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Study of Particulate at Roadside Microenvironments in Selected Heavily Trafficked Districts in Hong Kong

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ABSTRACT

This research aimed at using the field study data from November 1996 to February 1997 to evaluate the particulate air pollution in selected roadside microenvironments in Hong Kong. The study employed microenvironment monitoring technique to access the exposure of pedestrian to respirable suspended particulate and airborne lead at heavily trafficked roadside. A total of 62 roadside sites in 14 districts were selected which covered the most urbanized and densely populated area. It was found that pedestrians exposed to 24-hour average RSP and airborne lead typically ranged from 25.56 to 337.40 $\mu g/m^3$ and 0.0707 to 0.2857 $\mu g/m^3$. The average was 109.50 and 0.1445 $\mu g/m^3$ respectively. Moreover, the field data was compared with the data of Environmental Protection Department (EPD) measured at low roof top and street level monitoring stations. It was found that measurement at EPD monitoring stations might not reflect the actual roadside exposure. Most field study data was significantly higher than the nearby fixed station data. The effects of the different roadside microenvironment and landuse pattern RSP and airborne lead concentration.

INTRODUCTION

Hong Kong is among the most densely populated cities in the world and the population of about 6 million lives in a built up area of about 146 km^2. The residential, commercial and industrial activities are closely linked. The main built up areas and the urban centers are situated on both sides of the Victoria Harbor in Hong Kong Island and Kowloon Peninsula and is characterized by complex road network and high traffic flow. There are also a few new satellite towns in the New Territory with growing population and traffic.

Hong Kong has many unique air pollution problems which are complicated by high building density and the complex terrain. High rise buildings and on narrow streets have hampered the efficient dispersion of pollutants. Thus, air pollutant, especially particulate, post a threat to the health of pedestrians at busy and congested roads.

Moreover, with the growth in our economy, rapid developments in the road network and an increasing need for individual mobility, traffic increases continuously. In 1996, there were a total of 25.6 million vehicle-kilometers traveled by vehicles representing an average of 63.8 km per day per licensed vehicle. And there were about 470 and 870 million liters of petrol and diesel sold to petrol and diesel powered vehicles respectively. (Hong Kong Transport Department, 1996) (11) As a result, the pollutants emitted by these huge number of vehicles have found to be the main contributor to the local air pollution in Hong Kong. (Environmental Protection Department, 1996).(7) Although various current measures are introduced to reduce vehicle emission, the problem is still serious, particularly, in the urban areas with heavy traffic. This is reflected in the relatively high level of respirable suspended particulate and nitrogen dioxide which consistently breaches the Air Quality Objectives (AQO)of Hong Kong. (Environmental Protection Department, 1996) (8)

Particulate matter with aerodynamic diameters less than 10μm (PM_{10}) have found to associate with urban health problems such as the increases in daily mortality and asthma. (Dockery, 1994; Anderson, 1992) (1,4) In Hong Kong, apart from a small number of light goods vehicles, majority of commercial vehicles such as taxi, public light buses and heavy goods vehicles run on diesel fuel and contributes almost two-thirds of the total vehicle mileage as well as 98% of all emitted particulate. (Clean Air, 1995)(2) Diesel particles are small and respirable (less than 10 microns in diameter) and arise primarily through incomplete combustion of fuel. Hence, there is causes to concern about the effect of vehicle emission and pollutant dispersion in roadside microenvironments of heavily trafficked districts.

In the study of human exposure to air pollution, microenvironment was defined by Duan (1982)(5) to be a chunk of air with homogeneous pollutant concentration. The variation of concentration within the microenvironment was less than the variation between the microenvironment and its neighbouring microenvironments (Mage, 1985)(14). Emissions from motor vehicle vary with different driving condition which include driving mode, speed and engine temperature. Dispersion depends on meteorology and street condition. Thus, the air pollution levels vary along the different sub-microenvironment within the same street.

The Environmental Protection Department (EPD) operated nine air quality monitoring stations in the territory in 1996. Eight of them were located on low roof top (4 to 6) stories above street level, for the determination of the ambient air quality in a district. There was only one at Mong Kok which is at street level and is intended to measure the impact of vehicle emissions. There were also several short-term curbside measurements undertaken by EPD staff using a mobile laboratory in a few limited locations. It was found that the concentrations of pollutants were much greater at street level than at even a few meters above the street. (Rusco, 1995)(15) It is due to the more predominant ground level traffic emission which led to more severe pollution perceived by the ground level commuters. This study employed microenvironmental field study and analysis technique because the street commuters and pedestriansï¿½ exposure could not be inferred from ambient air quality measurements obtained at the fixed stations. With a view to human exposure in roadside microenvironment, a field study using microenvironmental technique to use to study the RSP and airborne lead in Hong Kong . The survey results are presented in this paper.

FIELD STUDY

Sampling Site Selection

A total of 62 roadside site in 14 districts (2 to 6 roadside sites within each district) were selected for the RSP study. (Figure 1 and Table 1) They cover most of the urbanized and densely populated Air Control Zones. (The location of the sites are shown on figure 1.) The selection was based upon the type of land use, the traffic flow and the population distribution. They are classified into (1) Urban and Industrial Area, (2) Urban and Residential Area, (3) Urban and Commercial Area, and (4) New town.

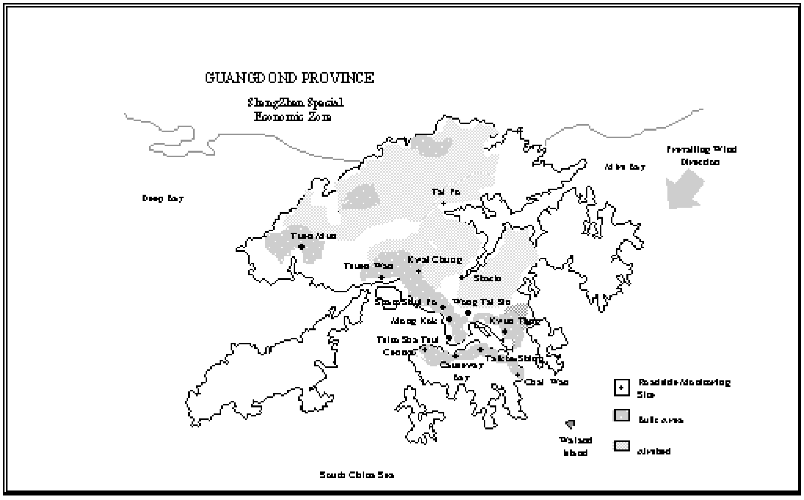


Figure1. Metropolien areas of Hong Kong and roadside PM10 monitoring sites.

Table 1. Roadside Site Location						
Area type	District	no. of site in each microenvironment				Total no. of site
		Junction	Traffic Light	Bus-stop	Normal	
Residential	Mong Kok	1	2	1	1	5
	Sham Shui Po	1	2	1	1	5
	Wong Tai Sin	1	0	0	1	2
	Taikoo Shing	0	1	0	1	2
Commercial	Central	2	1	1	2	6
	Causeway Bay	2	0	1	1	4
	Tsim Sha Shui	1	1	1	2	5
Industrial	Kwai Chung	1	1	1	2	5
	Chai Wan	0	1	0	1	2
	Tsuen Wan	1	1	1	2	5
	Kwun Tong	1	1	0	1	3
New Town	Shatin	2	2	2	2	8
	Tai Po	2	0	0	0	2
	Tuen Mun	1	2	1	2	6
					TOTAL=	60

All selection were characterized by the types of microenvironment incorporating the effect of traffic light, bus stop, road junction and normal traffic. The selection was also influenced by convenience and accessibility for sample collection. Care had been taken to limit the influence of the immediate local sources such as unpaved roads, railroads, construction sites and emission sources of factory and restaurant.

Survey Procedure and Data Collection

Sample Collection:

Sampling was conducted intensively from mid January to mid February 1997. The sampling duration was 24 hours for three day (two weekday and Sunday) for each sampling site. All samplers were mounted on light pole about 1m from the roadside and 3.5 m from the ground. MINIVOL portable samplers (Airmetrics) were used for RSP sampling which was battery powered. The flow rate of the inlet was 5 litres per minutes. The PM_{10} sampler which for allows the collection of particles less than or equal to 10µ m in diameter was used. Every day prior to sampling, the field operator had to check each sampler for proper operation and damage. Included in the daily quality control reviews were checks for battery power, flow rate, volume of air sampled, elapsed time, leaks, and unusual filter conditions including damage, odour, discoloration, or loose particles on the filter. Following common practice any abnormal conditions were noted on the field forms and flagged. (EPA, 1994)(9)

Gravimeric and Atomic Absorption Spectrometric Analysis:

An open top balance (Mettler AE163) with accuracy of 0.01 mg was used to weight the filter paper which was conditioned in an electronic desiccator before and after sample collection for 24 hours. The balance was placed on top of a concrete bench with anti-vibration table. The filter were stored flat on the petri dish and covered after conditioning or weighing had completed.

Standard acid digestion procedure for the RSP sample filters were followed. Lead was analyzed with Perkin-Elmer 3300 Atomic Absorption Spectrophotometer (AAS). The same procedure was carried out for sample, control filter blank and reagent blank. (ASTM D3559)

Comparison between different sampler:

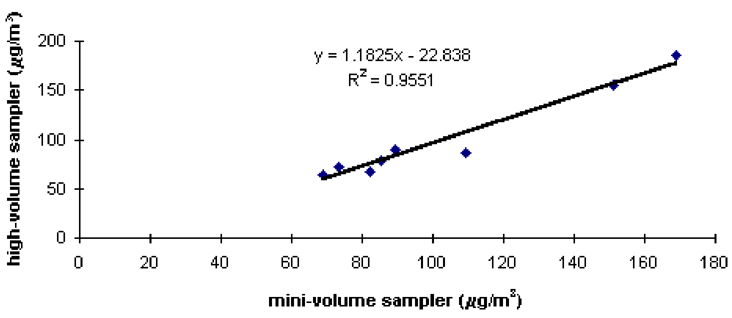
One TSP high volume sampler, one RSP high volume sampler and one RSP mini-volume sampler were operated at the HKPU road side site in the same period in order to determine the correlation between the different samplers. The samplers were placed on the pavement at about 0.5 metre from the roadside where 24- hour sample was collected.

RESULT AND DISCUSSION

A total of 180 PM_{10} samples were collected during the roadside study. Overall, 94.4 percent (170) of the samples collected had passed the screening check. The samples were rejected due to damage of the filter paper during handling and transportation, occasionally low flow rate of the sampler, and the malfunction of the samplers.

The mini-vol portable sampler is a new PM_{10} monitor and its performance is still under study. Hence, we had performed comparison data from the collocated portable and of the high-volume sampler to assess the performance of the portable sampler relative to a EPA reference methods. The average ratio of mini-volume to high-volume sampler was 1.07. The square of the correlation coefficient was 0.9551. (Figure 2) That is, the correlation between portable sampler data and high volume PM10 sampler is good. The result is close to those reported in an overseas study.(Eric S. Ringler,1992) On average, the portable sampler was slightly positively biased (by about 1 to 5 µg/m^3). The accuracy was within the 10 % flow audit limit. Thus, the data collected by mini-volume sampler can be converted to high-volume sampler scale by [0.954 x RSP measured by mini-vol sampler] for comparison with the data from EPD fixed station.

Fig 2. RSP Concentration measured by Mini-Volume Portable Sampler and High-Volume Sampler



Statistical results of the PM_{10} collected from the 14 districts operating are included in Table 2 and Table 3. The concentration level of PM_{10} ranged from 25.56 µg/m^3 to 337.46 µg/m^3. The concentration data were fairly symmetrically distributed with a mean of 109.50 µg/m^3 and a median of 101.62µg/m^3. (Figure 3) The overall mean concentration of PM_{10} was within both the RSP daily limit of the Hong Kong Air Quality Objective (HKAQO) (180 µg/m^3) and the daily PM_{10} limit of National Ambient Air Quality Standards (NAAQS) (150 µg/m^3) However, the mean concentration for the Central district (166.58 µg/m^3), one of the commercial area, exceeded the daily PM_{10} limit of NAAQS. Moreover, for the individual sampling points, there were 24 exceedances of the PM_{10} daily limit of NAAQS. The exceedances were measured at three districts belonging to different types of land use. The highest value was 337.40 µg/m^3 recorded at Central, one of the urban and commercial area with narrow streets and high buildings. The second highest value was 262.49 µg/m^3 recorded at the same district in a different micro-environment on the same day. The lowest value (25.559 µg/m^3) was measured at Taikoo Shing, one of the residential area with relative low traffic flow during high humidity period.

Table 2 Average RSP Concentration at Different Road Microenvironment

Area type	District	Average Concentration (mg/m^3)				District Average	Lowest Conc.	Highest Conc.	Land use type
		Junction	Traffic Light	Bus-stop	Normal	(mg/m^3)	(mg/m^3)	(mg/m^3)	average(mg/m^3)
Residential	Mong Kok	103.42	104.50	93.92	87.45	98.76	78.76	115.43	
	Sham Shui Po	117.81	137.86	163.78	111.62	133.78	87.81	182.61	
	Wong Tai Sin	60.15	----	----	126.38	93.27	36.43	169.70	
	Taikoo Shing	----	54.94	----	53.85	54.40	25.48	93.32	95.05
Commercial	Central	104.15	228.10	136.50	154.45	166.58	80.50	337.46	
	Causeway Bay	----	126.42	98.40	98.80	112.51	72.16	207.20	
	Tsim Sha Shui	106.53	101.35	107.10	112.48	107.99	91.29	136.08	129.03
Industrial	Kwai Chung	117.40	121.84	137.42	125.01	125.34	82.45	172.08	
	Chai Wan	----	55.50	----	61.20	58.35	38.71	75.99	
	Tsuen Wan	73.30	78.56	113.94	78.57	84.59	31.96	159.16	
	Kwun Tong	75.75	91.62	----	75.45	80.94	50.15	122.34	87.30
New Town	Shatin	120.72	125.57	120.78	95.67	115.68	56.16	241.88	
	Tai Po	----	134.28	----	----	134.28	106.94	153.42	
	Tuen Mun	74.80	104.52	85.31	79.36	87.98	25.63	179.90	112.65

Fig. 3 Mass Distribution of the RSP for the all area

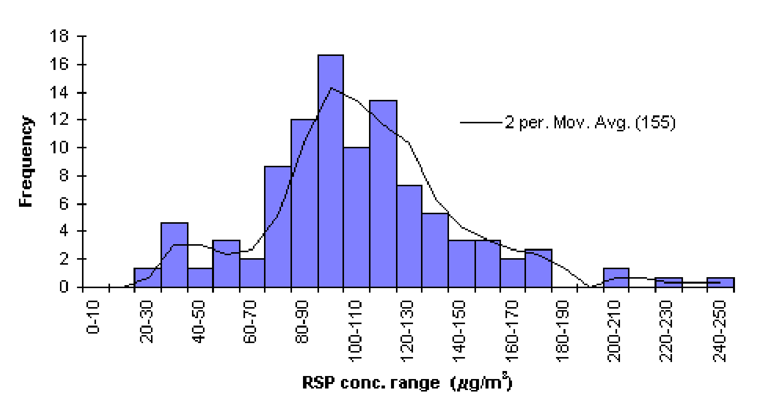


Table 3 Average APb Concentration at Different Roadside Microenvironment

Area type	District	Average Concentration (hg/m^3)				District Average	Lowest Conc.	Highest Conc.	Land use type
		Junction	Traffic Light	Bus-stop	Normal	(hg/m^3)	(hg/m^3)	(hg/m^3)	average(hg/m^3)
Residential	Mong Kok	127.14	182.68	127.86	112.50	135.46	88.75	285.71	
	Sham Shui Po	88.57	101.79	158.57	100.71	110.28	87.81	182.61	
	Wong Tai Sin	----	----	----	----	----	----	----	
	Taikoo Shing	----	----	----	----	----	----	----	122.87
Commercial	Central	134.29	137.38	144.99	144.00	140.28	102.86	202.14	
	Causeway Bay	----	109.46	109.29	138.57	116.70	70.71	166.43	
	Tsim Sha Shui	149.29	249.64	164.71	151.25	173.23	113.57	258.71	143.40
Industrial	Kwai Chung	136.43	123.57	134.64	118.9	127.86	108.57	160.71	
	Chai Wan	----	----	----	----	----	----	----	
	Tsuen Wan	----	----	----	----	----	----	----	
	Kwun Tong	----	----	----	----	----	----	----	127.86
New Town	Shatin	181.46	198.94	174.14	136.65	172.71	94.29	276.43	
	Tai Po	----	175.00	----	----	175.00	134.29	256.43	
	Tuen Mun	----	----	----	----	----	----	----	173.86

The results of airborne lead (APb) concentration from 8 districts were shown in Table 3. The mean concentration of each district ranged from 110.28 $\eta g/m^3$ to 175.00 $\eta g/m^3$. The highest value was 285.8$\eta g/m^3$ recorded at Mong Kok (residential area) and the lowest value was 70.7 $\eta g/m^3$ recorded at Causeway Bay.(commercial area). The average lead concentration was 144.5 $\eta g/m^3$. The lead concentration limit of NAAQS and HKAQO are both 1500 $\eta g/m^3$ for 3 month. Although our field results cannot directly compare with the standards, the indication is that the lead concentrations were low generally at all districts.

The APb concentration level measured in this field study was lower than that obtained in the previous study few years ago. (Helen Wu, 1991)(10) The result reflected the effectiveness of the current measures to tackle vehicle emissions by the Hong Kong Government. In the past, the gasoline contains high lead content. However due to the gradual implementation of the unleaded petrol since 1991, by 1995 unleaded petrol accounted for nearly 80% of total sales. (Environmental Protection Department, 1996) (7) Thus, the influence of auto-emission on the APb concentration became smaller.

Land Use Pattern Variation:

The RSP and APb pollution levels depends on the degree of urbanization, extent of industrial development and regional characteristics. Variation in APb and RSP concentration level may due to different traffic flow and the environmental condition for differing land use. In densely populated urban areas, such as Mong Kok and Sham Shui Po, goods vehicles and large buses were the principal contributors to vehicular emissions but taxis play an important role in the less polluted areas such as Taikoo Shing. In this study, the 14 selected districts can be classified by land use. The characteristics of the four land use categories and the variation of pollutant level within each category are as follow:

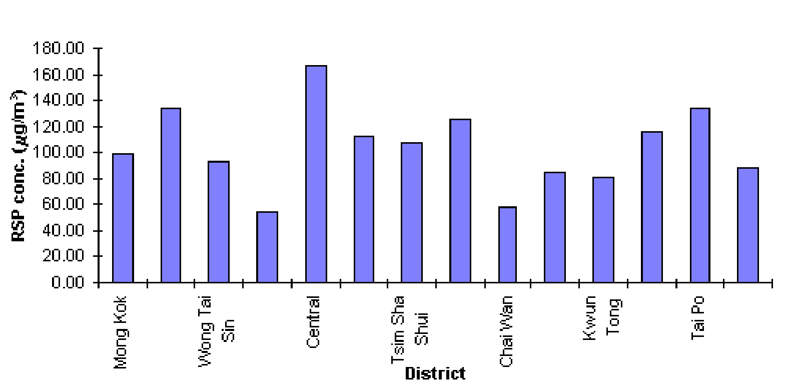
New town: In this study, 16 points covering three districts, Shatin, Tai Po and Tuen Mun were selected to represent new town. The characteristics of new town are roads that are surrounded by both old low-rise buildings and new built high-rise buildings. The density of the buildings is less, traffic is less heavy and these industrial setting is less. Vehicle types are mainly taxi and private car. The average RSP concentrations of these three districts were 115.68 $\mu g/m^3$ at Shatin, 134.28 $\mu g/m^3$ at Tai Po and 87.98 $\mu g/m^3$ Tuen Mun. The first two concentrations were higher than the last one because they were topographically confined by hills and the dispersion effect is less. The average APb concentrations of Shatin was 172.71 $\eta g/m^3$ and Tai Po was 175.00 $\eta g/m^3$.

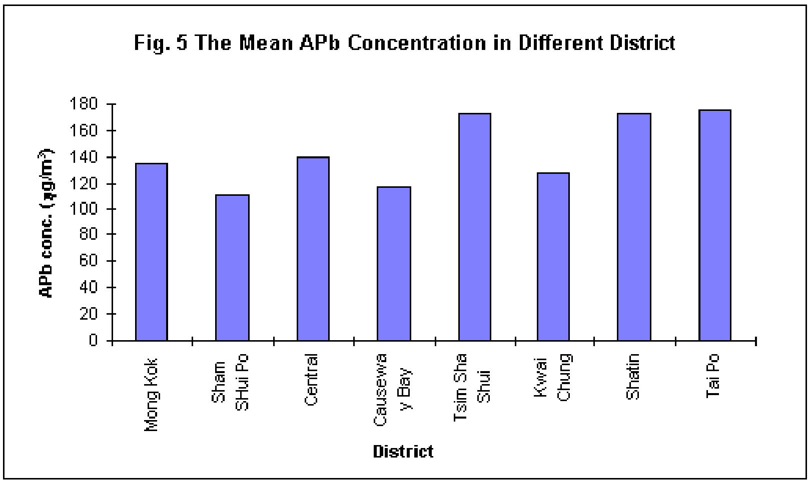
Residential Area :14 points covering four districts, Wong Tai Sin, Sham Shui Po, Monk Kok and Taikoo Shing were selected for this category. Except some high class private housing estate, such as Taikoo Shing, residential area in Hong Kong is usually density populated and the residential flats are very closed to the roads. All the selected district in this category have heavy vehicle flow except Taikoo Shing. Van, public light bus, taxi and buses are the major transport in this area. The maximum concentration level of RSP was 133.79 $\mu g/m^3$ in Sham Shui Po. The average APb concentration of Mong Kok was 135.46 $\eta g/m^3$ and Sham Shui Po was 110.28 ηg/m3

Commercial Area : The tall, dense high rise-buildings characterized the Central, Causeway Bay and Tsim Sha Tsui commercial districts and they are the busy commercial centers in Hong Kong. They have heavy traffic volume which composed large proportion of taxi and private cars. Urban canyon effect were found at Central and Causeway Bay due to the high-rise buildings. The particulate pollutants are trapped between the buildings, hence cause is poor dispersion. Thus, high concentration occurs at the urban canyon where junctions are the only ventilation outlet for dispersion of pollutants. Central have the highest average RSP concentration (166.58 $\mu g/m^3$) among all districts due to the canyon effect, heavy traffic, frequency stops and congestion, and the many construction sites nearby. Moreover, it had the highest average RSP concentration level among the four land use category. The average RSP concentration level ranged from 107.99 $\mu g/m^3$ to 166.58 $\mu g/m^3$, and the average APb concentration level ranged from 140.28 $\eta g/m^3$ to 173.23 $\eta g/m^3$.

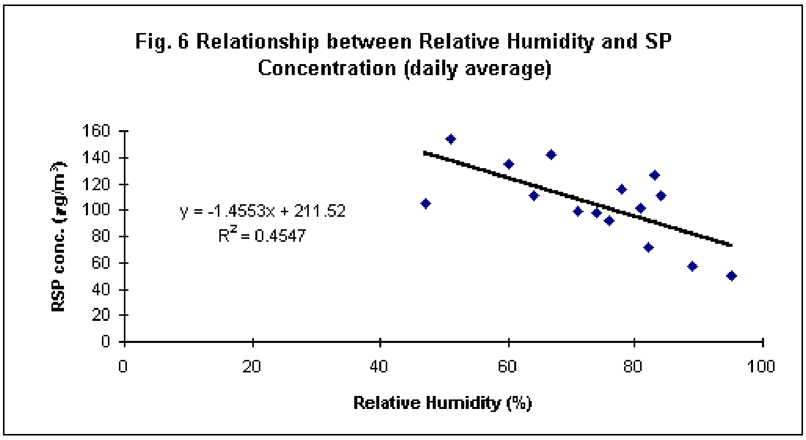
Industrial Area : The roads at the selected districts in this area were all surrounded by low-rise factories. The roads at the industrial area are intended for local distributors and they are narrow. Traffic is mainly dominated by goods vehicles and vans, and traffic volume is comparatively low. Many goods vehicles park at roadside for loading of goods and they usually occupied one traffic lane. Busy traffic periods for industrial area are always at the working hours and the traffic volume is very low other than the working hours. Thus, the RSP concentration of the industrial area is the lowest. The average RSP concentration level was ranged from 58.35 $\mu g/m^3$ to 125.34 $\mu g/m^3$. And the average APb level in Kwai Chung was 127.86 $\eta g/m^3$.

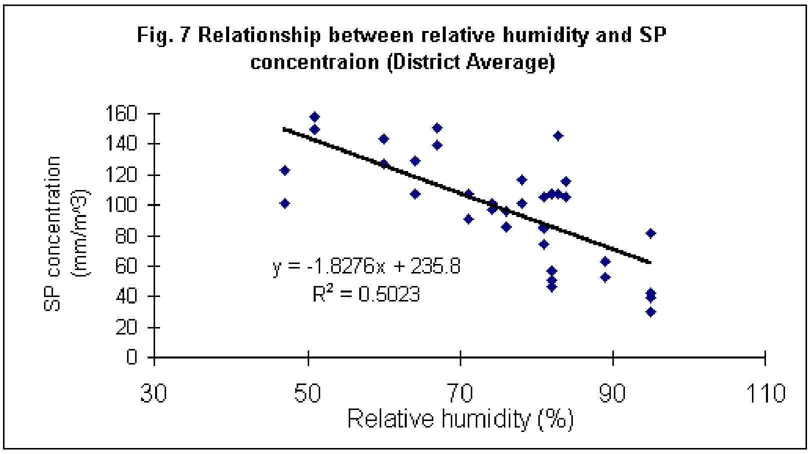
Fig.4 The Mean RSP Concentration in Different District





Figures 4 and 5, showed that the variation of the concentration of RSP and APb concentration level within the four land use categories were quite large. The result might due to the great variation in topography in Hong Kong and different building and traffic configuration in different district. Moreover, samples of the same land use category were collected in different day and the concentration might be susceptible to the influence of short-term fluctuation in meteorological condition. Figures 6 and 7, showed that there is correlation between the relative humidity and RSP concentration. (r^2 = 0.45 to 0.50)





Within the roadside microenvironment, submicroenvironments of different pollution levels can be identified according to the different functional usage of the road. The roadside microenvironment in this study was divided into submicroenvironments of junction, traffic light, bus stop and normal walkway. Besides the variation of the RSP and APb concentration level among land use category, variation can also be found within the roadside microenvironment of the same district. (Figure 8 to 10)

Fig. 8 Average RSP Concentration at Different Road Microenvironment

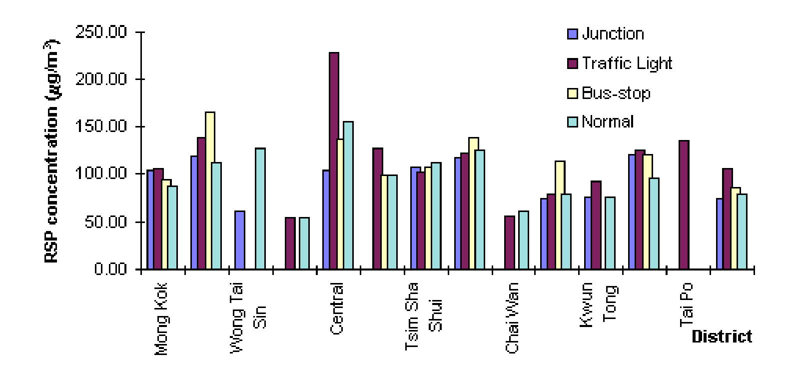


Fig. 9 Average APb Concentration at Different Road Microenvironment.

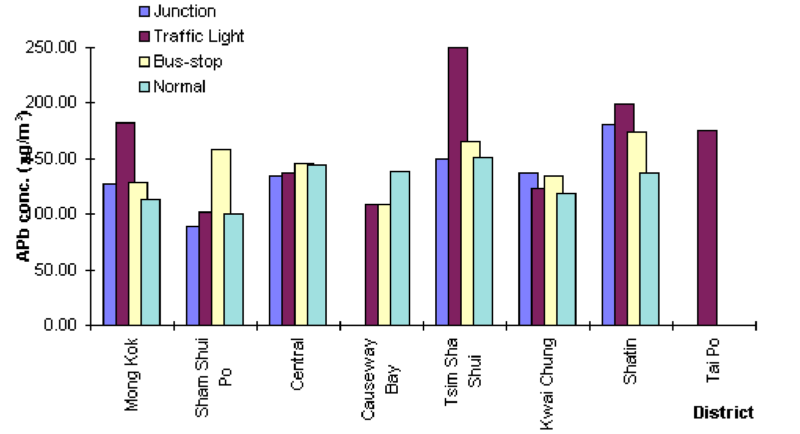
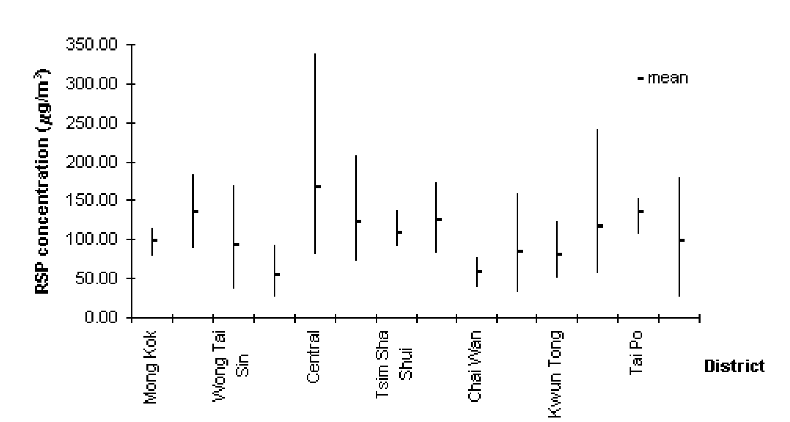


Fig. 10 The Lowest, Highest and Mean RSP Concentration in Different District



The variation might due to the variation of emission from motor vehicles which depends on conditions including driving conditions which include driving mode, speed and engine temperature (cold or warmed). At the streets, vehicles are usually in the cruise condition. Vehicles decelerate on approaching road junctions, idle in waiting behind traffic lights and accelerate on leaving the junctions. As a result emission at road junction will be different from roadside. (Leung, 1991; Tonkelaar, 1987) (13,16) This is also true for lead emission. Extensive stop-start of vehicle can result in a significant consumption of fuel and thereby enhance lead emission into the environment. Similar condition also occurs at the bus-stop and traffic light. (Kinard,1976; Ward, 1995)(12,17) However the degree of influence of different conditions on the roadside micro-environment still need to be analysed. Further study was needed in the future.

Comparison with Environmental Protection Department data:

The field data was compared to data of EPD measured at low roof top and road side monitoring stations. Our field study result, confirms the result from EPD that particulate pollution was serious in the urban areas with heavy traffic. 24 out of 170 samples breached the NAAQS.

From the data, it is noticeable that particulate concentration depends very much on the degree of urbanization, regional characteristics, and distance from the local emission source. There was a marked difference in particulate level in the Central district. In this built-up urban area, narrow roads are surrounded by tall buildings which inevitably trap the vehicular emissions in the road canyon. As diesel engine emission contains more particulate than petrol and a great proportion of running vehicles on roads are diesel taxi, vehicular emission of particulate is significant. As all the sampling sites were at the urban ground level, which is close to the influence of traffic impact, the effects and the concentration levels were much greater than those obtained in the EPD fixed stations at the roof top in the same district.

However in two districts, Mong Kok and Kwun Tong, the RSP concentrations were lower than the EPD data. The reasons were that it was raining at Kwun Tong and Mong Kok during the sampling period and there was washout effect on particulate. Moreover at Kwun Tong, because of the industrial land use, sampling at roof top was mainly influenced by the emission source of chimneys from the factories and hence higher concentrations measured by EPD. At Mong Kok, the fixed EPD station was also at low level, so the weather and the distance from the curbside were the dominant factors. For other districts, higher concentration measured at roadside showed that roadside particulate levels were higher than the ambient levels measured at roof-top. Similar results are obtained finding in previous studies (Chan & Wu, 1993)(3). It showed that EPD fixed station data underestimated the pollution levels at roadside in most of the sites. It was due to the predominant traffic emission sources which led to more severe pollution detected by ground level monitoring. As a result of atmospheric dilution of ground level emissions, lower values were detected at the elevated roof top stations. Ambient air quality data cannot reflect the real exposure level of pedestrians. More street level measurements should be carried out to assess the street level exposure of the general population in Hong Kong.

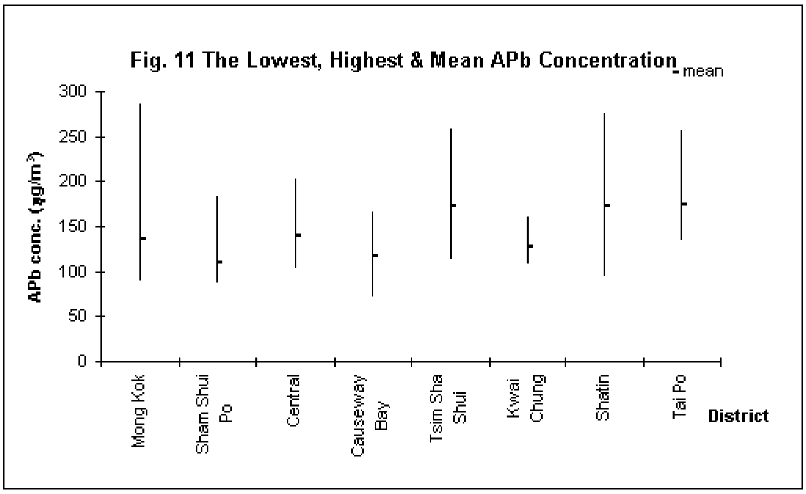


Fig. 11 The Lowest, Highest & Mean APb Concentration

CONCLUSION

This project studies the particulate level at roadside by using portable mini-volume sampler to obtain the pattern and spread of traffic related air pollution along a road different microenvironments. The performance of the portable mini-volume sampler was well correlated with the high-volume sampler but it was found to be 4.59% higher than the high volume sampler. From the field data of 14 districts, pedestrians were found to expose to 24-hour average RSP and airborne lead that ranged from 25.56 to 337.40 $\mu g/m^3$ and 70.70 to 285.7 $\eta g/m^3$ respectively. The average RSP and APb level were 109.50 $\mu g/m^3$ and 143.94 $\eta g/m^3$ respectively. Worst particulate air quality in Central the result of the urban canyon effect in commercial area.

The field data were compared with the data of the EPD. It was found that the average concentrations of the roadside field data at different districts were higher than the EPD data measured at elevated roof top stations. The underestimation of particulate level shows that the ambient air quality measured by the EPD cannot reflect the real exposure level of pedestrians on street level.

In this study, a picture of the preliminary particulate exposure levels over Hong Kong in various landuse and roadside microenvironments is presented. Roadside particulate level was also found to be higher than the ambient particulate concentration measured by EPD. Thus, more monitoring work should be done at roadside employing micro-environment monitoring technique for assessing the exposure level related to the human activity patterns.

References

1. Anderson, K.R., Avol, E.L., Edwards, S.A., Shamoo, D.A., Peng, R.C., Linn, W.S. and Hackney, J.D.(1992) Controlled exposuresof volunteers to respirable carbon and sulphuric acid aerosols. Journal of Air Waste Management Association 42, 711.
2. Cleaner Air, (1995) Further Proposals to Reduce Emissions from Diesel Vehicles - A Consultation Paper.
3. Chan L.Y. & Wu H. W.Y., (1993) A Study of Bus Commuter and Pedestrian Exposure to Traffic Air Pollution in Hong Kong, Environment International, Vol 19, no. 2, pp. 121-132.
4. Dockery, D.W. and Pope, C.A. (1994) Acute respiratory effects of particulate air pollution. Annual Reviews of Public Health 15, 107-133
5. Duan, N. (1982), æ/odels for Human Exposure to Air Pollution" in Environ. Int., Vol 8, 305-309.
6. Dzubay, T.G. and Stevens, R.K., " Sampling and Analysis Methods for Ambient PM10 Aersol" in Receptor Modelling for Air Quality Management. Elsevier Publisher.
7. Environmental Protection Department (1996), Environmental Hong Kong, 1996, Hong Kong.
8. Environmental Protection Department (1996), 1996 Air Quality in Hong Kong, Hong Kong Government.

9. EPA Contract 68-D3-0029, Work Assign. No. 1-36, "1994 Philadelphia $PM_{2.5}$ and PM_{10} Saturation Study - Final Report.
10. Helen W.Y. Wu (1991), æ# Pilot Field Study on the Exposure of Bus Drivers, Passengers and Pedestrians to Traffic-related Air Pollution". M.Phil .Thesis
11. Hong Kong Transport Department (1996) Annual Transport Digest 1996.
12. Kinard, J.T., Tisdale, J. & Alexander, E. (1976) Assessment of Lead Distribution Patterns in Urban and Rural Environments. Environ. Sci. Eng., All (2), 153-164.
13. Leung, R. P.M. (1991) Air Pollution Fro, Vehicles of Hong Kong. One Day Seminar On Ground Level Air Pollution In Urban Environment Proceedings 1-1 to 1-9
14. Mage, D.T. (1985), æ%oncepts of Human Exposure Assessment for Airborne Particulate Matter". Environ. Int., Vol 11, 407-412
15. Rusco, F.W. and Walls, W.D. (1995) Cleaning the Air Vehicular Emission Policy for Hong Kong. The Chinese Unviersity Press.
16. Tonkelaar, W.A.M. Baars, H.P. & Hout, K.D. (1987) Effect of Driving Conditions And Structure of Built-Up Areas On Average Levels of Air Pollution In Urban Roads. Sci. Total Environ., 59, 233-242
17. Ward, N.I. (1990) Lead Contamination of the London Orbital (M25) Motorway (Since Its Opening In 1986). Sci. Total Environ., 93, 277-283