THE STUDY
ON
ENVIRONMENTAL EFFECTS
OF COAL FIRING POWER STATIONS
AND
INTEGRATED STEEL MILL
IN THE REPUBLIC OF SINGAPORE
(PARTICULATE SURVEY)

(SUMMARY)

NOVEMBER 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

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(I) The Progress of the Study

In August 1979, the technical assistance consultative meeting was held in Singapore and Jurong Town Cooperation (JTC) who attended in the said meeting has requested Japanese Government to extend its technical assistance for the study on the environmental effects of coal firing power stations and integrated steel mill. Japanese Government has assigned Japan International Cooperation Agency (JICA) to carry out the study proposed by JTC through the Government of the Republic of Singapore.

JICA has sent a preliminary survey mission of 7 members headed by Mr. Ichiro Kikushima, deputy director of Pollution Control Guidance Division, Industrial Location and Pollution Control Bureau, Ministry of International Trade and Industry (MITI) for 13 days from December 8th to 20th 1980 to the Republic of Singapore. The preliminary survey team has discussed the matter with JTC, counterpart of Singapore side, and entered into agreement signing on SCOPE OF WORK and the Minutes of Meetings, in which the following matters were confirmed.

(1) Total time schedule for the environmental study
(2) The description of the study (term, survey items, survey areas & etc.)
(3) The description of simulation (term, simulation items & etc.)
(4) Contribution of Singapore side (cooperation for field survey, collection of data and information materials and so on)

JICA has conducted, according to the SCOPE OF WORK and Minutes of Meetings, the field survey on water quality and simulation works on Chemical Oxygen Demand (COD) and thermal effluents during February to December of 1981. Following to the survey on water quality, the field survey on air quality and simulation related to Sulpher Dioxide (SO_2) have been carried out during June 1981 to March 1982.

Through the progress of the above survey, the Government of Singapore has requested Japanese Government to conduct the additional study on particulate matter in order to make the study more comprehensive in 1982 and the proposal has been approved in June 1983.

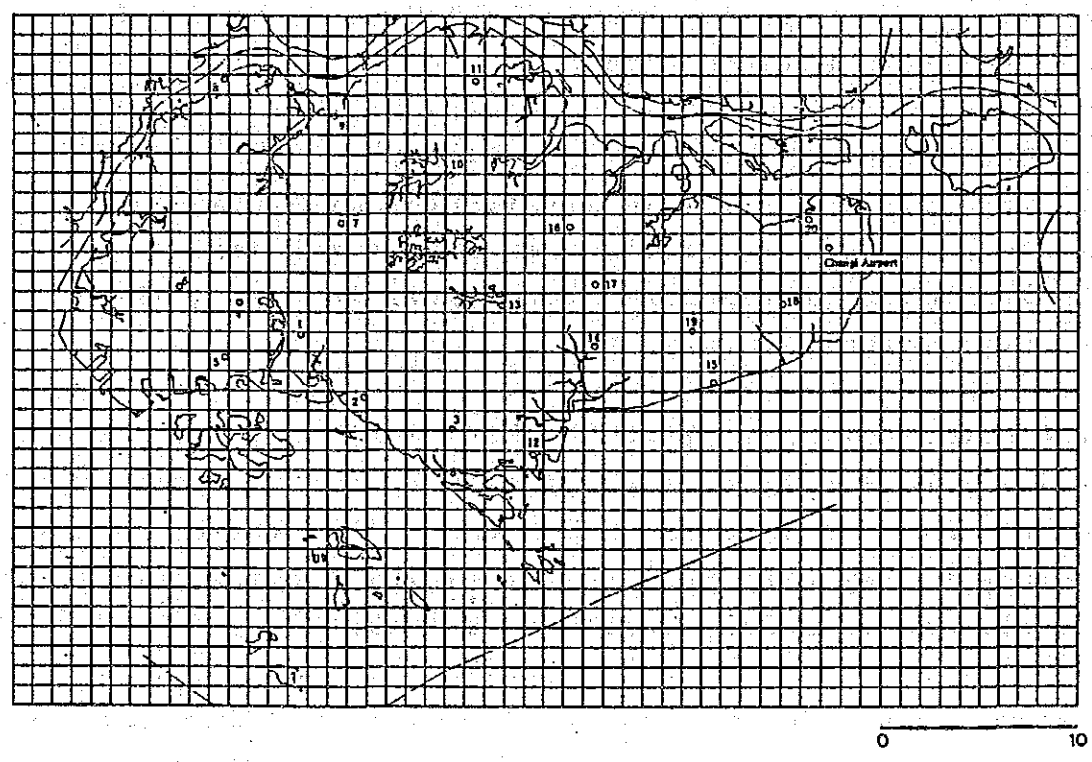
(II) Summary of Field Survey

The field survey is consisted of (1) short term field survey to monitor the particulate matter at as many points as possible for identifying the concentration distribution of the particulate matter in the object area, and (2) long term field survey to monitor variation of the particulate concentration in comparatively long term.

In the short term field survey, monitoring has been conducted for 14 days each of 4 times a year (December 1983, March-June-September 1984). At 20 monitoring stations shown in Fig. (II)-1, total particulate matter (TPM) and suspended particulate matter (SPM) have been monitored by high volume sampler in terms of daily average values. And at MP-1, 2 and 6, the monitoring of size distribution of the particulate matter has been conducted by Andersen sampler (average value of 12 days).

Besides the above, chemical components (33 elements, anion, elemental carbon and organic carbon) have been analyzed in Japan by the samples collected TPM for each one day of each field survey. (20 points x 4 field survey)

In the long term field survey, monitoring of SPM, SO_2, wind direction & velocity, solar & net radiation and temperature have been conducted for one year from December 7th 1983 to December 6th 1984, each in terms of the hour average values. Table (II)-1 shows monitoring items in each monitoring station.



MP1	Jurong Town Hall	MP11	Chong Pang Police Post
MP2	National University of Singapore	MP12	National Institute of Commerce
MP3	Bukit Merah Flatted Factory Block 1	MP13	Macritchie Reservoir Water Pumping Station
MP4	Boon Lay Apartment Block 200	MP14	Kallang Flatted Factory Block 3
MP5	Jurong Hill Top Restaurant	MP15	East Coast Swimming Lagoon
MP6	Nanyang Technological Institute	MP16	Ang Mo Kio Flatted Factory Block 5001
MP7	Bukit Panjang Police Post	MP17	Paya Lebar Police Station
MP8	Lim Chu Kang Marine Police Post	MP18	Changi Community Center, 16 km Changi Road
MP9	Kranji Sewage Treatment Plant	MP19	JTC Bedok Flatted Factory
MP10	Seletar Reservoir Water Pumping Station	MP20	Singapore Offshore Petroleum Services

Fig. (II)-1 Monitoring stations for TPM, SPM at short term field survey

Table (II)-1 Monitoring items by stations

Monitoring point	Monitored item	Monitored period	Monitoring method
MP-1 to 20	TPM	Each 14 days 1st-4th field survey	Daily average by high volume sampler
	SPM	Each 12 days 1st-4th field survey	Daily average by high volume sampler with cyclon
	Metal element, negative ion, carbon	Each 1 day of 1st-4th field survey	Neutron activation, X-ray fluorescence, ion-chromatography, differential thermal
MP-1, 2 & 6	Size distribution of TPM	Each 12 days 1st-4th field survey	12 days average by Andersen sampler
	SPM	12/7 '83 to 12/6 '84	One hour average by Beta ray analyser
MP-1, 2, 4, 6, 7, 14 & 20	SO_2	- ditto -	One hour average by SO_2 analyser
	Wind direction & velocity	- ditto -	10 min. trans. average by anemometer
MP-1	Temperature	- ditto -	Thermometer at 2 heights
Changi airport observatory	Solar & net radiation	- ditto -	One hour average by solar & net radiation meter

(II)-1 Summary of Short Term Field Survey Results

(1) TPM and SPM concentration by high volume sampler

Table (II)-2 and Fig. (II)-2 show seasonal average concentration of TPM and SPM monitored by high volume sampler. From the survey results, concentration at MP-7 (Bukit Panjang Police Post) and MP-17 (Paya Lebar Police Station) are found high compared with other stations. The results are suggesting that these two stations are located near to main road side of heavy traffic and they are influenced by automobile emission gas and particulates winded up by the traffic. No remarkable difference can be seen in the concentration of other 18 stations.

Table (II)-2 Seasonal average concentration of TPM and SPM monitored by high volume sampler

Monitoring stations	TPM ($\mu g/m^3$)					SPM ($\mu g/m^3$)				
	1st survey	2nd survey	3rd survey	4th survey	Average	1st survey	2nd survey	3rd survey	4th survey	Average
MP 1	60.3	99.3	51.9	62.9	68.6	28.5	47.0	25.4	34.6	33.9
MP 2	54.9	84.4	51.0	42.4	53.2	34.9	31.3	25.2	26.1	29.5
MP 3	52.7	79.8	60.6	72.8	66.7	28.9	42.6	21.7	33.0	31.3
MP 4	79.7	91.5	65.0	60.5	74.2	40.4	52.1	29.6	36.8	39.5
MP 5	78.5	95.4	67.8	72.9	78.2	41.8	43.2	21.7	31.1	34.5
MP 6	54.1	48.9	67.7	57.0	66.4	33.2	44.1	28.9	37.0	35.5
MP 7	102.2	144.2	145.8	148.2	134.6	51.1	63.6	55.4	51.6	55.5
MP 8	43.0	77.0	91.8	67.1	69.7	29.3	39.0	42.8	34.6	36.4
MP 9	49.0	90.8	101.9	91.3	83.3	28.8	47.5	42.1	43.0	39.9
MP10	58.5	65.3	54.2	45.9	56.0	28.0	33.1	28.6	22.6	26.8
MP11	55.1	81.2	97.1	78.1	77.9	33.3	39.6	49.0	39.4	40.3
MP12	61.7	98.5	59.6	69.9	69.0	27.3	34.6	28.5	27.0	27.4
MP13	40.2	75.5	58.6	55.7	57.5	21.1	39.9	27.9	35.9	30.2
MP14	52.9	74.4	63.0	62.9	63.3	25.6	41.7	31.1	34.7	33.3
MP15	38.8	56.1	37.8	44.9	44.7	20.1	28.9	16.2	23.6	22.2
MP16	46.5	83.1	85.4	78.3	72.3	20.5	48.0	34.7	37.9	34.0
MP17	103.2	120.1	67.2	61.7	93.1	29.5	53.6	38.7	41.3	42.8
MP18	56.7	63.9	59.4	73.8	63.5	31.1	30.1	27.3	41.0	32.4
MP19	67.8	61.7	59.0	61.7	62.6	32.5	29.9	29.5	31.1	30.8
MP20	41.5	54.1	81.9	76.1	63.4	17.0	24.0	24.3	32.5	24.5

Remarks: concentration is average value of 12 days

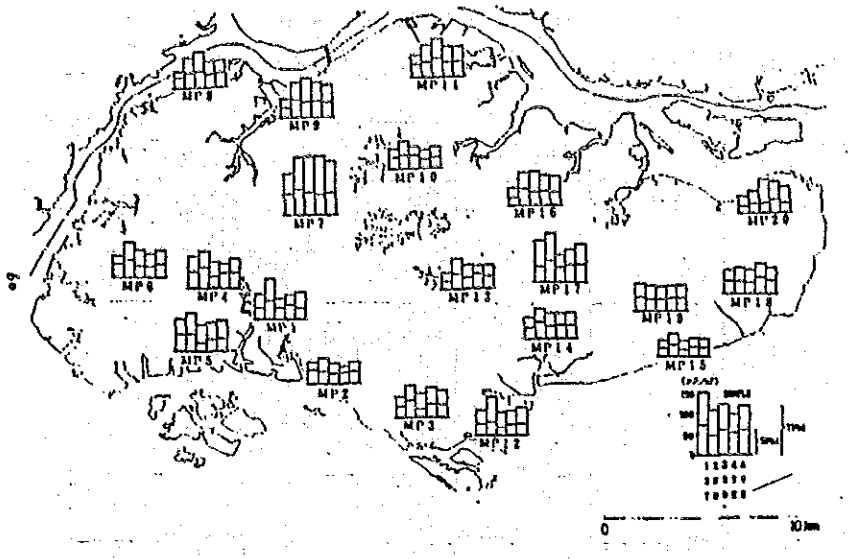


Fig. (II)-2 Seasonal average concentration of TPM and SPM monitored by high volume sampler

(2) Size distribution of TPM by Andersen sampler

Table (II)-3 and Fig. (II)-3 show concentration of the particulate matter by size monitored at MP-1, 2, and 6 (average of 12 days). From these results, particles under 2.1 microns (fine particles) are 60%, particles between 2.1 to 11 microns (coarse particles) are 30%, and the remaining 10% is particles over 11 microns. The size distribution of the particles shows in most cases the peaks at 0.4 micron and 4 microns. And at around 1 micron, the bottom is found. These 2 mountains type distribution of the particles are quite similar to the results of monitoring conducted in many countries including Japan.

In general, coarse particles larger than 2 microns are originated from natural background (soil winded, sea salt, volcano ash, botanical seeds and so on) and man-made sources (particulate from mechanical processes, particulate winded up by traffic, combustion facilities). Fine particles smaller than 2 microns are considered to be originated from man-made sources (combustion facilities, internal combustion engines and so on) and secondary particles reacted chemically from the gaseous substances in the ambient.

Judging from these facts, the particulate matter contributing to the concentration at each monitoring station is mainly from natural background.

Table (II)-3 TPM concentration by particle size monitored by Andersen sampler

(unit: $\mu g/m^3$)

Particulate size			1st survey			2nd survey			3rd survey			4th survey		
Classify	Stage	Rank (μm)	MP1	MP2	MP6	MP1	MP2	MP6	MP1	MP2	MP6	MP1	MP2	MP6
Coarse	0	11 ~	4.63	1.90	2.29	4.94	2.68	4.35	3.31	1.79	4.66	3.78	2.12	3.61
	1	7.0 ~ 11	2.34	1.12	1.14	1.72	1.55	1.88	2.09	1.30	2.27	1.58	0.79	1.39
	2	4.7 ~ 7.0	4.01	1.82	2.70	3.09	2.73	3.34	3.75	2.67	4.20	3.01	2.28	2.54
	3	3.3 ~ 4.7	3.60	2.84	4.54	5.82	2.35	6.22	3.53	4.81	6.72	5.09	2.07	4.36
	4	2.1 ~ 3.3	2.34	2.16	2.59	4.33	3.92	4.25	5.11	3.59	4.90	3.80	3.56	3.35
Fine	5	1.1 ~ 2.1	5.08	2.33	2.78	3.50	2.84	4.88	3.25	2.52	3.71	3.85	2.65	3.42
	6	0.65 ~ 1.1	1.75	2.94	2.66	2.25	1.29	2.78	1.08	1.18	2.04	2.84	1.37	2.26
	7	0.43 ~ 0.65	0.93	3.16	4.00	5.34	1.86	7.36	2.27	3.51	5.50	4.37	1.26	5.32
	8	~ 0.43	15.29	11.09	10.46	18.39	20.39	17.54	15.91	10.95	13.74	16.99	15.70	12.83
Total			40.0	29.4	33.2	49.4	39.6	52.6	40.3	32.3	47.8	45.3	31.8	39.1

(3) Chemical components contained in particulate matter

Table (II)-4 shows the results of analysis of 33 metal elements, anion, elemental carbon and organic carbon by neutron activation method, X-ray fluorescence analysis, ion chromatography analysis and differential thermal analysis from the samples collected each one day of 4 times short term field survey by high volume samplers.

From the results, sequence order of concentration of chemical components are found as; C, Si, Cl, SO_4^{2-}, Cl^-, Al - which means the concentration of soil, sea salt particle, secondary particles are comparatively found higher.

Table (II)-4 Average concentration of chemical components of particulate matter (average values of MP-1 to MP-20)

Method of analysis		Components	Unit	1st survey		2nd survey		3rd survey		4th survey		Average of four surveys	
				Average	Geometric mean	Average	Geometric mean	Average	Geometric mean	Average	Geometric mean	Average	Geometric mean
Element	Instrument activation analysis	As	ng/m³	0.884*	0.663*	0.486*	0.185*	0.343*	0.088*	0.105*	0.071*	0.379*	0.087*
		Al		1645.000	1299.212	2788.000	2113.725	1574.510	848.269	2819.500	1648.087	2542.250	1397.848
		Au		0.716	3.318	4.661	1.263	1.198	0.390	1.382	0.252	2.241	
		Ba		15.390*	5.246*	17.280*	7.264*	17.905*	5.197*	27.149*	6.793*	25.224*	6.468*
		Br		85.490	65.144	107.500	93.439	102.050	68.916	99.400	63.389	98.637	73.911
		Ca		1157.000	888.568	2470.500	1871.759	1638.060	886.169	2803.000	1872.364	1971.825	1149.857
		Cd		6.358*	4.327*	5.350*	3.691*	5.050*	3.718*	5.750*	4.295*	5.625*	3.936*
		Ce		1.585	1.069	2.392	2.036	1.687	1.253	3.862	1.368	1.842	1.350
		Cl		4748.000	4043.823	1938.500	1868.331	2995.040	2886.449	3899.000	3828.132	3420.375	3189.179
		Co		0.244	0.130	0.505	0.292	0.315	0.199	1.176	0.283	0.550	0.232
		Cr		6.152	2.382	7.043	5.499	6.159	3.769	7.552	4.156	6.222	3.767
		Cs		0.050*	0.037*	0.097*	0.031*	0.072*	0.028*	0.056*	0.033*	0.050*	0.031*
		Cu		52.750	28.159	109.250	89.671	48.590	29.865	86.159	58.683	84.513	38.387
		Fe		637.500	514.783	1498.000	1047.710	1022.750	638.193	1997.000	743.846	1042.563	719.728
		Hf		0.887	0.038	0.158	0.024	0.843	0.017	0.168	0.656	0.117	0.053
		K		273.500*	138.453*	877.000*	359.916*	435.500	254.822	578.000*	283.667*	540.500*	241.185*
		La		0.325*	0.137*	1.005*	0.522	0.568*	0.242*	0.685*	0.241*	0.646*	0.256*
		Lu		0.081*	0.003*	0.011*	0.006*	0.085*	0.002*	0.009*	0.001*	0.008*	0.002*
		Mg		11.185	10.295	34.170	23.738	25.568	13.225	17.705	10.475	22.310	13.568
		Na		1155.000	727.237	1378.500	1104.422	1539.000	1418.678	1999.000	1911.196	1492.625	1217.216
		Ni		9.888*	4.456*	5.890*	5.225*	6.235*	2.807*	9.428*	3.358*	7.900*	3.539*
		Sb		1.693	0.729	3.784	2.151	1.602	0.937	4.291	1.218	2.858	1.168
		Sc		0.182	0.134	0.347	0.264	0.201	0.124	0.316	0.202	0.262	0.176
		Se		0.992	0.525	1.840	1.111	0.436	0.222	1.119	0.551	1.057	0.593
		Sm		0.106	0.067	0.163	0.120	0.088	0.048	0.691	0.041	0.112	0.063
		Th		0.410	0.310	0.612	0.497	0.556	0.358	0.588	0.357	0.452	0.345
		Ti		83.600	47.298	134.500	100.510	97.650	47.218	87.500	33.547	100.103	50.950
		V		28.319	11.813	29.450	27.506	14.165	10.694	32.820	8.519	19.248	12.667
		W		0.589*	0.262*	0.478	1.021	1.307*	0.375*	0.976*	0.278*	1.337*	0.415*
		Zn		57.356	46.025	136.850	98.981	91.625	56.753	78.750	57.032	91.894	68.248
	X-ray fluorescence	Cd	ng/m³	2.455	1.428	3.180	1.705	3.215	1.685	4.430	2.958	3.320	1.888
		Pb		190.250	88.466	297.250	245.080	244.800	184.768	299.650	181.857	233.000	161.313
		S		1101.500	1019.757	1746.500	1508.264	1253.000	1123.558	1650.000	1465.435	1437.750	1281.696
		Si		7845.000	5186.413	9240.000	7652.588	9762.500	7872.121	13755.000	10224.695	9950.625	7319.383
	Ion chromatography	Cl^-	ng/m³	3319.000	3246.189	1313.000	1236.319	1858.040	1749.189	2825.500	2669.715	2328.625	2027.974
		NO_3^-		530.000	508.918	1649.000	1581.110	666.050	641.654	1457.000	1426.958	1075.512	916.474
		SO_4^{--}		2578.000	2329.492	4515.050	4267.527	1965.000	1612.612	3288.080	2987.022	3042.500	2688.283
	TPM	TPM	mg/m³	48.545	44.833	73.210	67.612	54.410	49.936	90.255	82.781	66.605	59.259
Carbon	Differential thermal analysis	Elemental C	mg/m³	12.365	11.449	18.840	17.323	10.635	8.962	18.095	15.605	14.472	12.962
		Organic C		4.029	3.658	4.440	3.808	3.585	2.702	5.325	4.755	4.352	3.490
		Total C		16.365	15.130	23.320	21.278	14.200	11.915	23.420	20.528	18.826	16.751
	TPM	TPM		33.570	30.218	48.745	44.093	29.770	25.735	45.740	42.576	37.296	32.867

Notes: (1) 1/10 of value was adopted for averaging with data below detection limit.
(2) * marked when data over 50% are found below detection limit.

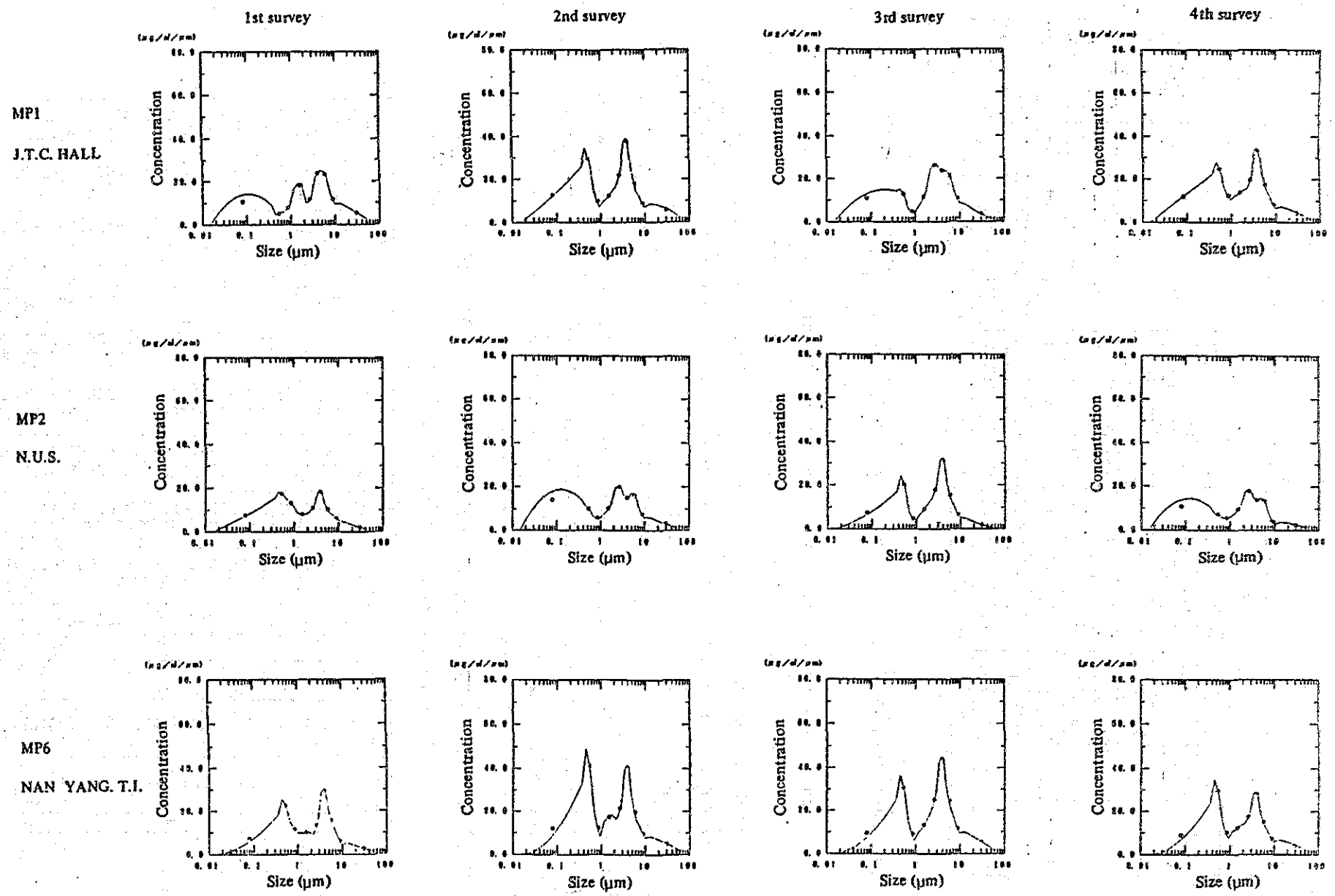


Fig. (II)-3 Size distribution of TPM monitored by Andersen sampler

(II)-2 Summary of Results of Long Term Field Survey

The effective monitoring time by station and by item is shown in Table (II)-5. Every station and every item are well exceeding the standard (6,000 hours).

Table (II)-5-(1) Effective monitoring hours of SPM

Monitoring station	Effective hours	Monitoring rate
MP-1	7,642 hours	87.0%
MP-2	8,166	93.0%
MP-6	7,618	86.7%

Remarks: December 7th 1983 to December 6th 1984 = 8,784 hours

Table (II)-5-(2) Effective monitoring hour of SO_2

Station	Effective monitoring hours (hr)	Monitored (%)
MP-1	8011 hours	91.2
MP-2	7645 hours	87.0
MP-4	8229 hours	93.7
MP-6	7515 hours	85.6
MP-7	8302 hours	94.5
MP-14	8011 hours	91.2
MP-20	8445 hours	96.1

Table (II)-5-(3) Effective monitoring hour of wind direction and velocity

Station	Effective monitoring hours		Monitored (%)	
	Wind direction	Velocity	Wind direction	Velocity
MP-1	8,376	8,164	95.4	92.9
MP-2	8,195	8,080	93.3	92.0
MP-4	8,400	8,327	95.6	94.8
MP-6	8,006	8,006	91.1	91.1
MP-7	8,447	8,316	96.2	94.7
MP-14	8,180	8,128	93.1	92.5
MP-20	7,759	8,197	88.3	93.3

Table (II)-5-(4) Effective monitoring hour of temperature

Station	Effective monitoring hours		Monitored (%)	
	1.5 m from ground	30 m from ground	1.5 m	30 m
MP-1	8,121	7,994	92.5	91.0

Table (II)-5-(5) Effective monitoring hour of solar & net radiation

Station	Effective monitoring hours		Monitored (%)	
	Solar radiation	Net radiation	Solar	Net radiation
Changi airport	8,737	8,431	99.5	96.0

(1) SPM concentration by Beta ray dust analyser

Table (II)-6 shows SPM concentration of each station by season and time. From the table, the concentration of night time is found higher than daytime at each station.

This adverse phenomenon will be discussed in the later part of the report, but it is quite clear that the contributing sources are different among SPM and SO_2.

Table (II)-6 Average concentration of SPM by season and day/night monitored by Beta ray dust analyser

(unit: $\mu g/m^3$)

Monitoring station	S. monsoon (4-10)			N. monsoon (11-3)			Annual		
	Day	Night	Total	Day	Night	Total	Day	Night	Total
(1) J.T.C. HALL	20.0	26.3	23.4	26.1	29.0	27.7	22.6	27.4	25.2
(2) N.U.S.	23.8	31.2	27.8	29.1	32.5	30.9	26.0	31.8	29.1
(6) NANYANG.T.I	20.7	32.4	27.1	19.8	30.8	25.8	20.4	31.8	26.6

Day: 7:00 - 17:59
Night: 18:00 - 6:59

Monthly variation and hourly variation of SPM concentration at monitoring stations are shown in Fig. (II)-4.

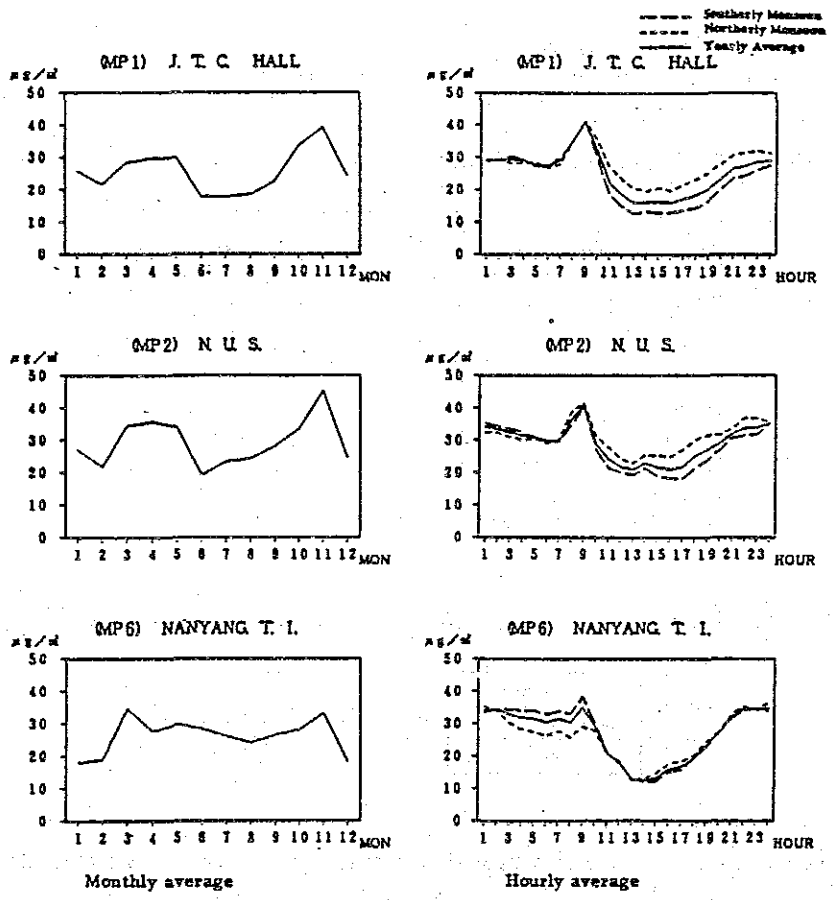


Fig. (II)-4 Monthly and hourly average of SPM concentration monitored by Beta ray dust analyser

From the figure, the concentration of March/May and October/November period is found higher at each station. This tendency is similar to that of SO_2. The daily variation pattern is found almost similar among stations, having its peak at 9 o'clock. And no difference between daily variation by season is found.

(2) SO_2 concentration and others

SO_2 concentration, wind direction & velocity and so on are found quite similar to the results of previous survey which was conducted during July 15th 1981 to July 14th 1982. An example of these results are shown in Fig. (II)-5 to (II)-8.

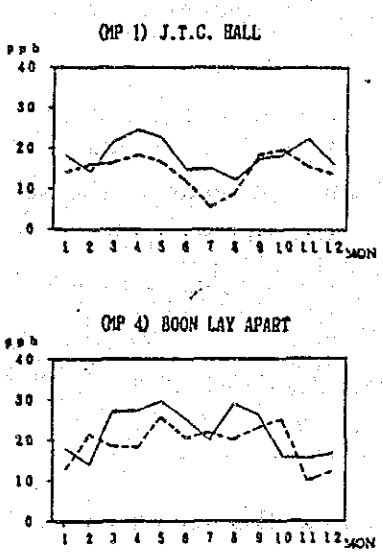


Fig. (II)-5 Monthly variation of SO_2 concentration

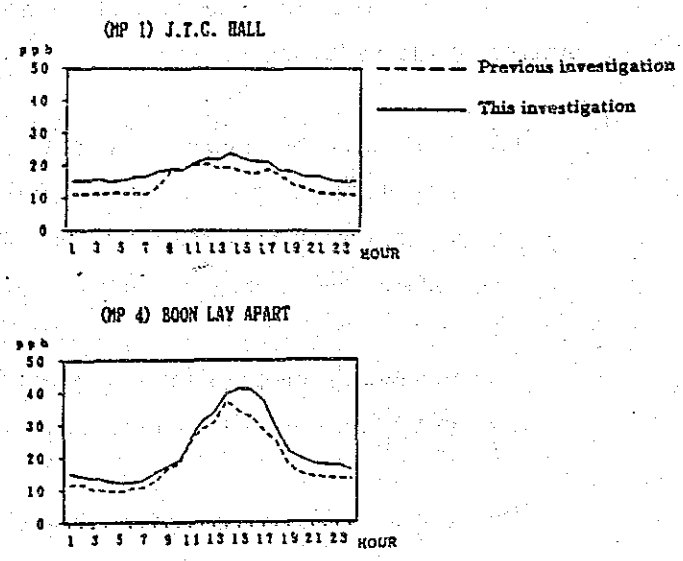


Fig. (II)-6 Hourly variation of SO_2 concentration

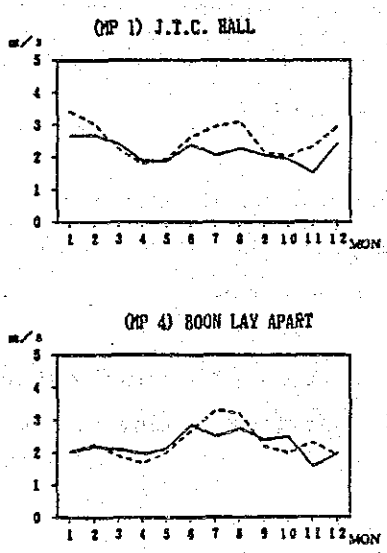


Fig. (II)-7 Monthly variation of wind velocity

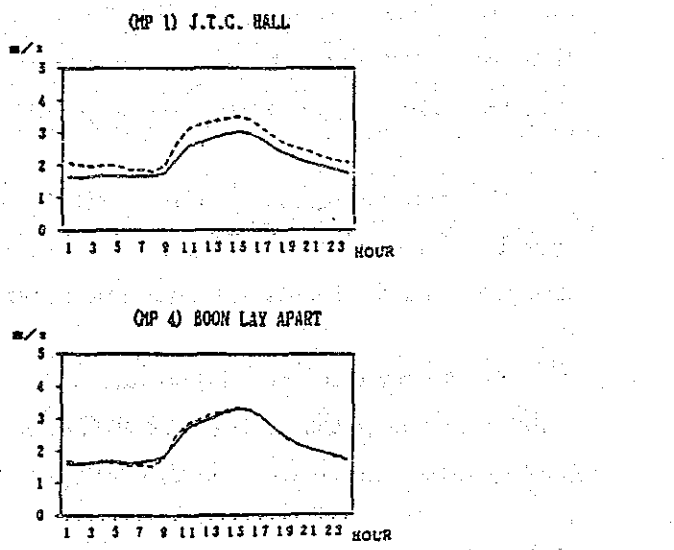


Fig. (II)-8 Hourly variation of wind velocity

(III) Summary of Simulation Results of Particulate Matter

The relation between emission sources and ambient concentration of air pollutants, particularly in the cases of gaseous substances such as Sulpher Dioxide and Nitrogen Dioxide, have been determined by the following processes.

(a) obtain the emission sources data of the present and reproduce the present concentration by air diffusion model,
(b) compare the above with the results of field monitoring,
(c) when the correlation between them is confirmed, proceed on for future prediction putting the necessary data, and then
(d) after diffusion calculation, assumption of future contribution by sources are obtained for evaluation.

However, the same processes cannot be applied to the simulation of particulate matter by the following reasons.

(a) the emission sources of the particulate matter are widely distributed and impossible to determine the emission volume from each source. The sources of the particulate matter are soil, sea salt and other natural background besides the particulate from the industrial activities, and other man-made sources.

(b) producing mechanism of secondary particles and removing mechanism are not yet fully identified scientifically.

(c) the new diffusion models should be developed taking the falling by gravity into consideration.

Under the circumstances, the monitored values obtained through the field survey in this study are taken up as the basic data representing the present concentration and diffusion concentration of the proposed coal firing power stations and integrated steel mill are added on the basic data to predict the future concentration.

The concentration of the particulate matter at the mesh points except 20 stations have been assumed by interpolation methods, and further particulate concentration of the proposed new factories have been polymerised on all the mesh points.

As the particulate matter are fallen by gravity in balancing condition between air resistance and gravity, the new diffusion model has been developed taking the fallout by gravity into consideration in this study.

Further, Miller et al. have proposed the assumption method for determining contribution rate by sources used "receptor model", and so in this study, the assumption of contribution rate by sources has been carried out, using the data on analysis of chemical components of the particulate matter.

(III)-1 Emission Volume of Particulate Matter from Coal Firing Power Stations and Integrated Steel Mill

Table (III)-1 shows the emission volume from the coal firing power stations and integrated steel mill, of which was agreed between two countries. As the particulate matter is quite different in diffusion behaviour by the size of particles, the emission volume by the size is also calculated.

Table (III)-1 Emission factors of coal firing power stations and integrated steel mill

Plant & facilities No.		Plant No.	Stack No.	Stack height (m)	Stack diameter (m)	Gas speed (m/s)	Gas temp. (°C)	Gas volume (Nm^3/H)	Treatment facility	Concentration (g/Nm^3-dry)	Particulate volume (kg/h)	Emission volume by size (kg/h)			
												under 2 μm	2-10	10-20	over 20 μm
SERAYA POWER STATION		63	2	183	7.62	25	150	2,650,000	E.P.	0.05	130	44.6	71.0	13.0	1.4
TEKONG POWER STATION		64	1	183	7.36	25	150	2,470,000	E.P.	0.05	120	41.2	65.5	12.0	1.3
TEKONG INTEGRATED STEEL MILL	Grate Kiln	65	1	170	8.97	30	100	5,000,000	E.P.	0.18	900	440.1	288.9	93.6	77.4
	Rebasing Furnace	65	2	70	1.45	30	500	63,000	Not installed	0.1	6	4.4	1.3	0.2	0.1
	Electric Arc Furnace	65	3	120	6.0	25	120	1,800,000	Bag filter	0.18	324	140.0	170.1	13.6	0.3

(III)-2 Results of Simulation

Table (III)-2 shows the contributing concentration (yearly average) of TPM and SPM from coal firing power stations and integrated steel mill which calculated by air diffusion model. The largest contributing concentration is found at MP-11 (Chong Pang Police Post) both in TPM and SPM which is located in the north of Singapore. Those concentrations are 0.40 g/m^3 of TPM and 0.30 g/m^3 for SPM. But in any case, the contributing concentration is very small.

Table (III)-3 shows the present monitored concentration and contributing concentration of coal firing power stations and integrated steel mill, calculated by air diffusion model, and summed up concentration for the future.

From the table, the contributing concentration of the proposed new factories is not more than 1% of the total sources.

Fig. (III)-1 shows the present mesh concentration estimated by interpolation methods and mesh concentration calculated by diffusion calculation are polymerised into isopleth which represents future concentration of TPM and SPM by mesh. Because of the contributing concentration by the proposed new factories are very small, the future concentration is not much changed with the present.

Table (III)-2 Contributing concentration of coal firing power stations and integrated steel mill at monitoring stations

(Unit; $\mu g/m^3$)

Monitoring stations	TPM All size	SPM Under 10 μm diameter	Concentration for size rank (Unit; $\mu g/m^3$)			
			2 $\mu m <$	2 ~ 10 μm	10 ~ 20 μm	20 $\mu m \leq$
(MP1) J. T. C. HALL	0.14	0.10	0.05	0.05	0.02	0.02
(MP2) N. U. S.	0.12	0.08	0.04	0.04	0.02	0.02
(MP3) BUKIT MERAH P. P.	0.14	0.10	0.05	0.05	0.02	0.03
(MP4) BOON LAY APART	0.19	0.15	0.07	0.08	0.02	0.02
(MP5) JURONG HILL TOP	0.13	0.09	0.04	0.05	0.02	0.02
(MP6) NANYANG. T. I.	0.16	0.12	0.06	0.07	0.02	0.02
(MP7) BUKIT PANJANG P. P.	0.18	0.14	0.07	0.07	0.02	0.02
(MP8) LIM CHU KANG M. P. P.	0.17	0.13	0.06	0.07	0.02	0.02
(MP9) KRANJI SEWAGE T. P.	0.19	0.15	0.07	0.08	0.02	0.02
(MP10) SELETAR E. M. P. S.	0.20	0.15	0.07	0.08	0.02	0.03
(MP11) CHONG PANG P. P.	0.40	0.30	0.15	0.15	0.04	0.06
(MP12) NATIONAL. I. C.	0.15	0.11	0.05	0.05	0.02	0.03
(MP13) MACRITCHIE R. M. P. S.	0.15	0.11	0.05	0.05	0.02	0.03
(MP14) KALLANG P. P.	0.17	0.11	0.06	0.06	0.02	0.04
(MP15) EAST COAST S. LAGOON	0.22	0.13	0.07	0.07	0.02	0.06
(MP16) ANG MO KIO P. P.	0.23	0.16	0.08	0.08	0.02	0.04
(MP17) PAYA LEBAR P. S.	0.18	0.12	0.06	0.06	0.02	0.04
(MP18) CHANGI. C. CENTER	0.19	0.13	0.07	0.07	0.02	0.04
(MP19) JTC BEDOK P. P.	0.19	0.13	0.06	0.06	0.02	0.05
(MP20) SINGAPORE O. P. S.	0.26	0.21	0.11	0.10	0.02	0.03

Table (III)-3 Predicted concentration of TPM and SPM at monitoring stations

(Unit; $\mu g/m^3$)

Monitoring stations	TPM			SPM		
	T1 Monitored concentration by high volume sampler	T2 Contributing concentration by new factories	T1 + T2 Future predicted concentration	S1 Monitored concentration by high volume sampler	S2 Contributing concentration by new factories	S1 + S2 Future predicted concentration
(MP1) J. T. C. HALL	68.6	0.14	68.7	33.9	0.10	34.0
(MP2) N. U. S.	53.2	0.12	53.3	29.5	0.08	29.6
(MP3) BUKIT MERAH P. P.	66.7	0.14	66.8	31.3	0.10	31.4
(MP4) BOON LAY APART	74.2	0.19	74.4	39.5	0.15	39.7
(MP5) JURONG HILL TOP	78.2	0.13	78.3	34.5	0.09	34.6
(MP6) NANYANG. T. I.	66.4	0.16	66.6	33.5	0.12	33.6
(MP7) BUKIT PANJANG P. P.	134.6	0.18	134.8	55.5	0.14	55.6
(MP8) LIM CHU KANG M. P. P.	69.7	0.17	69.9	36.4	0.13	36.5
(MP9) KRANJI SEWAGE T. P.	83.3	0.19	83.5	39.9	0.15	40.1
(MP10) SELETAR E. M. P. S.	54.0	0.20	54.2	28.0	0.15	28.2
(MP11) CHONG PANG P. P.	77.9	0.40	78.3	40.3	0.30	40.6
(MP12) NATIONAL. I. C.	69.0	0.15	69.2	27.4	0.11	27.5
(MP13) MACRITCHIE R. M. P. S.	57.5	0.15	57.7	30.2	0.11	30.3
(MP14) KALLANG P. P.	63.3	0.17	63.5	33.3	0.11	33.4
(MP15) EAST COAST S. LAGOON	44.7	0.22	44.9	22.2	0.13	22.3
(MP16) ANG MO KIO P. P.	72.3	0.23	72.5	34.0	0.16	34.2
(MP17) PAYA LEBAR P. S.	93.1	0.18	93.3	42.8	0.12	42.9
(MP18) CHANGI. C. CENTER	63.5	0.19	63.7	32.4	0.13	32.5
(MP19) JTC BEDOK P. P.	62.6	0.19	62.8	30.8	0.13	30.9
(MP20) SINGAPORE O. P. S.	63.4	0.26	63.7	24.5	0.21	24.7

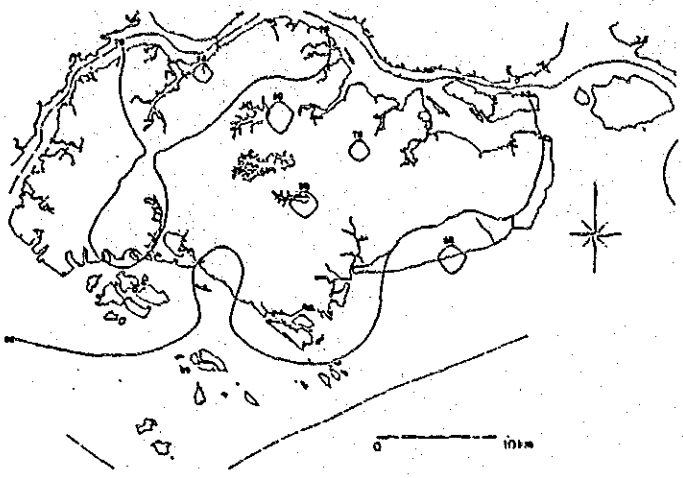


Fig. (III)-1-(1) TPM future predicted concentration

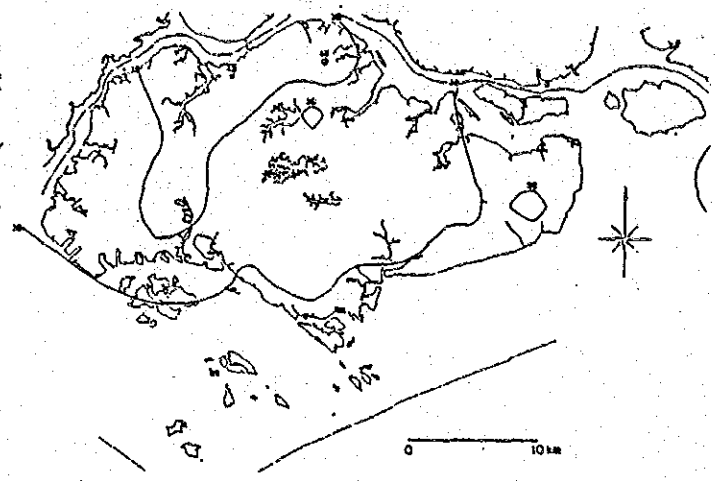


Fig. (III)-1-(2) SPM future predicted concentration

(III)-3 Contribution Rate of Particulate Matter of the Present by Types of Emission Sources

Table (III)-4 shows contribution rate of particulate matter of the present by types of emission sources, estimated by Chemical Mass Balance method (CMB), a method of receptor model, based on the average values monitored at 20 stations and 4 times (seasons) a year through this environmental study. (CMB method is equal to Chemical Element Balance method)

Table (III)-4 Contribution rate of the present by types of emission sources

Emission source	Calculated value (g/m^3)	Monitored value (g/m^3)	Contribution rate (%)
Soil	17.5	-	26.2%
Sea salt	4.3	-	6.4
Automobile (Gasoline)	1.3	-	2.0
Fuel combustion	1.8	-	2.7
Iron & Steel	1.0	-	1.5
Wastes incineration	0.6	-	0.8
Cemented solids	4.0	-	6.0
Total	30.5	66.6	45.8

From the table, it is identified that contribution of particulate matter is highest in natural sources such as soil, sea salt and so on, and sources of human activities are contributing in low ratio. These results are very much similar to that of Japan. The sources and their contribution rate enumerated in the table are only limited to 45.8% of the total concentration and remaining about 55% is not identified which is assumed to be from automobile (Diesel), secondary particulate and so on, and at the present stage of analytical technology, it is unable to identify.