EJ095198410188

Airborne Suspended Particulate Pollution in Hong-Kong
香港大氣飄塵的污染*

Yat-man Yan**
丘 逸 民

摘 要

藉自行設計的高流量空氣採樣器在香港五個土地利用區進行了建物底層及頂層環境大氣中飄塵的樣本採集，並藉原子吸收光譜儀分析飄塵中某些重金屬的含量，並評估了大氣飄塵的污染與氣象因子間的關係。

大氣中飄塵及重金屬的濃度具時間上及空間上的差異性，在都市及工業區域，某些採樣日的飄塵濃度已超過美國政府所訂之一級標準。在已分析之重金屬物中，鉛的濃度也與世界上很多大都市一樣，遠超過各國所訂之環境大氣品質標準。其次，由於衆多的人爲污染源，大氣中的飄塵如與地表土相較，高度富集了鉛、銅、鋅等重金屬物。

如以都市中高大建物的高度範圍言，飄塵污染的垂直變化確實存在，而且與都市中垂直土地利用及街廓間大氣擴散情況有關。

由於香港都市結構之複雜性及缺乏小區域大氣環流之觀測，故各土地利用區之飄塵污染與大氣因子諸如風速、雨量、混合層高度間之相關程度不高甚或不顯著。

1. Introduction

Hong Kong, due to its rapid growth of industrialization and urbanization in the past three decades, is now facing various atmospheric environmental problems. For instance, many industries are developed nearly or inside the populated urban areas. Increasing number of motor vehicles are congested in the streets blocked by highrise buildings that render poor circulation in the city, all these may lead to a high degree of air pollution. As a result, the atmospheric environment of Hong Kong has been deteriorating and hence has

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* This paper is the summarized report of the M. Phip. thesis of the author.

** Teaching Assistant, Department of Geography, National Taiwan Normal University.

aroused much public concern.

For effectively managing the atmospheric environment, a comprehensive understanding of the present status of the air quality in Hong Kong is essential. Hence, a number of studies dealing with atmospheric pollution have been done in Hong Kong, but most of them are directed to sulfur dioxide. However, few of the studies of the particulate pollution are available and discussed as below.

In 1978, Kwong[1] used the Hi-Vol air samplers to collect the suspended particulates and analysed chemical compositions by means of reactor neutrons and Gamma-ray spectrometer. However, meteorological effects and spatial variation of the suspended particulates were not incoporated in his study.

In an interim report for the air quality studies in Junk Bay, Steven et al.[2] indicated that the mean TSP level ranges from 70 to 78 ug/m^3, which is not serious but is high in a rural environment.

EPA[3] had conducted a study of air pollution from road traffic in 1982. Results indicated that the roadside suspended particulate levels and airborne Pb concentration were similiar to the measurements in other parts of the world.

As the overall studies about the present status of the airborne suspended particulate pollution in Hong Kong is still insufficient, it is hoped that this study may provide useful information to fulfill the existing gap of knowledge about the atmospheric pollution in Hong Kong. Furthmore, the results of this research are expected to serve as reference for the control and management of the ambient air quality in Hong Kong for both the departments of Hong Kong Government and other private agencies concerned.

Therefore, three objectives are attempted to achieve, namely,

1) the spatial distribution of,

2) the vertical variation of, and,

3) the meteorological implication of the airborne suspended particulate pollution in Hong Kong.

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1. L.S. Kwong, *A Study of Air Pollution in Hong Kong: Non-Destrictive Multi-element Determination of Air Particulates by Means of Reacter Neutrons and Ge (Li) Gamma-Ray Spectrometer.* M. Phil. Thesis, Unpublished, Department of Physics, C.U.H.K., Hong Kong, 1978.
2. T.Y. Steven, and F. Tromp, *An Interim Report for the Air Quality Studies in Junk Bay*, Report No. EPA/TM10/82, EPA, Hong Kong Government, 1982.
3. EPA, *Air Pollution from Road Traffic - EPA Roadside Monitoring Study.* Report No. EPA/TM2/82, Hong Kong Government, 1982.

2. Methodology

Hi-Vol air samplers have been designed by the author for collecting the total suspended particulates in the atmosphere (see Fig. 1). The samplers have air flowrates ranging from 0.28-0.33 m^3/min and the Whatman 41 filter paper was used.

Since the hygroscopic nature of this cellulose fiber filter , may lead to unacceptable weighing error[4], it is therefore imperative to maintain the filter paper under constant temperature and relative humidity during tare and gross weighing. Therefore, the air-conditioned environmental laboratory in the Department of Geography of The Chinese University of Hong Kong, is taken as a clean, constant temperature and relative humidity environment (temp: 23±3°C, r.h.: 50±3%) for weighing operations. Before tare weighing and gross weighing, the filters are exposed in the environmental laboratory for at least 24 hours.

When analysing the chemical compositions of the suspended particulates collected on the filters, the filters were first dry ashed at 500°C and then were mixed up with 10ml nitric acid ($1HNO_3+3H_2O$) in the test tube, The mixture were digested in the sand bath and were boiled for about 1 hour. After digesting, the heavy metallic elements would be dissoloved. The solution was refluxed with distilled water to access 50ml flask. Finally, the solution could be loaded in a small bottle with a wide orifice for percipitation. After purification, the solution could then be analyzed to quantify the concentration of the heavy metallic elements which consisted of Cd, Cr, Cu, Fe, Mn, Pb, Zn, Ni by means of atomic absorption spectrophotometry.

Fifteen clean filters are also treated by the same procedures and the analytical results are taken as the blanks of the filters, which can be seen in Table 1.

Since iron is common and is in quite a constant proportion in the earth crust, it is selected as a reference element for calculating enrichment factor of other element. The enrichment factor can determine whether or not the concerned element derives from anthropogenic sources.

$$\text{The Enrichment Factor } EF_{(x)} = \frac{(x/Fe) \text{ aerosols}}{(x/Fe) \text{ crust}}$$

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4. J. Strand, T. Stolzenberg, and A.W. Andren, A Constant Relative Humidity - Temperature Chamber for the Accurate Weight Determination of Air Particulate Matter Collected on Filters, *Atmospheric Environment*, Vol. 12, pp. 2027-2028, 1978.

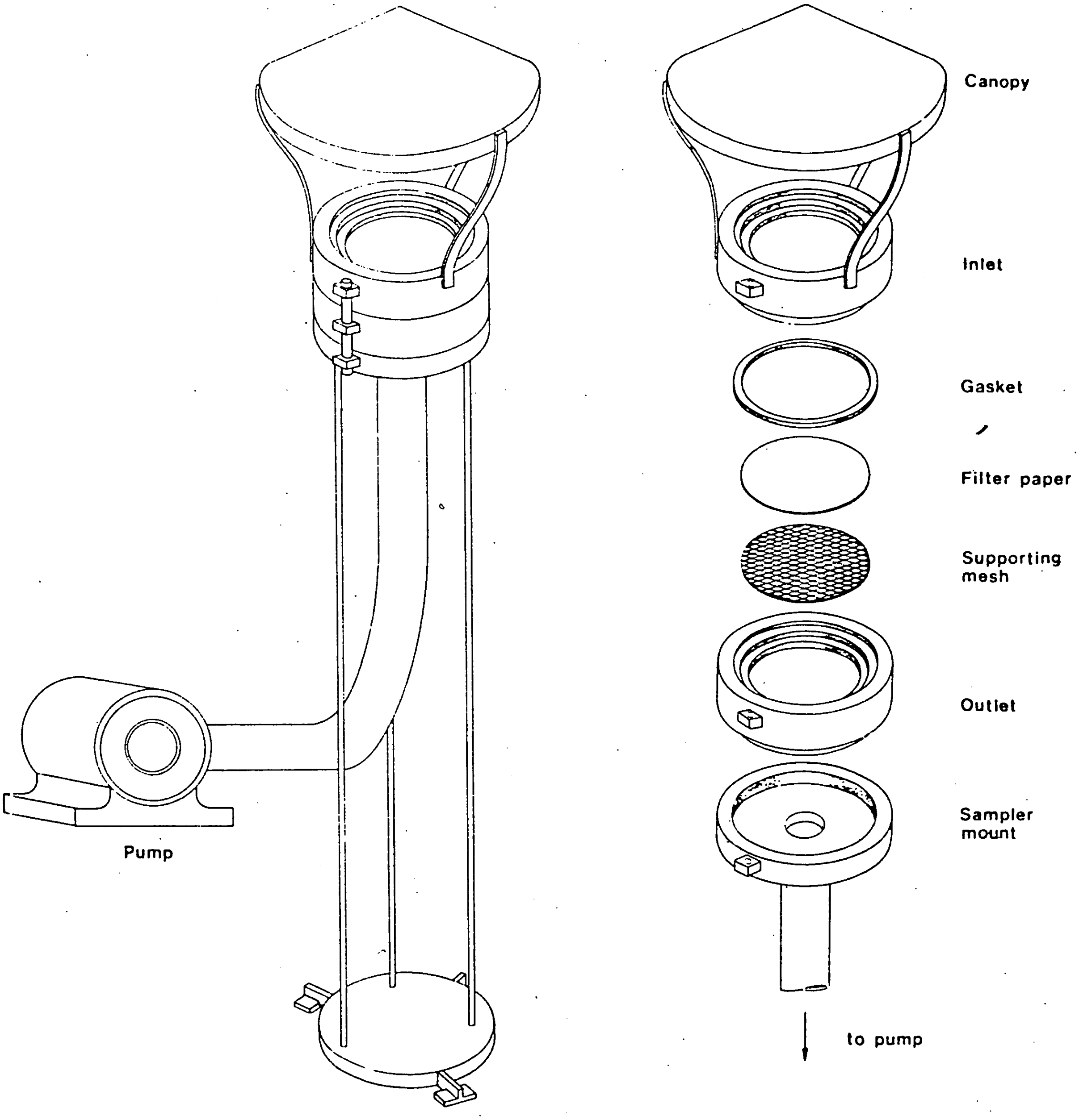

FIGURE 1 A HIGH VOLUME AIR SAMPLER (LEFT) AND ITS EXPLODED DIAGRAM (RIGHT).

Table 1. The Blanks of the W41 Filters

Elements	Mean	Standard Deviation
Zn	10.19	±7.94
Fe	7.25	±2.61
Pb	4.38	±2.74
Cu	1.50	±0.61
Ni	1.25	±0.83
Mn	0.31	±0.14
Cd	0.31	±0.11
Cr	0.28	±0.14

Units: ug/g

If the EF of a certain element in the atmosphere is approximately equal to 1 or below 1, it is believed that this element mainly comes from natural sources. When the EF is greater than 1, it is assumed that this element is the result of emissions from anthropogenic sources.

Collection of air samples was commenced from 15th July, 1982 and ended on 15th January, 1983. Sampling sites include nonurban area, industrial-residential area, commercial-residential area, high-class residential area and industrial area. The locations of these sites are selected as follows: (see Fig. 2)

(1) nonurban area: the campus of the Chinese University of Hong Kong

(2) high-class residential area: Kowloon Tong Middle School at Kowloon Tong District

(3) Commercial-residential area: Shum Shui Po District

(4) industrial-residential area: Tai Kok Tsui District

(5) industrial area: Kwai Chung District

To investigate the vertical variation of particulate pollution, one Hi-Vol sampler was set on the bolony of the 1st floor, and another one was set on the roof of the buildings at the sampling site at Kwai Chung, Tai Kok Tsui and Sham Shui Po. The paired T-test is employed to determine whether sigificant difference exists between ground-level and roof-level particulate pollution.

Multiple regression method is adopted to determine the relationship between the TSP concentration and the meteorological parameters such as mixing depth, surface wind speed and rainfall.

All data are processed and analysed in the Computer Center of C.U.H.K.

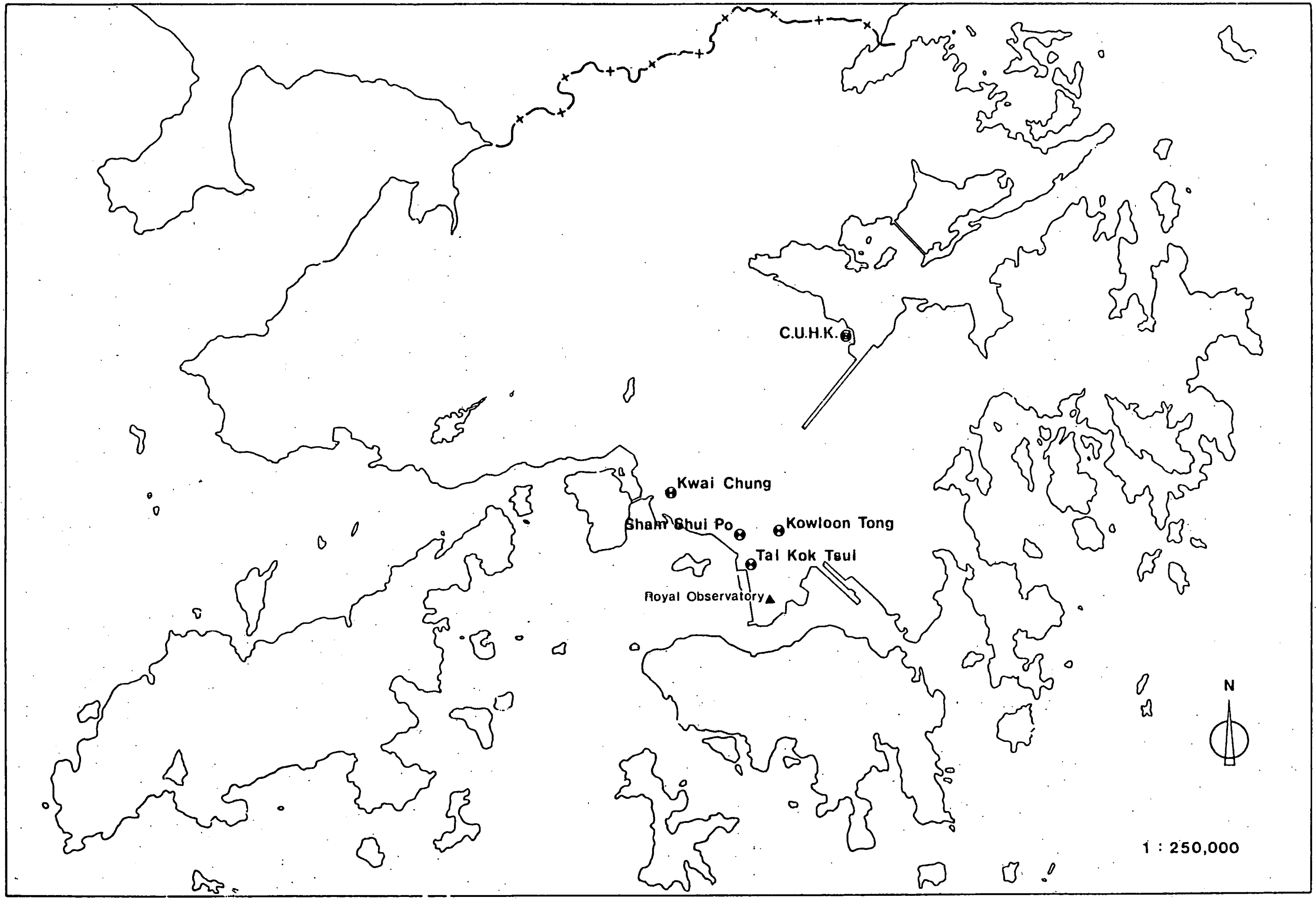

Figure 2 The locations of the monitoring sites.

by employing installed "statistical package for social sciences".

3. Results and Discussions

3.1 Spatial distribution

Using primary standard and the secondary standard provided by U.S. EPA (1971), each monitoring day is classified as a "clean day", a "normal day" or a "polluted day", When particulate concentration is below 150ug/m^3, between 150ug/m^3 and 260ug/m^3, or above 260ug/m^3 respectively. The frequency percentage of the classified air quality over five designated land use areas is given in Fig. 3.

At the campus of C.U.H.K., being in a rural environment, the mean concentration of TSP is 66.78ug/m^3, and is well below the secondary standard. All of the sampling days were classified as the "clean day".

While at Kowloon Tong District, a high-class residential area[5] with low industrial activities and low population density, mean concentration of TSP is 88.3ug/m^3, only 7% of sampling days fall between 150ug/m^3 and 260ug/m^3. It is considered as a less polluted area.

At Tai Kok Tsui, a residential-industrial district (Liang, 1972), small-scale industrial and business dominate at ground-floor, whereas the upper floors are used for residential as well as industrial purposes. The mean concentration of TSP is 163.2ug/m^3. About 71% of sampling days fall between 150ug/m^3 to 260ug/m^3, but no concentration above 260ug/m^3 has been exceeded. It is considered as "lightly polluted" area.

At Sham Shui Po, a typical commercial-residential district (Liang, 1972), where retail business and service business are dominated at the ground floor, and the residents occupied the upper floors. The mean concentration of TSP is 224.ug/m^3. There are 24% of sampling days are above 260ug/m^3, and 68% of the days are between 150ug/m^3 and 260ug/m^3.

At Kwai Chung, an industrial district, where consists mainly of multi-storey industrial buildings, the mean concentration of TSP is 277.9ug/m^3 and the maximum concentration may reach to 478.9ug/m^3. There are 33% of the sampling days fall between 150ug/m^3 and 260ug/m^3, and 55% of the days exceed 260ug/m^3, the primary standard. It is believed that the ambient air quality at the ground-level in this area is rather poor.

Heavy metals such as Fe, Cu, Zn, Ni, Pb, Mn, Cd and Cr in the collected

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5. C.S. Liang, Urban Land Use Analysis, Hong Kong: Errest Publications, Chapter 5, pp. 79-111, 1972.

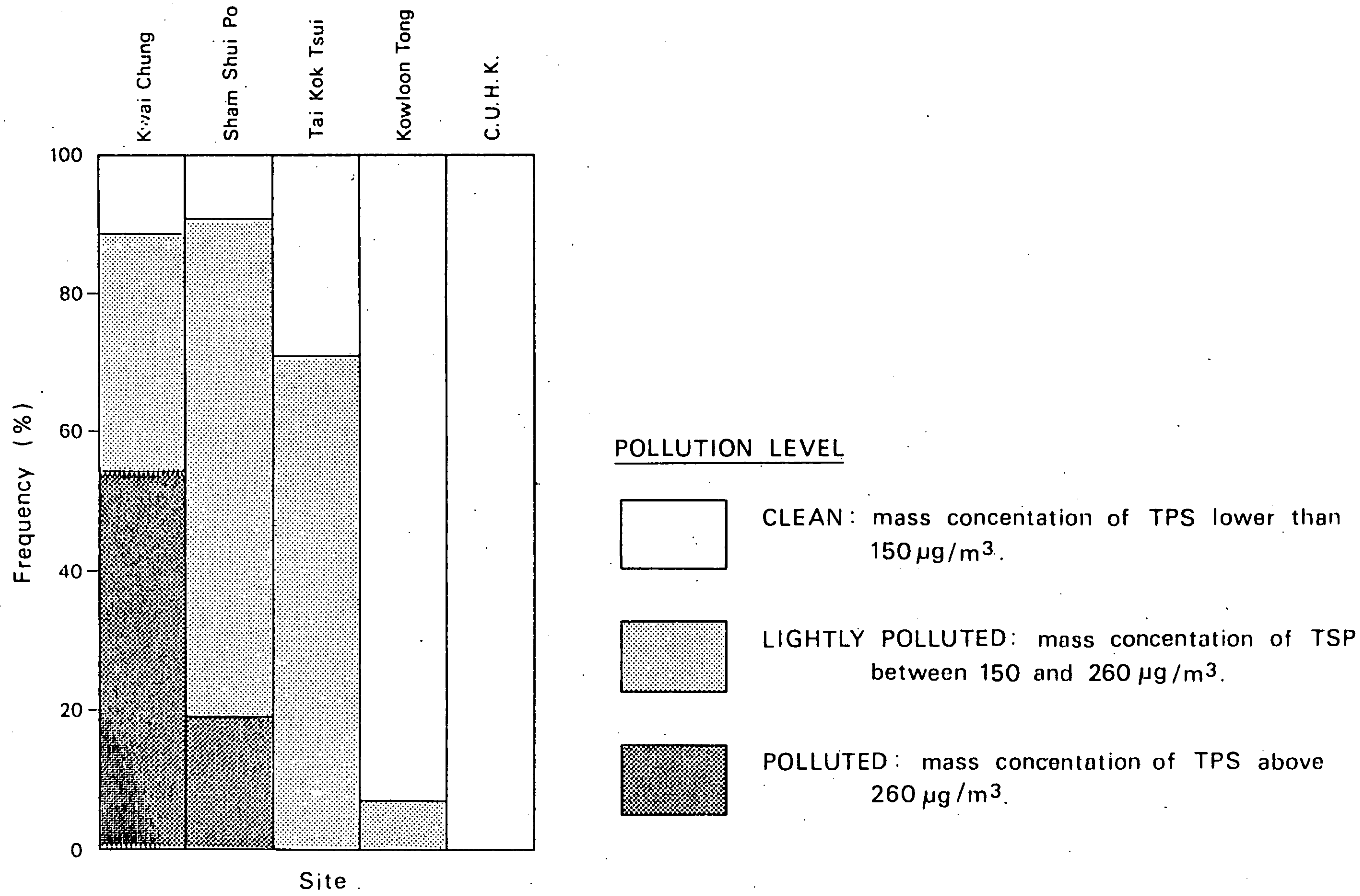

Figure 3. The frequency of pollution levels at the five land-use areas.

Table 2 The Ambient Air Quality at Five Landuse Areas

Element \ Concentration \ Site		C.U.H.K.	Kwai Chung	Sham Shui Po	Tai Kok Tsui	Kowloon Tong
TSP	Min.	7.0	111.2	110.0	84.2	28.7
	Mean.	66.8	277.9	224.3	163.2	88.3
	Max.	145.0	478.9	328.7	244.5	208.9
Fe	Min.	0.15	1.37	0.80	1.12	1.11
	Mean	1.15	4.50	2.66	2.27	2.49
	Max.	3.84	10.87	5.57	4.64	6.30
Cu	Min.	ND	0.036	0.028	0.008	0.024
	Mean	0.019	0.262	0.084	0.064	0.053
	Max.	0.073	2.228	0.246	0.192	0.428
Zn	Min.	ND	0.29	0.05	0.08	0.13
	Mean	0.20	3.78	0.75	1.16	0.46
	Max.	2.24	20.18	2.02	6.06	2.09
Ni	Min.	ND	ND	ND	ND	ND
	Mean	0.011	0.063	0.021	0.020	0.016
	Max.	0.244	0.234	0.067	0.063	0.034
Pb	Min.	0.036	0.351	0.178	0.487	0.387
	Mean	0.665	2.794	0.798	0.822	0.729
	Max.	2.502	11.836	1.435	2.019	1.700
Mn	Min.	0.005	0.049	0.043	0.030	0.029
	Mean	0.039	0.181	0.119	0.119	0.093
	Max.	0.206	0.469	0.205	0.340	0.244
Cd	Min.	ND	ND	ND	ND	ND
	Mean	0.0010	0.0029	0.0023	0.0021	0.0014
	Max.	0.0056	0.0081	0.0063	0.0090	0.0091
Cr	Min.	ND	0.0058	ND	Not analysed	ND
	Mean	0.0037	0.0934	0.0127		0.0039
	Max.	0.0352	1.1655	0.0606		0.0171

Units: ug/m³

ND: below detection limits

samples are also analyzed. The enrichment factors of these elements are computed for the five sites, and are provided in Table 3.

Comparing with the various national ambient air quality standards (see Appendex), concentrations of Ni, Mn, and Cr are minimal for all five sites. The low EF values of these elements reflected that these elements mainly derived from the natural sources. Slight pollution of Cu, Zn and Cd are observed, and the EF values of these element are greatly higher than 1, which indicate that the related anthropogenic activities are quite significant. Extreme high concentration and EF value of Pb at all five sites, however, are mainly contributed by the congested traffic elsewhere in this colony.

In conjuction Table 3 with Table 2, Kwai Chung district is the most polluted area, where multi-storey industrial buildings with various types of factories dominate. The particulate pollution of the ambient air either mass concentration of TSP or heavy metal concentration has been in a serious condition. The ambient air quality tested in most of the sampling days is far above the maximum permitted level of several countries. With this poor air quality, it is apparant that the health of the workers and the dwellers nearby will be suffered in the long run.

Table 4 and Fig. 4 show the concentration and enrichment factors of airborne elements in some other countries. By comparing the particulate pollution level from each other, the problems are similiar to those of other industrialized and modernized cities, but an extreme high Pb concentration was detected in Hong Kong in comparison with the maximum values at other cities. The EF of Zn, Mn and Cd in Hong Kong are lower than the other cities, because there are no important heavy industrial mills which are the main sources of these elements.

3.2 Vertical variation

Three sites are selected for study of vertical variation of aerosol pollution. They are namely Sham Shui Po, Tai Kok Tsui and Kwai Chung. Hi-Vol samplers are set at the balony of the 1st floor and the roof of the buildings with 12, 22 and 33 storeys respectively.

Concentration of total suspended particulates and airborne elements of Fe, Cu, Ni, Pb, Mn, Cr, and Cd are tabulated in Table 5. At Sham Shui Po and Kwai Chung, the concentration of TSP and the airborne Pb at the ground-level smbient air are significantly higher than that at the roof-level. However, at Tai Kok Tsui, the difference between both levels are not significant. These results can be tracted to the vertical land use pattern at these districts.

Table 3 The Enrichment Factor of Airborne Elements at Five Land-use Areas

Element	Enrichment Factor \ Site	C.U.H.K.	Kwai Chung	Sham Shui Po	Tai Kok Tsui	Kowloon Tong
Cu	Min.	ND	1.99	1.14	0.71	0.76
	Mean	2.43	6.87	3.85	3.61	2.50
	Max.	10.4	55.04	12.31	12.95	12.70
Zn	Min.	ND	15.6	1.8	5.3	3.5
	Mean	22.9	67.1	26.6	51.0	17.7
	Max.	554.9	167.2	77.3	390.1	67.5
Ni	Min.	ND	ND	ND	ND	ND
	Mean	0.828	1.252	0.659	0.839	0.585
	Max.	9.632	5.011	2.019	3.144	1.649
Pb	Min.	15.6	43.906	57.9	80.1	35.0
	Mean	377.515	394.434	160.9	205.0	168.9
	Max.	1276.304	1918.826	330.0	592.2	361.3
Mn	Min.	0.082	0.107	0.159	0.141	0.136
	Mean	0.232	0.279	0.311	0.357	0.252
	Max.	0.575	0.519	0.526	1.267	0.578
Cd	Min.	ND	ND	ND	ND	ND
	Mean	35.6	23.7	29.7	28.7	20.2
	Max.	155.2	60.7	78.7	129.0	78.3
Cr	Min.	ND	0.181	ND	Not analysed	ND
	Mean	0.204	1.565	0.339		0.124
	Max.	0.683	20.853	1.655		

ND: below detection limits

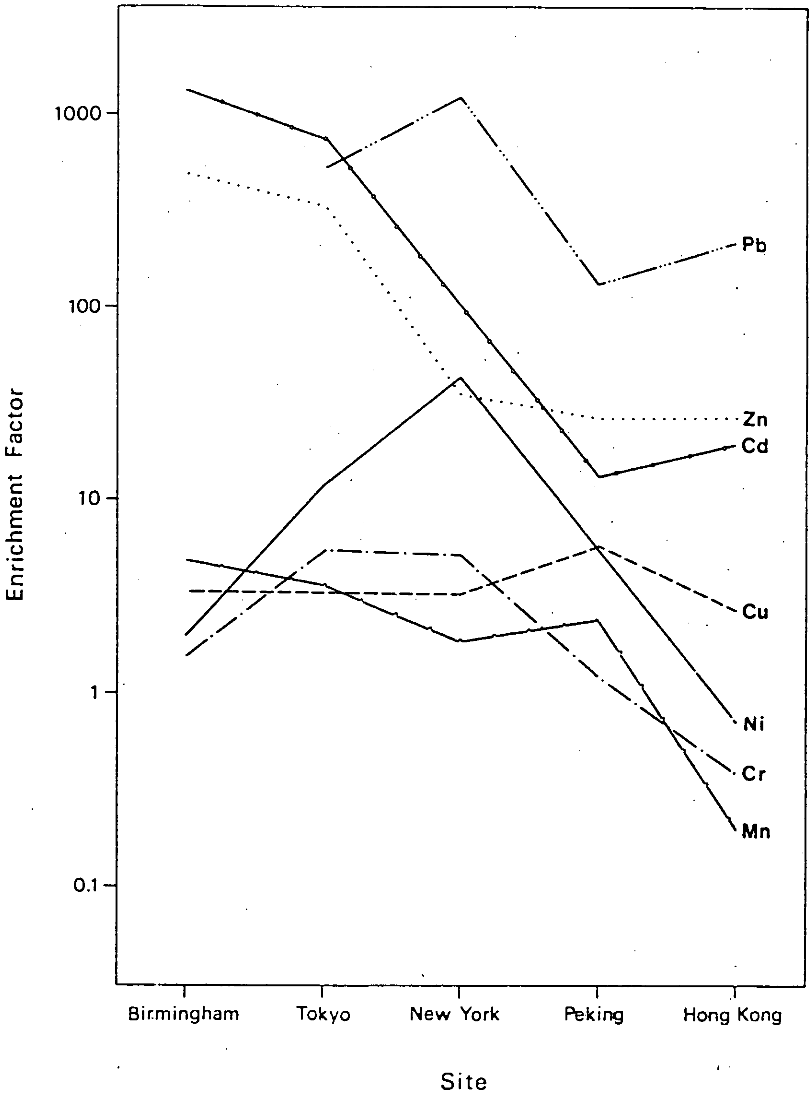

Figure 4 Enrichment factor of elements in airborne particles in some other countries.

Source: Wong, et al. (1980).

Table 4 The concentrations of airborne elements in various metropolitan areas

Cities	Item	TSP	Heavy Metals							
			Fe	Cu	Zn	Ni	Pb	Mn	Cr	Cd
Tokyo	Mean	220	4.5	0.068	<1.1	0.05	<0.30	0.15	<0.04	
	Min.	74	0.6	0.015	<1.1	<0.03	<0.30	<0.10	<0.04	
	Max.	419	13.7	0.250	2.1	0.11	1.18	0.35	0.047	
New York	Mean		3.4	0.37	0.4	0.187	1.9	0.05	0.002	0.000
Birming-ham	Mean	142	1.7	0.06	1.09	0.004		0.15	0.005	0.008
Peking	Mean	525	16.8	0.098	0.56	0.024	0.56	0.71	0.031	0.008
	Min.	130	0.97	0.02	0.02	0.004	0.13	0.07	0.007	0.0001
	Max.	1550	130.7	0.25	1.63	0.05	1.36	3.5	0.07	0.0016
Hong Kong	Mean	145.4	2.29	0.080	1.05	0.02	1.05	0.09	0.02	0.0018
	Min.	7.0	0.15	ND	ND	ND	0.03	0.01	ND	ND
	Max.	478.8	10.87	2.228	20.18	0.24	11.83	0.46	1.16	0.009

Units: ug/m^3

Sources: (Wong, et al., 1980)[6], (Corn, 1976)[7], (Butler, 1979)[8] and (Kran Lan et al., 1972)[9].

6. A.P. Wong, et al., Chemical Characteristics of Airborne Particles in Beijing Area, *Acta Sciential Circumstantiae*, Vol. 1, No. 3, pp. 220-233, 1981.
7. M. Corn, Properties of Nonviable Particles in Air, in A.C. Stern ed. *Air Pollution*, Vol. 1, Part A, Capter 3, pp. 78-158, 1976.
8. J.D. Butler, *Air Pollution Chemistry*, Academic Press, 1979.
9. Lan Kran et al., *Environmental Science*, a Chinese Transcription, Shanghai, Scientific Press: 1978.

Liang[10] indicated that Sham Shui Po district is dominated by the residential landuse, but at the ground-floor, the buisness landuse included the resturants, which are the main sources of soot emissions, are broadly and densely distributed at the groundfloor. Otherwise, the high traffic flow volume on the roads, which are blocked by congested highrise buildings, may introduce a large amount of soot and airborne Pb into the ground-level ambient air.

Kwai Chung district was newly developed since 1970. The industrial buildings are typically high (the building that the sampler site on is 33 storeys). To compare this great height with the width of the narrow streets, the serious "street canyon" effect can be imagined and this effect may cause the accumulation of the soots emitted from the numerous heavy lorries passing by, and of the waste gases and minute solids, mostly exhausted through the window by the exhaust systems, in the lower floors ambient air. Besides, the higher concentration of airborne Cu at the roof-level ambient air may be due to the numerous small electrical factories and engineering workshops, which mainly distributed at the small units in the upper floors.

Liang (1972) indicated that Tai Kok Tsui district is the mixed industrial and residential zone, in which the vertical land use except for the ground-floor are the combination industrial and residential. The mixing ratio of industrial land use to residential land use did gradually increase even to gain access to 100% at the top floor from the ground floor upward. Even the roofs of the buildings are usually utilized as godowns or taken as the workshops for various types of products. Otherwise, the sampler is sited near the seashore, the strong sea breeze may reduce the "street canyon" effect on the lower floors ambient air. Therefore, at this district, the mass concentration of TSP and airborne Pb between the ground-level and the roof-level ambient air are not significant different. Moreover, the pollutants emitting from such small-scale factories at the roof or upper floors even cause a high concentrations of other airborne elements in the roof-level ambient air.

3.3 The implications of meteorological parameters in the particulate pollution

In this section, the daily maximum mixing depth, the daily amount of rainfall, and the daily average wind speed in each sampling day, are taken into account in evaluating their relationships to the particulate pollution level at each monitoring site through multiple regression procedures. Following the use of a computer, the standardized regression equations for the monitoring sites are listed below:

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10. as 5.

Table:5: The Concentrations of the Airborne Pollutants at the Roof-level and Ground-level Ambient Air at the Monitoring Sites

Site	Items	TSP		Airborne elements															
				Fe		Cu		Zn		Ni		Pd		Mn		Cr		Cd	
		Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level	Mean Range	Sign level
Sham Shui Po	Roof	248 202-281	0.03	2.87 1.70-5.40	0.39	0.07 0.041-0.16	0.20	0.62 0.067-1.40	0.38	0.037 0.022-0.05	0.66	0.732 0.37-0.88	0.06	0.140 0.037-0.035	0.58	0.016 ND-0.02	0.38	0.002 ND-0.004	0.30
	Ground	277 190-329		2.55 1.64-4.03		0.06 0.035-0.10		0.81 0.26-1.42		0.033 0.009-0.06		0.86 0.66-1.28		0.121 0.05-0.21		0.012 ND-0.033		0.0013 ND-0.004	
Kwai Chung	Roof	197 95-314	0.00	2.32 1.0-5.0	0.002	0.47 0.25-0.8	0.003	1.05 0.39-1.83	0.02	0.128 0.05-0.42	0.39	1.02 0.41-1.52	0.007	0.096 0.036-0.21	0.006	0.031 0.01-0.05	0.008	0.0026 ND-0.006	0.72
	Ground	318 240-410		5.04 1.7-10.0		0.24 0.07-0.5		1.71 0.39-4.32		0.099 0.04-0.23		3.80 1.74-11.8		0.202 0.061-0.44		0.09 0.006-0.24		0.0024 ND-0.007	
Tai Kok Tsui	Roof	136 69-174	0.50	2.52 1.17-3.53	0.76	0.13 0.05-0.17	0.00	1.98 0.20-10.3	0.45	0.051 0.015-0.15	0.005	0.674 0.41-1.09	0.17	0.0152 0.04-0.29	0.70	Not analyzed		0.0021 ND-0.0045	0.16
	Ground	144 84-233		2.22 1.42-4.68		0.06 0.01-0.12		1.28 0.08-3.3		0.019 ND-0.026		0.384 0.48-1.29		0.14 0.03-0.34				0.0015 ND-0.0043	

Units: ug/m^3

ND: below the detection limits

Sign level: The significance level of the paired T-test

$Y_M = -0.155X_1 - 0.072X_2 - 0.164X_3$ ---------------- (Kwai Chung)

$Y_M = -0.109X_1 + 0.408X_2 - 0.170X_3$ ---------------- (Sham Shui Po)

$Y_M = -0.181X_1 - 0.045X_2 + 0.193X_3$ ---------------- (Tai Kok Tsui)

$Y_M = -0.052X_1 + 0.352X_2 + 0.291X_3$ ---------------- (Kowloon Tong)

$Y_M = -0.221X_1 + 0.195X_2 + 0.200X_3$ ---------------- (C.U.H.K.)

where X_1 = the amount of daily rainfall

X_2 = the daily average wind speed

X_3 = the daily maximum mixing depth

Y_M = the mass concentration of TSP in the ambient air

However, in the regression analysis, some procedures ought to be employed to determine whether the variability of the pollution level is implicated in the predictors (independent variables) or only in other uncertain factors, or sampling fluctuation due to measurement error.[11] These testing procedures includes: (1) the over-all F-test; (2) the F-test for a subset of regression coefficients; (3) the F-test for a specific regression coefficient.

The over-all F-test is employed to determine whether or not the variation in pollution levels is significantly explained by the combined linear influence of independent variables (see Table 6). The results indicate that at the four monitoring sites in the urban area, the observed significance levels are greater than 0.05, some of them are smaller than 0.1, which mean that three meteorological parameters together may not or may only partially explain the particulate pollution level in the urban areas. In the contrast, in the open country such as the campus of C.U.H.K., these meteorological variables combined can significantly predict the particulate pollution level.

Since the insignificance of multiple R may be due to some extreme insignificant regression coefficients, a stepwise selection procedure is employed to determine which variables should be deleted from the equations[11]. Below are the revised regression equations after the stepwise selection procedures. The significance level is 0.1

Y_M = no variables (Kwai Chung)

$Y_M = -0.109X_1 + 0.408X_2 - 0.171X_3$ (Sham Shui Po)

$Y_M = 0.193X_3$ (Tai Kok Tsui)

$Y_M = -0.052X_1 + 0.352X_2 + 0.291X_3$ (Kowloon Tong)

$Y_M = -0.221X_1 + 0.195X_2 + 0.200X_3$ (C.U.H.K.)

11. Marija J. Norusis: *SPSS introductory guide: basic statistics and operations*, McGraw-Hill Book Company, Chapter 10, pp. 91-129, 1982.

Table 6 The Overall F-test for Goodness of Fit of Regression Coefficients (Dependent Variable: Mass Concentration of TSP)

Site	Multiple R	R square	D.F. (K-1, N-K-1)	F Value	Sign. Level
Kwai Chung	0.207	0.043	(3, 32)	0.476	$>$ 0.1
Sham Shui Po	0.431	0.186	(3, 33)	2.51	$<$ 0.1
Tai Kok Tsui	0.337	0.117	(3, 34)	1.45	$>$ 0.1
Kowloon Tong	0.472	0.223	(3, 26)	2.488	$<$ 0.1
C.U.H.K.	0.392	0.153	(3, 88)	5.310	$<$ 0.05

Multiple R = multiple correlation coefficient
R square = square of multiple correlation
D.F. = degree of freedom

It is interesting that no variables can be entered into the equation for the monitoring site of Kwai Chung District at the 0.1 significance level. It reflects that not only all of the independent variables are combined, but also the most important variable is insignificant to predict the pollution level in such a polluted industrial area. Certainly, there should be some other uncertain factors contributing much effects on the particulate pollution rather than solely meteorological parameters.

However, even the subset of variables is significant and the multiple R of the subset of regression coefficient is assumed to be not zero, it does not mean that all regression coefficients are not zero since an extreme significant variable may greatly increase the significance of the subset of the variables.[12] In order to determine which specific variable is significant. The F-test for the specific regression coefficient is employed in this study. The results is listed on Table 7.

Besides the mass concentration of TSP, the airborne Pb is the main anthropogenic pollutant in Hong Kong (refer to 3.1 and 3.2). Therefore, the implications of the meteorological parameters on this element are also drawn out through the same statistic procedures (see Table 8 and Table 9). The regression equations are listed below.

12. As 11.

Table 7 The F-test for the Specific Regression Coefficient
(Dependent Variable: Concentration of TSP)

Site	Variable	B	Beta	STD error B	D.F. (1, N-K-1)	F value	Sign. level
Kwai Chung	Mixing depth	-0.39	-0.164	0.043	(1, 32)	0.833	> 0.1
	Rainfall	-0.20	-0.145	0.250		0.636	> 0.1
	Wind speed	-2.60	-0.072	0.275		0.171	> 0.1
	(constant)	338.14					
Sham Shui Po	wind speed	8.755	0.408	3.563	(1, 33)	6.038	< 0.05
	Mixing depth	-0.340	-0.171	0.033		1.045	> 0.1
	Rainfall	-0.427	-0.109	0.686		0.387	> 0.1
	(constant)	207.20					
Tai Kok Tsui	Mixing depth	-0.196	0.193	0.019	(1, 34)	1.066	> 0.1
	Rainfall	-0.317	-0.181	0.326		0.945	> 0.1
	Wind speed	-0.520	-0.045	1.937		0.072	> 0.1
	(constant)	148.71					
Kowloon Tong	Wind speed	5.777	0.352	2.895	(1, 26)	3.982	< 0.1
	Mixing depth	0.420	0.291	0.026		2.598	> 0.1
	Rainfall	-0.252	-0.052	0.885		0.081	> 0.1
	(constant)	20.427					
C.U.H.K.	Rainfall	-2.58	-0.221	0.12	(1, 88)	4.395	< 0.05
	Wind speed	2.22	0.195	1.12		3.919	< 0.1
	Mixing depth	0.17	0.200	0.01		3.605	< 0.1
	(constant)	38.79					

B = partial regression coefficient   Beta = standardized partial regression coefficient

(1) The initial model

$Y_P = -0.151X_1 - 0.139X_2 - 0.346X_3$ (Kwai Chung) .... (1)

$Y_P = *X_1 - 0.122X_2 - 0.274X_3$ (Sham Shui Po) .... (2)

$Y_P = -0.038X_1 - 0.429X_2 - 0.165X_3$ (Tai Kok Tsui) .... (3)

$Y_P = 0.128X_1 - 0.246X_2 - 0.194X_3$ (Kowloon Tong) .... (4)

$Y_P = -0.084X_1 - 0.386X_2 - 0.058X_3$ (C.U.H.K.) .... (5)

(2) The revised Model

$Y_P = -0.346X_3$ (Kwai Chung) .... (1)'

Y_P = no variables (Sham Shui Po) .... (2)'

$Y_P = -0.429X_2 - 0.165X_3$ (Tai Kok Tsui) .... (3)'

Y_P = no variables (Kowloon Tong) .... (4)'

$Y_P = -0.084X_2 - 0.386X_3 - 0.058X_4$ (C.U.H.K.) .... (5)'

where Y_P = the concentration of airborne Pb in the ambient air

After the overall F-test (see Table 8), it is also found that only at the campus of C.U.H.K., the model is significant at the 0.05 significance level. It reflects that these meteorological parameters combined are insignificant for predicting the concentration of Pb at these districts in the urban area.

Table 8 The Overall F-test for Goodness of Fit of Regression Coefficient (Dependent Variable: Concentration) of Pb)

Site	Multiple R	R square	D.F. (K-1, N-K-1)	F value	Sign. Level
Kwai Chung	0.369	0.136	(3, 32)	1.687	> 0.1
Sham Shui Po	0.284	0.080	(3, 33)	1.492	> 0.1
Tai Kok Tsui	0.425	0.181	(3, 34)	2.504	< 0.1
Kowloon Tong	0.342	0.117	(3, 26)	1.150	> 0.1
C.U.H.K.	0.407	0.165	(3, 82)	5.413	< 0.05

Multiple R = multiple correlation coefficient

R square = square of multiple correlation coefficient

D.F. = degree of freedom

*: The variable is too significant that the F-level and the tolerance levels are not sufficient for further calculation.

Table 9 The F-test for the Specific Regression Coefficient
(Dependent Variable: Concentration of Airborne Pb)

Site	Variable	B	Beta	STD error B	D.F. (1, N-K-1)	F value	Sign. level
Kwai Chung	Mixing depth	-0.050	-0.246	0.002	(1, 32)	4.099	< 0.1
	Rainfall	-0.126	-0.151	0.014		0.761	> 0.1
	Wind speed	-0.302	-0.139	0.361		0.699	> 0.1
	(constant)	11.215					
Sham Shui Po	Mixing depth	-0.00308	-0.274	0.0002	(1, 33)	2.722	> 0.1
	Wind speed	-0.149	-0.122	0.020		0.541	> 0.1
	Rainfall*						
	(constant)	1.228					
Tai Kok Tsui	Wind speed	-0.384	-0.428	0.014	(1, 34)	7.161	< 0.05
	Mixing depth	-0.0013	-0.165	0.0001		0.846	> 0.1
	Rainfall					0.046	> 0.1
	(constant)						
Kowloon Tong	Mixing depth	-0.00197	-0.194	0.0002	(1, 26)	1.018	> 0.1
	Wind speed	-0.272	-0.236	0.022		1.571	> 0.1
	Rainfall	-0.0435	0.128	0.006		0.429	> 0.1
	(constant)	1.038					
C.U.H.K.	Wind speed	-0.590	-0.386	0.015	(1, 88)	14.565	< 0.01
	Rainfall	-0.0175	-0.084	0.002		0.633	> 0.1
	Mixing depth	0.00069	0.058	0.000		0.295	> 0.1
	(constant)	0.967					

B = partial regression coefficient Beta = standardized partial regression coefficient
* = the variable is too significant that the F-level or tolerance-level insufficient for further computation

After the stepwise selection procedure, there are no variables entering into the equation for Sham Shui Po and Kowloon Tong Districts. This shows that the meteorological parameters have not significant influenced the variation of airborne Pb in these districts.

However, only the general proporties of these regression model are introduced, the relations of each meteorological parameters to the particulate pollution may be discussed in the following.

a. rainfall

In the study, it is found that there is only a significant inverse relationship between the mass concentration of TSP and the daily rainfall at the campus of C.U.H.K. At other monitoring sites, the relationships between the rainfall and TSP or airborne Pb are not significant (see Table 7 and Table 9). It is believed that in the urban area, the day-to-day fluctuations of the various small, low pollution sources and the complicated micrometeorological conditions due to the effect of congested high buildings may lead to more changes of particulate pollution level than the precipitation.

In the open country as on the campus of C.U.H.K., the amount of precipitation can significantly predict the variation of the particulate pollution in the atmosphere since the observed significance level is less than 0.05. For instance, the minimum levels were recorded at two consecutive sampling days (29 December, 1982 and 30 December, 1982); the levels are 7.0 and 8.8 ug/m^3 respectively; the rainfall of those days are 71.1 mm and 20 mm per day respectively. This is an evidence that a lower particulate pollution level may be induced by the cleansing effect of the heavy rainfall.

With respect to the low ability of from precipitation to predict particulate pollution level, a defect in the regression models ought to be evaluated here. It is assumed that the cleansing effect of the precipitation would reduce the particulate pollution level not only on that rainy day but also on the succeeding days although it has no rainfall record. In these quantitative models, the precipitation effects on such succeeding days cannot be evaluated.

b. The wind speed

Many dispersion models dealing with a highly elevated emission source in the open country or the multiple, small, low volume sources in the urban area, take surface wind speed as a dispersion parameter. However, it is found that at Kowloon Tong District and the campus of C.U.H.K., the density of the population and buildings are low, and except the exhaust soot from the automobiles, there are no significant pollution sources (see Table 7 and Table 9). Therefore, there are less pollutants needed to be dispersed by the wind, and by contrast, the strong wind may lead to the resuspension of street dust and the surface soil. The significant positive relationship between the TSP and the wind speed can be the evidence that the resuspension effect of the wind is implicated in the higher concentration of TSP in the ground-level ambient air. However, for the airborne Pb, a significant inverse relationship between wind speed and Pb concentration is the evidence that the dispersion effect of the strong wind is implicated in the lower concentration of airborne Pb in the ground-level ambient air on the campus of C.U.H.K.

In the urban areas in Hong Kong, the buildings are typically high and congested. The roads are the "canyon-like" streets as they are relatively narrower to compare with the buildings. In such areas, the prevailing strong winds may cause a downwash effect behind the buildings and the eddies circulated within the street canyons, and both can accumulate the pollutants and raise the street dust in the "canyons". Thus, the measured ground-level TSP is strongly influenced by the aerodynamics of nearby high buildings and the dispersion effect of the wind is reduced. Therefore, at the Sham Shui Po District, as the monitoring site is surrounded by tall multi-storey buildings, the strong wind even causes a higher concentration of particulates, thus, the significantly positive correlation between the TSP and the wind speed is obtained.

In the Tai Kok Tsui and Kwai Chung districts, the relationships between wind speed and the TSP are insignificantly inverse. It reflects that the dispersion effect of the wind is insignificant in the ground-level ambient air. However, in considering the airborne Pb, a significantly inverse relationship is found at the Tai Kok Tsui District. These reflect that the strong wind still can disperse the emitted anthropogenic pollutants and reduce their concentration.

The results seem to show that in these districts, the wind may in some cases, resuspended the surface dust to raise the concentration of TSP, and in other cases, disperse the emitting pollutants to reduce the concentrations of such airborne elements. However, since the number of sampling days are small, the real effect of the wind speed cannot be assessed in this study. It needs much observations and further studies.

c. The mixing depth

It is recognized that the lapse rate near the ground, especially on a sunny afternoon, is often superadiabatic but that at equilibrium it becomes more nearby dry adiabatic. Thus, the mixing depth is defined as the top of a surface-based layer in which the vertical conventional current is relatively vigorous and in which the necessary lapse is approximately dry adiabatic. It is believed that the higher the mixing depth, the greater the temperature of ground-layer air is, and this results in strong vertical turbulance and eddies near the ground.

At the campus of C.U.H.K. and in the Kowloon Tong District, the relationships between the concentration of TSP and the mixing depth is significantly positive. These reflect that the higher concentrations of TSP is implicated in the unstable atmospheric conditions, under which the stronger mixing currents and eddies near the ground may cause the resuspension of the surface dust. However, at Tai Kok Tsui, Sham Shui Po and Kwai Chung districts, the relationships are not significant. (see Table 7 and Table 9)

For airborne Pb, the significantly inverse correlation between the concentration of airborne Pb and the mixing depth at Kwai Chung District is found. It reflects that the airborne Pb may be significantly dispersed by the strong conventional currents under the instable atmospheric conditions in this district. In the other districts, the correlations are not significant.

4. Conclusions and suggestions

The spatial variation of particulate pollution does exist in Hong Kong. Among all monitoring sites, the highest level of pollution was detected in Kwai Chung District since numerous pollutants are emitted from the factories. It is interesting that even in the commercial-residential areas, in which fewer factories are located, the particulate pollution level is so high that the level is above the primary air quality standard, which would be harmful for the dwellers. The high level of particulate pollution in this district seems to be due to the numerous small pollution sources such as the restaurants, domestic cooking facilities and automobiles, and the congested high buildings may contribute to the poor ventilation conditions.

Since the spatial variations in particulate pollution exist, the divisional ambient air quality standards for each land use zone should be declared when the overall air quality control bill be enacted in the near future.

The vertical variation of the particulate pollution is very complicated. It depends on vertical land use patterns, ventilation conditions at the lower floors, and other uncertain factors. Therefore, the ambient air quality at the roof may not necessarily be better than that at the ground-level.

As vertical variations in particulate pollution levels really do exist, the observed air quality monitored at the roof of the building may not be exactly the ambient air quality of the represented region. Therefore, for monitoring and managing the particulate pollution problem, which site is most appropriate to be adopted for the study of ambient air quality is an important issue, especially in a city full of dense and tall buildings, within which the "street canyon" effect is serious.

Among the airborne elements analyzed in this study, lead is cause for the most serious concern, as the airborne lead pollution levels are higher than the national maximum permitted levels in many countries. Even at the campus of The Chinese University of Hong Kong, which lies in a nonurban area. The control programme of related emission sources must be immediately taken into action. To reduce the volume of lead in motor fuel may be the most efficient method, as the automobile is the main source of the airborne lead.

Rainfall is usually taken as the important cleansing factors for atmosphere pollution. However, in this study, the effect of this meteorological parameter is varied and seems to be of only local significance. It cannot act as a predictor for the variability of the pollution levels of the airborne particulates in the urban area.

The wind speed and the mixing depth are usually considered as the dispersion parameters in the prediction of the concentrations of the pollutants, but in this study, the effects only have local significance. In the urban area, these dispersion effects are not significant and cannot be taken as the predictors for the variation of the concentrations of the pollutants.

With regard to inference or generalizations, the regression equations and their coefficients are not mentioned here, because they have only local significance. However, this is not an unusual matter because even many pollution estimating models are also based on experimental diffusion trials mainly over open country. However, it is far from complete, particularly for the densely populated cities. The process of transport and diffusion of pollutants in the metropolitan regions is very complicated and it is hard to be generalized as the effects of the micrometeorological and anthropogenic conditions are uncertain.

However, in relatively open spaces, i.e. Kowloon Tong District and campus of C.U.H.K., the effects of the meteorological parameters on the pollution level are relatively more significant than in the densely populated urban areas. In these areas, there are fewer pollution sources, and in addition to low density population and buildings, the predictions of meteorological parameters are higher as the other factors are less significant.

In the commercial-residential areas, which are congested with tall multi-storeys buildings, the dispersion effect is weak due to the poor ventilation in the "street-canyons". Thus, the ambient air quality of airshed at such lower levels would be of considerable concern, since the pollutants may be stagnated or accumulated between the buildings, and the dwellers living at the lower floors may be directly affected.

In comparison with some big cities in the world, the present status of particulate pollution in Hong Kong is not cause for serious alarm. However, in the industrial areas and the densely populated areas, efficient control and management are urgently required as the concentrations are far above national ambient air quality standards.

For the management of atmospheric environment, the continual monitoring, evaluation and observation of the ambient air quality is necessary, but the monitoring sites must be carefully considered, as distance from the emission sources or even from the nearby high buildings, the plot of the samplers, and the ventilation conditions, can all affect the actual status of the represented regions.

Appendex National Ambient Air Quality Standards for Suspended Particulates

/Country	Long-term standard		Short-terms standard		Notes
	ug/ ug/m³	Averaging time (hours)	ug/m³	Averaging time (minutes)	
Argentina	100	30 days			
Bulgaria, Czechoslovakia, E. Germany, Finland, Romania U.S.S.R.	150	24	500	30	
Canada-					
Acceptable level	70	1 year			a
Acceptable level	120	24			b
Canada-					
Desirable level	60	1 year			c
Colombia	100	24			
Hungary	200	24			
Hungary, Turkey	100	24			d, e
Israel	200	24			
Israel	75	1 year			
Italy	300	24	750	120	f
Japan	100	24	200	60	g
Poland	200	24	600	20	
	75	24	200	20	h, i
	130	1 year			
Spain	200	30 days			j
	300	24	600	30	j
British	40	1 year			
	120	24			k

(to be continued)

Appendex (cont'd)

NOTE:

a. National Air Quality Objectives in Canada

b. Maximum acceptable level in Canada

c. Desirable level in Canada

d. Recommended standard in Turkey

e. Residential areas in Turkey

f. Once is 8 hours in Italy

g. Average of hourly means for 24 hour value in Japan

h. Specially potected areas in Poland

i. Particle size 20 um.

j. Proposed standard in Spain

k. 98% of observations below this value, the permissible 2% of observations over this limits may not fall on consecutive days

Source: Newill (1976)