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Chemical characteristics of aerosols at coastal station in Hong Kong. II. Environmental behavior of trace elements during the April 1995 to April 1996

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Abstract: An one-year of sampling aerosol program was carried out during the period of April 1995 to April 1996 at coastal region, Cape D'Aguilar, in Hong Kong. The trace element composition of aerosol particles (TSP and PM₁₀) were measured and analyzed by using the Instrumental Neutron Activation Analysis (INAA) and Inductive Couple Plasma-Mass Spectrometry (ICP-MS) techniques. The results showed that the polluted elements such as: V, Zn, As, Pb, Cd, Sb, I, Se, Bi, with high enrichment factor ($E.F$) values, are derived from anthropogenic sources, while Sc, Al, Fe, Mn, Sm, La, Sr are less than 10 in $E.F$, these elements are related the crust and soil. The concentration of the trace elements are present seasonal variation i.e. summer low and winter high, whereas the V or noncrustal V (V^*) present summer high and winter low, this phenomenon might be explained by local or regional oil combustion sources. Use three type of elemental ratio, e.g. La/Sm, Mn^{*}/V^{*} and Bi/Al indicate that both TSP and PM₁₀ of La/Sm ratios are mainly related to soil and dust, Mn^{*}/V^{*} are probably represent fossil combustion and Bi/Al are possibly associated with refuse incineration, ferromanganese alloys and aluminum production. The varimax rotation factor analysis for trace elements was performed. By means of the absolute principal component analysis (APCA) and multiple regression, the contribution of trace elements to possible sources and overall means of trace elements were estimated. The results showed that the present station is impacted by the anthropogenic species, although the quantities are different during the summertime and wintertime.

Keywords: TSP; PM₁₀; trace elements; enhancement factor; element ratios; seasonal variation; factor analysis

Introduction

It has shown that at coastal area, Cape D'Aguilar, in Hong Kong the aerosols particles comprise a large number of sea salts and small amount of trace elements contented in TSP and PM₁₀ (Cheng, 2000). Due to the atmosphere is recognized as an important source of trace elements to marine ecosystems (GESAMP, 1990), thus the study of environmental behavior of trace elements at coastal area and their contribution to sources in the marine boundary layer are very meaningful. Owing to the trace elements contented in TSP and PM₁₀ carry much information on the history of an air mass during its transport. Information of that includes both natural and anthropogenic species which may have transported through vast distances from continental or local sources as well as from marine sources. The coastal aerosol components have the potential to provide indicators of air pollutants. It is consequently becoming very important to study the content of trace elements bearing aerosols which can be used to predict the effect regulatory and characteristics of emission source.

The major aim of this study is to provide a set of trace element concentration for TSP and PM₁₀ which were sampled during the April 1995-April 1996. Based on enrichment

factor ($E.F$), seasonal variation, elemental ratio, varimax rotation factor analysis, absolute principal component analysis (APCA) and overall means of trace elements estimated by multiple regression, we attempt to explain the behavior of trace elements more detail and quantitatively estimate its contribution to possible sources. The obtained results show that the present station is impacted by continent and local sources either summertime or wintertime, though the magnitude of quantities are different.

1 Experimental

Site location: The station established at Cape D'Aguilar located at end of a long peninsula on the southeastern of Hong Kong Island. It is also located between the continent of Asia and the ocean (South China Sea and North Pacific Ocean) and is in a zone where different types of air masses meet. The location was described in previous study (Cheng, 2000). The prevailing winds for Hong Kong mainly are easterly or southeasterly in summer and bring in the least air pollutants from the marine sources, while during the winter season, prevailing winds are from north and northeast and bring in the air pollutants from local and industrial region or the Chinese mainland. Occasionally urban plumes affected the levels of

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atmospheric species. The weather condition therefore influences greatly the characteristics of aerosols.

Atmospheric aerosol samples were collected during the April 1995 to April 1996. The sampler was installed at a height of 60 m above sea level and high volume air sampling techniques were used to collect the aerosol for analysis. The General Motor Works GMW (model SAUV-11H) high volume air sampler was adopted for collecting PM₁₀ and GMWL-2000 high volume air sampling system for collecting TSP. The samplers were manufactured by General Metal Works Inc. and Andersen Samplers Inc. Aerosols were collected by drawing air at a rate of 1270 L/m ($\pm 12\%$) for PM₁₀ and 1370 L/m ($\pm 7\%$) for TSP through a Whatman-41 filter (20 × 25 cm). Under high volume sampling conditions Whatman-41 filters are relatively efficient (Prospero, 1989). In the marine boundary layer the filters have efficiencies of greater than 95% for SO₄²⁻, Na⁺, K⁺, Mg²⁺ and 90% for NH₄⁺-N, NO₃⁻ and \cong (80% for Pb, Mn, Cd and Ni (Yaqub, 1991). Hence Whatman-41 filter was adopted for collection aerosol during entire program. The field blank was measured i.e. the filters were exposed in sampler except for without drawing air, the other operation conditions was similar to the collection aerosol samples.

After sampling, the filters were sealed in clean plastic bags and transported to the laboratory, then stored in refrigerator. The temperature was maintained at -18°C , before analyzing the filters were cut into several portions for individual analysis. The Al, As, Br, I, La, Sb, Sc, Se, Sm, V, Zn and total Mg, Na, Cl elements were measured by INAA operated by Institute of High Energy Physics, Chinese Academy of Sciences. The operation procedure was described in previous study (Cheng, 2000). The uncertainties in the concentration of most elements are estimated about $\pm 12\%$ – $\pm 15\%$. The Mn, Cd, Pb, Sr and Bi trace elements were measured by ICP-MS techniques. A acid digestion procedure (Schlieckmann, 1984) was adopted for determination of Mn, Cd, Pb, Sr and Bi. The samples were digested with a mixture of nitric, perchloric and hydrofluoric acids at 150°C in open platinum (or PTFE) crucibles. The ratios of adding acids (HNO₃-HClO₄-HF) was 1.5:1:1. After the complete dissolution of the filter samples or field blank filters were achieved and dried, then redissolved the residue in a few ml of 5% HNO₃ solution and finally made up in 10 ml with 5% HNO₃. The acid solution was analyzed by ICP-MS techniques.

Analysis was carried out on a Plasma Quad II Turbo ICP-MS instrument from VG Elemental, U.K. Some of the most important instrumental conditions are as same as Berg *et al.* (Berg, 1994).

For ensure the quality of analysis data, the standard reference material 1648 (National Institute of Standards and Technology, NIST) was employed. A comparison was made

and listed as follows:

Elements	Observed, $\mu\text{g/g}$	Stdev, $n = 7$	NIST values
Mn	873.21	36.64	[860($\mu\text{g/g}$)]*
Zn	4691.71	62.6	0.476 \pm 0.014%
Cd	75.27	2.87	75 \pm 7 $\mu\text{g/g}$
Pb	6419.49	290.7	0.655 \pm 0.008%
Sr	260.01	18.50 ($n = 12$)	-
Bi	6.44	0.62 ($n = 8$)	-

The results showed that the difference of analysis data between observed and NIST values are acceptable. [*] values in parentheses are not certified, but are given for information only.

2 Results and discussion

2.1 Mean concentrations

The arithmetic mean concentration of the trace elements are presented in Table 1. In Hong Kong an urban air monitoring net work has been established and the aerosol composition were measured (Fung, 1995). Since the present site is located at coastal region where the degree of pollution and weather condition are different from the urban areas. Therefore the present aerosol concentrations are lower than those of urban areas. However a few of the present data can approximately compare with ground station data during PEM-WEST B in Feb. 1994. For instance based on the figure published, the concentrations of Al presenting in TSP and PM₁₀ are close to those ($\geq 500 \text{ ng/m}^3$) reported by Arimoto *et al.* (Arimoto, 1997). The anthropogenic element concentrations, such as; Sb and As, according to the published figure's data estimated are approximately close to our work. It is obviously shown that a few data from Asia including Hong Kong regions are available for comparison. As a result, our present work is first time to describe systematically the environmental behavior of trace elements at coastal area in Hong Kong.

2.2 Enrichment factor

Enrichment factor ($E.F$) has been used to determine the possible sources of the different components in aerosols (Wiresma, 1986). The atmospheric Al concentrations can be elevated by pollution emissions, particularly in some regions of Asia (Arimoto, 1997). Compared the typical Sc/Al ratios of average crustal rock 2.7×10^{-4} (Mason, 1982) with the concentrations of Al, Sc in a surface soil sample collected from the central area of station, the concentration values are 72600 and 19.9 $\mu\text{g/g}$, the Sc/Al ratio is 2.74×10^{-4} . The results of Sc/Al ratio for TSP and PM₁₀ are 1.9×10^{-4} ($S.E.$ mean 0.049×10^{-4} , Stdev 0.52×10^{-4} , $n = 114$) and 2.7×10^{-4} ($S.E.$ mean 0.20×10^{-4} , Stdev 2.81×10^{-4} , $n = 189$) respectively. Thus in present work Al was chosen temporarily an indicator. The $E.F$ of trace elements were calculated by following equation

$$E.F = [X/Al]_{\text{air}} / [X/Al]_{\text{crustal}}$$

Where, $[X/Al]_{\text{air}}$ is a concentration ratio of an element X to

that of Al in atmospheric particulates and $[X/Al]_{\text{crust}}$ is a (Mason, 1982).
concentration ratio of an element X to that of Al in crust

Table 1a Annual concentration of trace elements for TSP at Cape D'Aguliar Station in Hong Kong during the April 1995 to April 1996

Elements	Mean*	S. E. mean	Median	Geomean	Stdev	Min	Max	No.
Al	655.74	83.41	340.00	331.76	890.53	33.00	6130.00	114
As	3.11	0.32	1.90	1.81	3.05	0.15	13.00	90
Bi	1.23	0.17	0.47	0.36	1.84	0.0025	10.68	118
Br	62.34	4.54	50.00	43.37	48.23	5.50	195.00	113
Cd	0.93	0.10	0.60	0.37	1.06	0.008	6.28	121
Cl	15028.95	1303.21	11000.00	9074.70	13914.52	390.00	89600.00	114
Fe	415.16	41.43	245.00	234.20	442.36	23.00	2500.00	114
I	2.69	0.18	2.02	2.18	1.84	0.30	11.40	105
nss-K ⁺	366.64	34.82	221.75	203.39	379.80	10.99	2263.84	119
La	0.77	0.09	0.47	0.40	0.90	0.021	4.50	108
Mg	2243.42	172.70	1930.00	1593.14	1843.90	240.00	11600.00	114
Mn	15.62	1.68	10.09	7.72	17.94	0.52	109.03	114
Na	8862.63	552.70	8200.00	6770.96	5901.24	1100.00	24800.00	114
Pb	40.73	3.99	25.45	16.68	43.70	0.273	226.30	120
Sb	1.60	0.20	0.91	0.67	2.18	0.032	17.00	114
Sc	0.12	0.01	0.07	0.06	0.13	0.0023	0.72	114
Se	1.18	0.09	0.82	0.80	1.00	0.012	4.80	113
Sm	0.13	0.02	0.07	0.06	0.19	0.002	1.40	107
Sr	12.30	1.03	10.03	8.38	11.34	0.84	79.86	121
V	7.04	0.61	4.95	5.37	6.47	0.80	48.00	112
Zn	70.08	7.08	46.50	32.96	74.91	1.00	390.00	112

Note: * Concentration units: ng/m³

Table 1b Annual concentration of trace elements for PM₁₀ at Cape D'Aguliar Station in Hong Kong during the April 1995 to April 1996

Elements	Mean*	S. E. mean	Median	Geomean	Stdev	Min	Max	No.
Al	535.70	44.54	332.00	275.07	612.33	20.00	3460.00	189
As	3.49	0.27	2.40	1.98	3.44	0.10	24.00	165
Bi	2.10	0.20	0.95	0.57	2.72	0.0005	13.46	184
Br	33.57	1.60	33.00	26.51	21.63	2.90	123.00	183
Cd	1.00	0.07	0.79	0.46	0.97	0.0041	5.93	187
Cl	5930.76	462.72	4880.00	3836.68	6361.31	27.00	67600.00	189
Fe	339.89	26.10	230.00	199.12	358.77	14.00	2600.00	189
I	2.75	0.11	2.40	2.28	1.55	0.30	8.60	186
nss-K ⁺	411.34	29.89	244.16	215.60	415.21	2.92	1968.50	193
La	0.67	0.05	0.43	0.38	0.69	0.04	3.70	175
Mg	1133.70	73.59	960.00	869.34	1011.63	74.00	11200.00	189
Mn	13.75	1.05	9.59	6.62	14.51	0.13	93.06	190
Na	4672.43	200.95	4350.00	3813.10	2762.56	260.00	13800.00	189
Pb	49.26	3.56	35.33	22.68	49.00	0.38	255.58	189
Sb	1.66	0.12	1.30	0.84	1.69	0.023	9.50	189
Sc	0.15	0.02	0.075	0.061	0.32	0.002	3.10	189
Se	1.40	0.08	1.20	1.02	1.01	0.0083	6.50	181
Sm	0.10	0.01	0.058	0.053	0.13	0.004	1.30	173
Sr	6.57	0.37	5.40	4.73	5.13	0.17	33.49	190
V	6.33	0.75	3.90	4.50	10.36	0.60	131.00	189
Zn	73.01	4.77	58.00	37.90	65.64	0.69	340.00	189

Note: * Concentration units: ng/m³

The results of $E.F$ are shown in Fig. 1. Based on the value of $E.F$ and Rahn's suggestion (Rahn, 1976), the nonenriched elements such as: Sc, Al, Fe, Mn, Sm, La and Sr are less than 10 in $E.F$. This means that these elements are related the crust and soil, the elements: V, Zn, As, Pb, Cd, Sb, Se, Bi, the $E.F$ values ranged between 50–3000 can be attributed to anthropogenic elements.

2.3 Elemental ratios

2.3.1 Ratio of lanthanum to samarium (La/Sm)

Olmets and Gorden (Olmets, 1985) have suggested that La/Sm ratio can be used as an indicator of oil combustion. They found that the La/Sm concentration ratio in fine fraction (aerodynamic equivalent diameter < 2.5 μm) of atmospheric particles is higher than those in soil. At Cape D'Aguliar

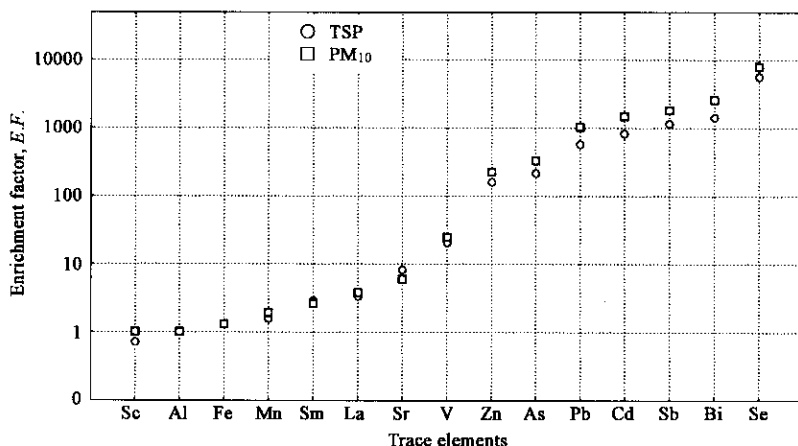


Fig.1 Enrichment factor of 15 trace elements at coastal station in Hong Kong

Station the ratio of La/Sm is 8.6 in soil, whereas the annual average concentration ratios of La/Sm are 6.70 (S.E. mean 0.20, Stdev 2.60, n = 104) for TSP and 7.61 (S.E. mean 0.20, Stdev 2.55, n = 163) for PM₁₀ respectively. Comparison of concentration ratios of La/Sm between in soil and in particles (TSP and PM₁₀), it can reasonably assume that most of the REE (rare earth elements) constituents in TSP and PM₁₀ are derived from the crust and soil. At urban area the correlation between La/Sm ratios and Pb concentrations has been used to indicate unleaded gasoline resulted in emissions of REE (Hashimoto, 1994), however at coastal area in Hong Kong the correlation coefficients (r) of those for TSP and PM₁₀ are statistically insignificant (r² = 0.0009, 0.003). This relationship again showed that almost of REE probably is derived from the crust and soil.

2.3.2 Noncrustal V and Mn (V* and Mn*)

The concentration ratio of Mn and V, suggested by Rahn (Rahn, 1981) may serve as an indicator of fossil burning in the urban area. Further, Dutkiewicz *et al.* (Dutkiewicz, 1987) successfully applied the concentration ratios of noncrustal Mn and V (Mn*/V*) and noncrustal vanadium (V*) related concentration ratio to assign the origin of aerosols as a function of the structure of energy sources. The Mn* and V* concentrations were calculated according to the suggestion of Rahn and Lowenthal (Rahn, 1985) and an attempt was made to explain the relationship among the possible sources.

The elemental ratio to V* and Se, combined with the data which measured by Dutkiewicz *et al.* (Dutkiewicz, 1987) for coal and oil combustion areas in U.S., are given in Table 2. The results showed that the TSP and PM₁₀'s ratio of Mn*/V*, Zn/V*, V*/Se are close to or slightly lower than those of Dutkiewicz *et al.* (Dutkiewicz, 1987), while in the case of Zn/Se the present work is about 3—4 times higher than those of Dutkiewicz *et al.* This means that coal and oil combustion probably dominate the aerosol composition in air over present site.

Table 2 Elemental ratio to V* and Se at Cape D'Aguitar Station in Hong Kong during the April 1995 to April 1996

	TSP	PM ₁₀	Coal- and oil-combustion aerosols
Mn* /V*	1.08 ± 1.13, n = 89	1.22 ± 0.63, n = 169	3.1 ± 2.4
Zn/V*	8.22 ± 1.65, n = 110	10.82 ± 1.56, n = 188	7.5 ± 1.9
As/V*	0.41 ± 0.26, n = 87	0.60 ± 0.26, n = 164	0.68 ± 2.1
Se/V*	0.19 ± 0.27, n = 110	0.29 ± 0.21, n = 180	0.74 ± 1.4
Sb/V*	0.16 ± 0.19, n = 110	0.24 ± 0.08, n = 188	0.20 ± 1.6
V* /Se	5.13 ± 1.85, n = 110	3.42 ± 1.66, n = 180	1.3 ± 1.4
Mn* /Se	5.88 ± 1.69, n = 93	3.77 ± 0.94, n = 162	5.1 ± 2.5
Zn/Se	41.08 ± 2.39, n = 112	36.40 ± 2.14, n = 181	11 ± 1.8
As/Se	1.76 ± 0.91, n = 90	1.58 ± 0.62, n = 157	0.97 ± 1.6
Sb/Se	0.83 ± 0.64, n = 114	0.80 ± 0.61, n = 181	0.27 ± 1.4

Notes: geometric mean ± 1σ; n stand for sampling numbers

2.3.3 Ratio of bismuth (Bi) to aluminum (Al)

Bismuth (Bi) could be a better tracer for volcanic emission than sulfur compounds, the fossil combustion, refuse incineration, ferromanganese alloys and aluminum production are also attributed to anthropogenic sources of Bi (Ferrari, 2000). For identification of possible sources of aerosols, it is meaningful to measure the Bi content in TSP and PM₁₀. The analytical data of soil showed that concentration of Bi, Al are 3.59 μg/g, 72600 μg/g respectively. The average ratio of Bi/Al in bulk crustal material is 2.5 × 10⁻⁶ (Mason, 1982), while the ratio of Bi/Al in soil at present station is 49.45 × 10⁻⁶, which are ~ 20 fold higher than those of bulk crustal material. The ratio of Bi/Al is 34.94 × 10⁻⁴ (S.E. mean 7.31 × 10⁻⁴, Stdev 77.04 × 10⁻⁴, n = 111) for TSP and 63.52 × 10⁻⁴ (S.E. mean 10.58 × 10⁻⁴, Stdev 143.45 × 10⁻⁴, n = 184) for PM₁₀ respectively. It may be identified that Bi is originated possibly from the anthropogenic sources i. e. fossil combustion, refuse incineration and metal industries (ferromanganese alloys and aluminum production).

2.3.4 Seasonal variation of trace elements

It is found that the concentration of trace elements present seasonal variation. The seasonal variation pattern of Mn*/V*, Bi, Sb, Cd, Sr and V are displayed in Fig.2 to

Fig. 7 (aggregated line plot). These phenomena may be explained qualitatively by the first, the trace elements probably are transported from different sources to the present coastal station (Dutkiewicz, 1987). Secondly the seasonal variation of V is different from most other trace elements, i. e. the high concentrations of V or noncrustal V (V^*) are occurred in summer, whilst the low concentrations in winter (Fig. 7). They are represented the residual oil combustion (Castanho, 2001; Thurston, 1985) and might be attributed that the local or regional sources of V are located near at Hong Kong (e. g. Shenzhen located within 100 km of Hong Kong where is one of the fastest economically growing metropolis in China) or adjacent coastal region sources (e. g.

Xiamen located just northeast of Hong Kong) or marine sources which impact on the station when the prevailing winds are easterly and southeasterly during the summertime. Thirdly based on one year (April 1995—April 1996) back-trajectory analysis, it was found that during the summertime the prevailing winds for Hong Kong briefly are easterly and southeasterly. The present station received the least anthropogenic species (e. g. the noncrustal V), although the different pathway of air masses came from the marine. In winter the prevailing winds briefly are northerly and northwesterly, an air mass brought large amount of anthropogenic species directly reached station from mainland of China or local and industrial region (Man, 2001).

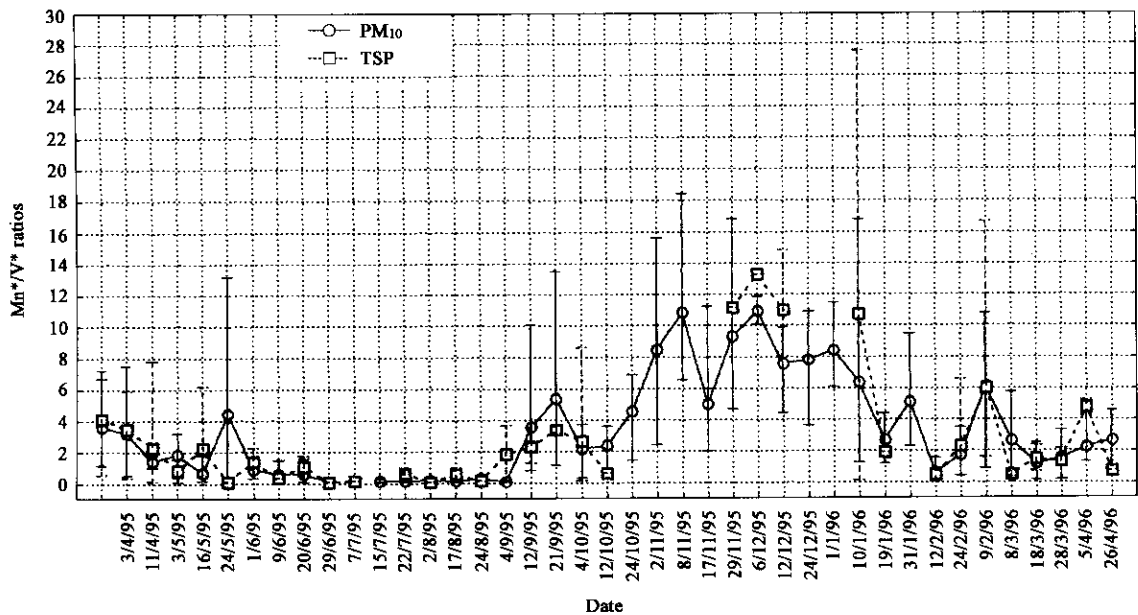


Fig. 2 Daily median ratios of Mn^*/V^* at Cape D' Aguilar Station

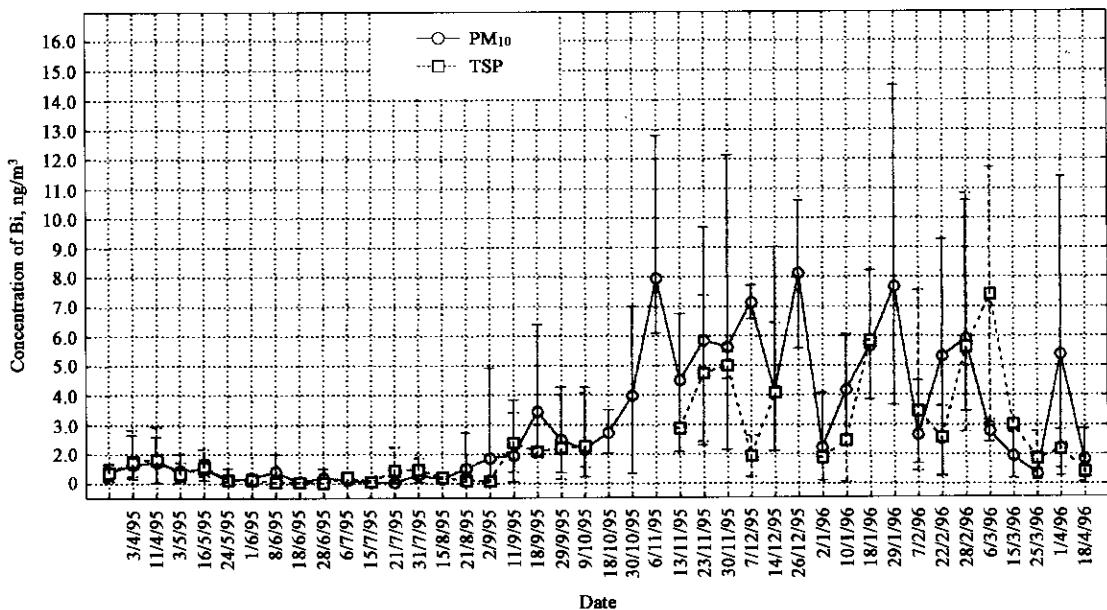


Fig. 3 Daily median ratios of Bi at Cape D' Aguilar Station

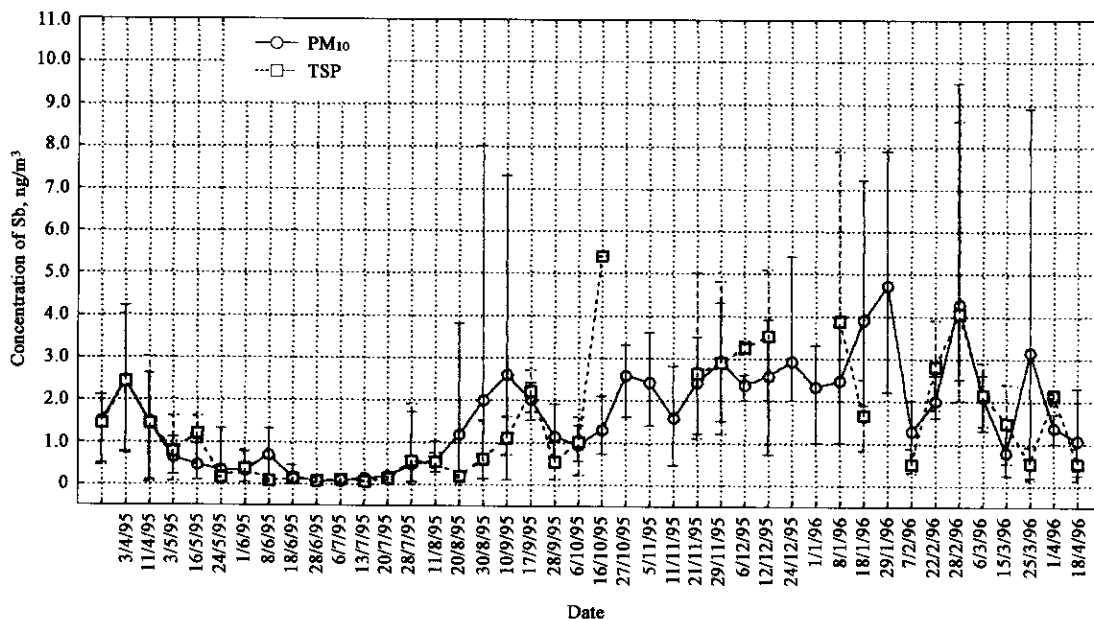


Fig. 4 Daily median ratios of Sb at Cape D' Aguilar Station

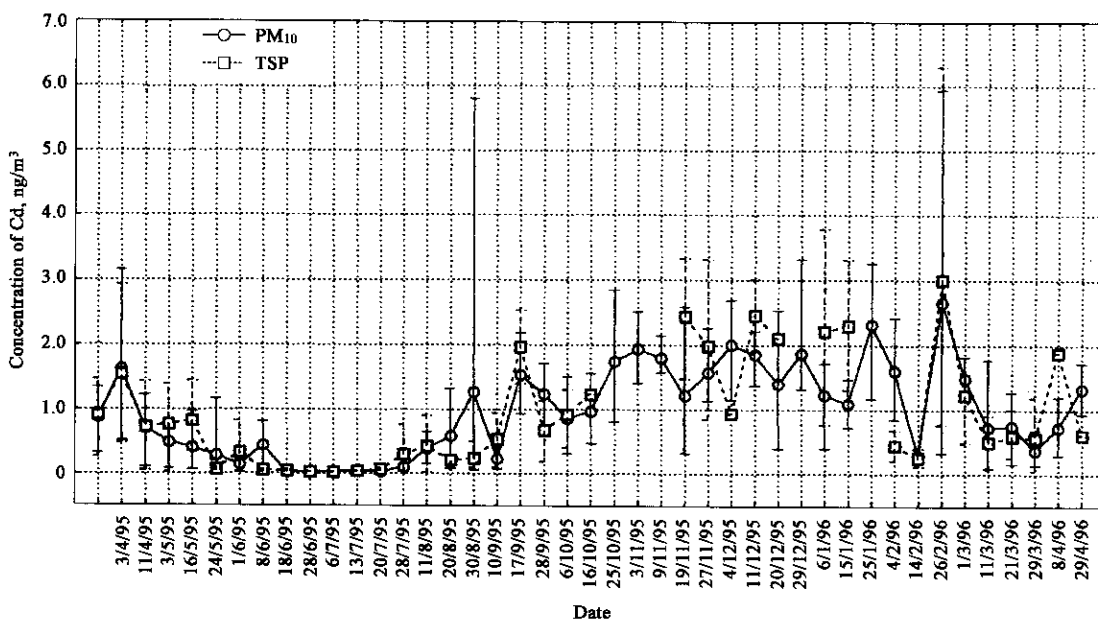


Fig. 5 Daily median ratios of Cd at Cape D' Aguilar Station

2.3.5 Factor analysis

The varimax rotation factor analysis was used qualitatively to identify the possible sources of TSP and PM₁₀, the absolute principal component analysis (APCA) (Thurston, 1985) also was performed for quantitative estimation their contributions to the possible sources. The 18 trace elements including nss-K⁺ (Hitchcock, 1980; Cheng, 2000) were prepared, so that it can identify adequately the possible sources of trace elements.

First, the factor loading matrix after varimax rotation (SPSS for windows 6.0 release SPSS Inc., 1993) for the TSP and PM₁₀ are shown in Tables 3 and 4. The 4 factors explained 83.2% (TSP) and 81.9% (PM₁₀) of the total

variance of the data set. Table 3 presents TSP factor loading. The first factor (Pc 1), eigenvalues 10.72 explaining 59.6% of the variance, has high loadings for elements: Cl, Na, Mg, and Br indicating obviously from marine sources.

The second factor includes Se, Zn, I, Sb and nss-K⁺, eigenvalues 2.09 accounting 11.6% of the variance, mainly represent the fossil combustion, municipal incineration and nonferrous metal production emissions. Because there are two large thermal power stations in Hong Kong, both consuming low sulfur coal (< 1% sulfur), they are located to the west of the station (~ 30 km). Hong Kong had more than 462000 licensed vehicles at end of 1994, petrol was used for these vehicles, about 75% of which were unlead fuel (Environmental Protection Department of Hong Kong,

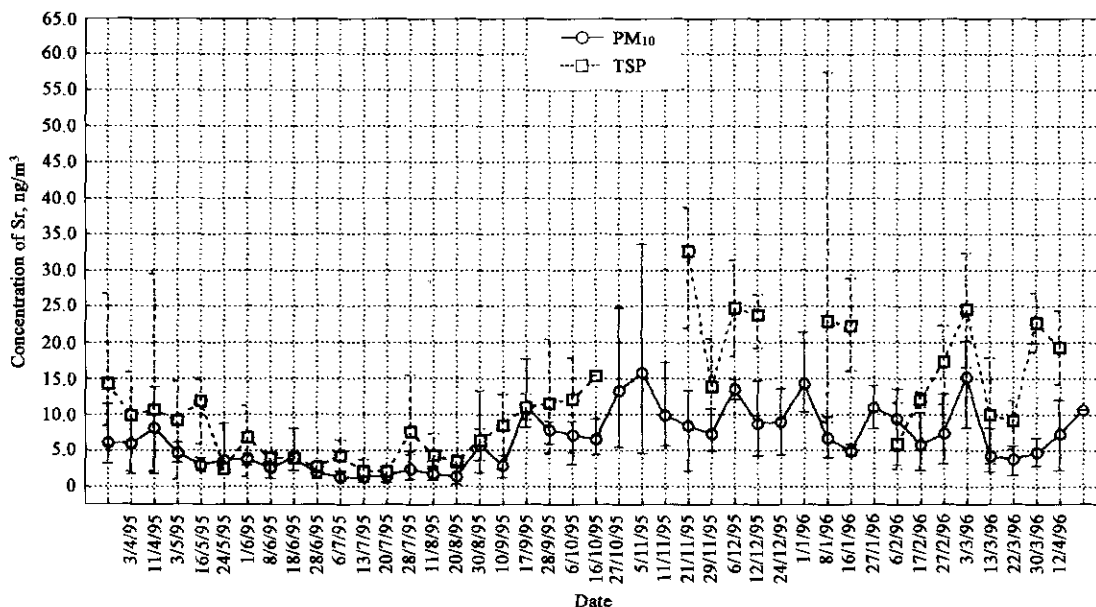


Fig. 6 Daily median ratios of Sr at Cape D' Aguilar Station

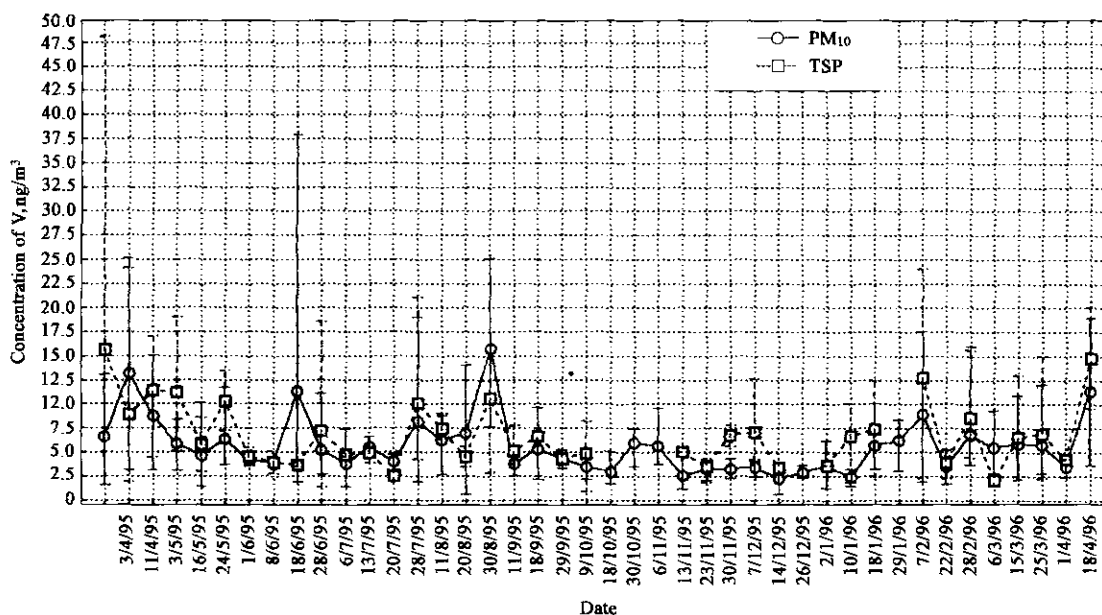


Fig. 7 Daily median ratios of V at Cape D' Aguilar Station

1995). A waste incinerator is also located to the northwest, the waste burning is a source of $nss\text{-}K^+$. Most of the Se is from fossil combustion and marine (biogenic) emission. The correlation between Se and I ($r = 0.62, 0.72$ for TSP and PM_{10}) suggested that the sources of Se are also important sources of I. Based on the box model, Vogt R. *et al.* (Vogt, 1999) stated that in the marine boundary layer, the iodine compounds are largely derived photochemically from several biogenic alkyl iodides e. g. $CH_2I_2, CH_2CHI, C_2H_2I, C_3H_7I$ or CH_3I which are released from the sea. Their photodissociation produced some inorganic iodine gases which can rapidly react in the gas and aqueous phase with other halogen compounds. Vogt R. *et al.* (Vogt, 1999) also suggested that almost all particulate iodine is in the chemical

form of IO_3^- . It indicated that iodine in TSP or PM_{10} is mainly generated from marine and anthropogenic sources including possible biomass source at Cape D' Aguilar Station in Hong Kong (Cheng, 2000).

The third factor (Pc3), eigenvalues 1.40 explaining 7.8% of the variance, has high loading for Mn, Pb Cd, Sr and moderate loading for Bi appearing to represent mainly the industrial, vehicular emissions, and perhaps ferromanganese alloys production The third factor showed that the multiple sources may impact on the Cape D' Aguilar Station.

The fourth factor (Pc4), eigenvalues 0.76 accounting 4.2% of the variance, with moderate loading for Fe, Sc, La, and Al. These elements are obviously originated from crustal or solid component.

Table 3 Varimax rotated factor matrix of trace elements for TSP at Cape D'Agular Station in Hong Kong during the April 1995 to April 1996

Elements	Pc1	Pc2	Pc3	Pc4	Communality
Cl	0.91		0.28	0.19	0.955
Na	0.90	0.16	0.27	0.23	0.958
Br	0.85	0.33	0.31	0.19	0.974
Mg	0.84	0.24	0.30	0.34	0.976
Se		0.83	0.24	0.17	0.780
I	0.16	0.77	0.19	0.19	0.690
Zn	0.24	0.75	0.21	0.46	0.875
Sb	0.17	0.70	0.0	0.36	0.660
nss-K ⁺	0.19	0.70	0.27	0.51	0.886
Mn	0.19	0.17	0.84	0.30	0.860
Pb	0.23	0.31	0.79	0.32	0.884
Cd	0.17	0.38	0.79	0.19	0.835
Sr	0.33	0.13	0.78	0.15	0.756
Bi	0.32		0.63		0.505
Fe	0.26	0.33	0.25	0.78	0.853
La	0.31	0.40	0.28	0.77	0.933
Sc	0.33	0.36	0.34	0.77	0.945
Al	0.16	0.43	0.21	0.62	0.643
Pat of var	59.6	11.6	7.8	4.2	
Eigenvalue	10.73	2.09	1.40	0.76	
Possible sources	Sea salts	Fossil emissions	Industries and vehicular emissions	Dusts and soils	

Note: Total matrix sampling adequacy 0.832

Table 4 Varimax rotated factor matrix of trace elements for PM₁₀ at Cape D'Agular Station in Hong Kong during the April 1995 to April 1996

Factor isolated	Pc1	Pc2	Pc3	Pc4	Communality
Zn	0.82	0.22	0.17	0.36	0.854
Sb	0.81	0.14	0.12	0.17	0.724
nss-K ⁺	0.77	0.25	0.24	0.39	0.869
Se	0.74	0.25	0.35	0.25	0.801
I	0.67	0.16	0.38	0.21	0.670
Cl		0.93	0.17	0.23	0.953
Na	0.23	0.89	0.24	0.19	0.943
Br	0.39	0.80	0.19	0.16	0.863
Mg	0.26	0.80	0.31	0.35	0.923
Pb	0.36	0.21	0.84	0.17	0.904
Cd	0.33	0.17	0.81	0.14	0.813
Mn	0.16	0.19	0.76	0.51	0.888
Sr		0.29	0.71	0.44	0.791
Bi	0.40	0.33	0.52		0.541
Fe	0.31	0.24	0.38	0.76	0.884
Al	0.40	0.29	0.36	0.74	0.921
La	0.45	0.32	0.29	0.71	0.883
Sc	0.20	0.17		0.67	0.521
Pat of var	59.2	9.4	7.6	5.7	
Eigenvalue	10.66	1.69	1.37	1.02	
Possible source	Fossil emissions	Sea salts	Industries and vehicular emissions	Dusts and soils	

Note: Total matrix sampling adequacy 0.819

Table 4 is the results of varimax rotation factor analysis for PM₁₀. Because the particle sizes (aerodynamic equivalent diameter) of PM₁₀ are smaller than those of TSP and the enrichment factor of anthropogenic elements for PM₁₀ such as:

Sb, Se and Pb are higher than those of TSP. Thus the first factor (Pc1), eigenvalues 10.66 explaining 59.2% of the variance, has high loadings for Zn, Sb, nss-K⁺, Se, and I indicating likely from industrial emission and fossil combustion. The iodine (I) with nss-K⁺, Se located same group which demonstrating I mostly originated from marine and anthropogenic sources. The second factor (Pc2) eigenvalues 1.69 accounting 9.4% of the variance, Cl, Na, Br and Mg can be attributed to sea salt component. The third factor (Pc3), eigenvalues 1.37 accounting 7.6% of the variance, included Pb, Cd, Mn, Sr and Bi which are indicative of fossil fuel combustion, vehicular emission, possible refuse incineration and metal industries. The fourth factor (Pc4), eigenvalues 1.02 accounting 5.7% of the variance, including Fe, Al, La and Sc with moderately loading, are represented dust and soil composition. Since at coastal station in Hong Kong the concentration of Al in PM₁₀ are lower than those of TSP. The Al is predominantly in the super-micron fraction and the mass median diameter (MMD) of Al is about 7 μm (Prospero, 1995; Arimoto, 1997). The factor analyses again showed that at coastal station in Hong Kong, sea salts have the greatest loading for TSP, while anthropogenic species are high loading for PM₁₀.

In order to quantify the contribution of trace elements to possible sources, the absolute principal component analysis (APCA) (Thurston, 1985) was performed and the overall means of trace elements were estimated by multiple regression. The results are listed in Table 5 and 6 for TSP and PM₁₀. The results showed that the mean concentration among the observed and estimated by the APCA or by multiple regression are approximately consistent with each other, the maximum relative errors are < ± 30%. Since there is no mass data for TSP and PM₁₀, it therefore can not calculate exactly the percentage of each trace elements contribution.

3 Conclusions

Our attempt is to interpret the behavior, contribution and identification of possible sources of trace elements at coastal station in Hong Kong. The trace elements: Se, Bi, Sb, As, Cd, Pb, and Zn are high enrichment elements, they may derived from anthropogenic sources such as: fossil emission, vehicular emission, possible refuse incineration, ferromanganese alloys and aluminum production. The *E.F* values of Sc, Al, Fe, Mn, Sr, Sr, La and Sm are less than 10. These elements may originate from crust and soil. The *E.F* values of V are greater than 10, it may probably generate from crude oil combustion, industrial emissions and mostly non-ferrous smelters. The another major groups are Cl, Na, Mg, and Br are derived from marine sources. The noncrustal Mn, V and parts of Sr may associate with industrial emission.

Table 5 Contribution to possible sources for TSP at Cape D'Aguilar Station in Hong Kong during the April 1995 to April 1996

Elements	Sea salts *	Fossil combustions *	Industries and vehicular emissions *	Crust and soil *	Sum of mean estimated contributions	Observed mean concentrations	Overall means estimated by multiple regression
Cl	8219.14		3324.40	2441.23	13984.77[1212.67]	15028.95[1303.21]	14579.56
Na	4767.23	1023.6	1911.40	1705.37	9407.69[586.69]	8862.63[552.70]	8878.46
Br	31.81	15.07	15.41	10.02	72.31[5.26]	62.34[4.54]	64.81
Mg	1128.80	395.09	545.87	629.78	2699.54[207.81]	2243.42[172.70]	2254.51
Se		0.698	0.23	0.17	1.10[0.09]	1.18[0.09]	1.27
I	0.30	1.47	0.407	0.433	2.61[0.17]	2.69[0.18]	2.82
Zn	10.66	36.9	11.903	27.436	86.92[8.78]	70.08[7.08]	72.32
Sb	0.164	0.79		0.494	1.45[0.19]	1.60[0.20]	1.79
nss-K ⁺	57.54	180.90	78.784	156.98	474.20[45.09]	366.64[34.82]	404.60
Mn	1.76	1.96	10.36	3.85	17.93[1.93]	15.62[1.68]	17.79
Pb	5.78	8.97	25.55	10.89	51.19[5.01]	40.73[3.99]	47.25
Cd	0.095	0.25	0.578	0.147	1.071[0.11]	0.93[0.10]	1.07
Sr	2.35	1.20	7.62	1.496	12.664[1.06]	12.30[1.03]	12.84
Bi	0.237		0.607	0.104	0.948[0.13]	1.23[0.17]	1.32
Fe	65.15	97.09	82.65	271.13	516.02[51.50]	415.16[41.43]	457.38
La	0.145	0.214	0.174	0.502	1.03[0.115]	0.77[0.086]	0.82
Sc	0.024	0.030	0.032	0.076	0.16[0.02]	0.12[0.01]	0.13
Al	62.85	199.17	109.82	340.85	712.69[90.65]	655.74[83.41]	712.29

Notes: Concentration units: ng/m³, [] values in parentheses standard for S. E. mean, * possible sources emissions

Table 6 Contribution to possible sources for PM₁₀ at Cape D'Aguilar Station in Hong Kong during the April 1995 to April 1996

Elements	Fossil combustions *	Sea salts *	Industries and vehicular emissions *	Crust and soil *	Sum of mean estimated contributions	Observed mean concentrations	Overall means estimated by multiple regression
Zn	34.82	10.87	9.08	19.30	74.07[4.84]	73.01[4.77]	82.13
Sb	0.78	0.15	0.14	0.22	1.31[0.10]	1.66[0.12]	1.86
nss-K ⁺	186.33	68.25	71.71	130.23	456.10[31.52]	411.34[29.89]	470.31
Se	0.61	0.23	0.37	0.28	1.49[0.08]	1.40[0.08]	1.52
I	1.08	0.28	0.79	0.46	2.61[0.11]	2.75[0.11]	2.91
Cl		3758.68	719.28	1113.09	5591.05[436.21]	5930.76[462.72]	5971.78
Na	604.73	2840.47	832.70	735.85	5013.35[215.61]	4672.43[200.95]	4910.46
Br	7.44	18.44	4.71	4.38	34.97[1.67]	33.57[1.60]	35.98
Mg	167.22	615.96	256.94	331.18	1371.31[89.01]	1133.70[73.59]	1151.55
Pb	10.08	7.00	31.40	6.83	55.31[4.00]	49.26[3.56]	54.67
Cd	0.19	0.11	0.61	0.12	1.04[0.02]	1.00[0.07]	1.09
Mn	0.84	1.73	7.87	5.82	16.23[1.25]	13.75[1.05]	15.27
Sr		1.25	3.51	2.42	7.18[0.41]	6.57[0.37]	6.93
Bi	0.48	0.48	0.83		1.79[0.17]	2.10[0.20]	2.29
Fe	61.24	54.78	94.81	214.39	425.21[32.65]	339.89[26.10]	383.87
Al	125.55	103.82	141.71	326.10	697.18[56.97]	535.70[44.54]	587.29
La	0.17	0.14	0.14	0.39	0.84[0.07]	0.67[0.05]	0.71
Sc	0.018	0.017		0.080	0.11[0.02]	0.15[0.02]	0.17

Notes: Concentration units: ng/m³, [] values in parentheses standard for S. E. mean, * possible sources emissions

By means of elemental tracer to identify source have been developed, the average ratios of La/Sm for TSP and PM₁₀ are 6.70 and 7.60, close to soil ratio of La/Sm (i.e. 8.6). It can therefore reasonably assume that most of the REE constituents of TSP and PM₁₀ are originate from the crust and soil. The ratio values of Mn^{*}/V^{*}, Zn/V^{*} and V^{*}/Se for TSP and PM₁₀ are close to or slightly lower or higher than those of Dutkiewicz's value, this means that the emissions of fossil combustion, refuse incineration and possible metal industries probably dominate over present station.

The another elemental ratio is bismuth to aluminum (Bi/Al). The ratio values of Bi/Al are 34.94×10^{-4} for TSP,

63.52×10^{-4} for PM₁₀. These results showed that Bi are derived from the anthropogenic sources, i. e. fossil combustion, refuse incineration, ferromanganese alloys production.

The trace elements are all present seasonal variation, i. e. concentration of those are presented summer low and winter high, however the seasonal variation of V or noncrustal V^{*} is different from most of other trace elements, i. e. the high concentration of V are occurred in summer, whilst the low concentration in winter. The reason of that may be explained by influence of local, regional or marine sources which impact on the station during the summer when the

prevailing winds briefly are easterly and southeasterly. The seasonal variation of trace elements may be interpreted qualitatively by back-trajectory analysis.

The factor loading matrix after varimax rotation identifies qualitatively to its possible source: sea salt components, crust or soil and anthropogenic species. The anthropogenic sources are industrial emission or fossil combustion, vehicular emission, possible refuse incineration, ferromanganese alloys and aluminum production. The absolute principal component analysis (APCA) and multiple regression are used to estimate the contribution of each trace elements to possible sources. All these results demonstrated that the multiple sources have impacted on the Cape D'Aguiar Station.

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