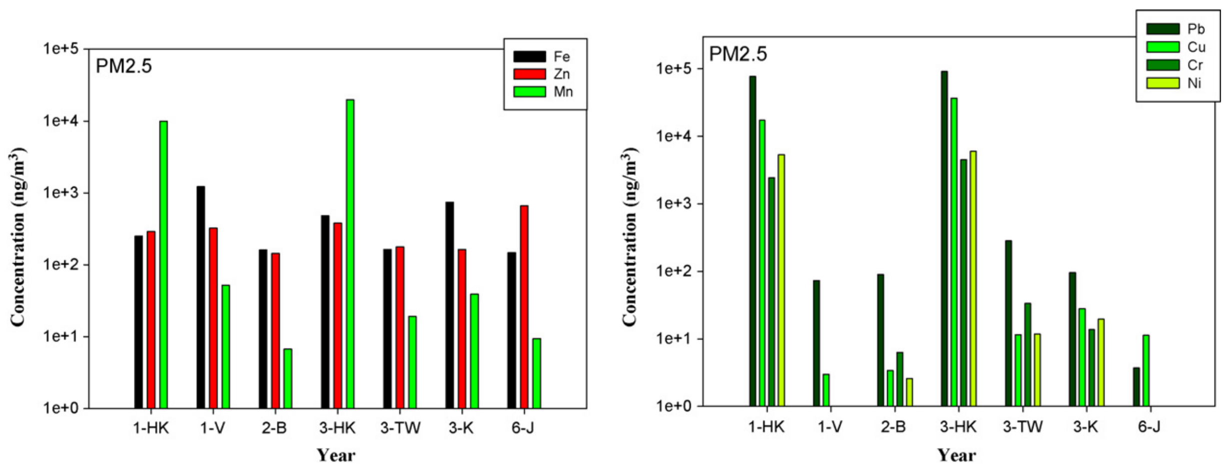

Fig. 3. Average concentration metallic element in $PM_{2.5}$ at Asian countries during years of 2000–2007. 1, 3-HK (2001, 2003, Hong-Kong), 1-V (2001, Vietnam), 2-B (2002, Bangladesh), 3-TW (2003, Taiwan), 3-K (2003, Korea), 6-J (2006, Japan).

the results also indicate that the average lowest concentrations for all metallic elements was found were in India (except for Zn) [27] for all Asian countries studied during 2001–2007. The average metallic element concentration was found lowest in 2004 than that of 2003 in Taiwan.

However, the average concentrations of Fe, Zn, Cu, Ni and Mn were highest in 2003 than in 2002 in Korea. The highest average concentrations of Pb, Cr, Cu, Ni and Mn were found in Hong-Kong compared with the rest of the other Asian countries during 2000–2007.

Fig. 3 shows the average concentrations of Fe, Pb, Cr, Cu, Ni, Zn and Mn in $PM_{2.5}$ were among all Asian countries during 2000–2007. The order of average concentrations (ng/m^3) in Hong-Kong [16] was Pb (76,860) > Cu (17,320) > Mn (9960) > Ni (5340) > Cr (2430) > Zn (290) > Fe (250). The order of average concentrations (ng/m^3) in Vietnam [17] was Fe (1222) > Zn (326) > Pb (73) > Mn (52) > Cu (3) for Asian countries during years of 2000–2007.

In Bangladesh [49], the order of average concentrations (ng/m^3) [49] was Fe (160.5) > Zn (144.4) > Pb (89.4) > Mn (6.7) > Cr (6.3) > Cu (3.4) > Ni (2.6).

In Hong-Kong [20], the order of average concentrations (ng/m^3) was Pb (91,260) > Cu (36,780) > Mn (19,720) > Ni (6000) > Cr (4,510) > Fe (480) > Zn (380). In addition, the order of average concentrations (ng/m^3) in Taiwan [21] was Pb (283.1) > Zn (177.8) > Fe (162.8) > Cr (33.5) > Mn (19.1) > Cu (11.8) > Ni (11.5) during 2000–2007.

In Korea [23], the order of average concentrations (ng/m^3) was Fe (743) > Zn (163) > Pb (96.4) > Mn (39) > Cu (27.8) > Ni (19.6) > Cr (13.7). The order of average concentrations (ng/m^3) in Japan [25] was Zn (660.7) > Fe (147.3) > Cu (11.3) > Mn (9.4) > Pb (3.7) during 2000–2007.

To summarize, the highest average concentrations of Pb, Cr, Cu, Ni, and Mn were in Hong-Kong for all Asian countries studied during 2000–2007.

3. Conclusions

1. The average concentrations for Pb, Cu, Zn and Mn in TSP were found to increase during the period of 2002–2005 in Beijing (China) with the highest concentrations noted in 2005, but decreased in the year of 2006. The lowest concentration was found in 2006. These averages were about 5–10 times higher as those of the other Asian countries studied. In addition, the average concentration of Fe, Pb, Cu and Zn were highest in 2007 in Hong-Kong. The mean concentration for Cr and Ni were found to be highest in Japan than in the rest of the other Asian countries during the year of 2000–2007.
2. The average concentrations for metallic elements Fe, Zn, Cu, Ni and Mn in PM_{10} were found highest in Korea in 2003, while the average concentration of Pb, Zn, Cu, Ni and Mn were found highest in 2003 in Hong-Kong.

3. The average concentrations of Fe, Pb, Zn, Cu, Ni, Cr and Mn in $PM_{2.5}$ were found highest in 2003 than in 2001 in Hong-Kong. Finally, the average highest metallic elements concentration of Pb, Cu, Mn, Cr and Ni in either PM_{10} or $PM_{2.5}$ were found to be highest in Hong-Kong compared with the rest of the other Asian countries during years of 2000–2007.

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