

## ELEMENTAL ENRICHMENT AND ITS ATTRIBUTION TO NATURAL AND ANTHROPOGENIC SOURCES IN FINE AND COARSE AEROSOLS OF KUALA LUMPUR

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**Abstract.** A total of 139 collocated samples of fine and coarse atmospheric aerosols collected from July 1988 to December 1990 in Kuala Lumpur were analysed for their elemental composition, and for their associated concentrations in the sampled air. Nine elements i.e As, Br, Co, Ni, P, Pb, S, Sb, and Zn, were found to be strongly attributed to anthropogenic sources. Their elemental enrichment factors in fine and coarse size fraction were more than 17 times higher than those found in the crustal rock. Whilst, Ca, Fe, K, Mn, and V could be attributed to both anthropogenic and soil related aerosols. Both Al and Cl were exclusively originated from soil and marine in all size fractions respectively.

**Key Words:** Air pollution, aerosol, trace elements, enrichment factors

### 1 INTRODUCTION

The characterization of atmospheric aerosols according to size and elemental composition is paramount in understanding their origins and possible health effects. Interest in determining the concentrations of the trace elemental components in atmospheric aerosols is growing rapidly in Malaysia.

Rashid *et al.*, [1] made the first attempt to analyze 25 elemental concentrations in the total suspended particulate matter sampled at one site in Kuala Lumpur. The authors demonstrated that the elemental constituents of the Kuala Lumpur aerosols can be classified into two source categories: (i) soil and (ii) anthropogenically derived aerosols. Studies on selected atmospheric trace elements in the Kuala Lumpur area and in other parts of the country have been reported [2,3].

The present study examines the enrichment of trace elements found in aerosol samples collected at one site in Kuala Lumpur which were segregated into fine and coarse particulate fractions. It seeks to classify the origins of these elements as natural (soil and marine) or anthropogenic.

### 2 MATERIALS AND METHODS

#### Sampling Site and Data Collection

The air samples were collected on the Universiti Teknologi Malaysia campus, located 2 km northeast of the centre of the capital city, Kuala Lumpur, situated in the Klang Valley Region (Figure. 1). The site is a mixed airshed region of commercial and residential areas which is surrounded by many industrial activities. The region is the most rapidly developed and densely popu-

lated area in the country. Its climate is typical of humid tropics with uniformly high temperatures and heavy annual rainfall.

Daily (24 hr average, midnight-to-midnight) inhalable particle samples segregated into fine particulate (FP, particles with aerodynamic diameter,  $d_a \leq 2.5 \mu\text{m}$ ) and coarse particulate (CP,  $2.5 \mu\text{m} \leq d_a \leq 10 \mu\text{m}$ ) fractions were collected using a Sierra Andersen automatic dichotomous air sampler (Model 244). The aerosols were collected from July 1988 to December 1990. The sampler was operated at  $16.7 \text{ l min}^{-1}$  with a sampling frequency of once a week. The flow rate of the sampler was routinely checked and calibrated using a calibrated rotameter. The sampler was placed on a roof-top of a building (*ca* 15 metres height) at the Universiti Teknologi Malaysia campus. The site is carefully selected in order to give a representative sample of the aerosol concentrations which affect the general air quality in the surrounding area.

The fractionated fine and coarse aerosols were collected on 37 mm diameter membrane filters. These filters were equilibrated in a desiccator for at least 24 hrs before weighing. The filters were weighed in batches along with three control filters in order to avoid any erroneous gravimetric results [4]. The gravimetric analysis of the filters was performed on a CAHN 30 microbalance.

### 2.1 Elemental Analysis

A total of 139 collocated samples of inhalable fine and coarse aerosols were analysed sequentially using three different analytical techniques. The K, P, S and Si elements were analysed using the wavelength dispersive XRF spectrophotometer (Philips Model PW1450) equipped with a computer control data processing facility. The XRF was operated at 60 KV 40 mA with fluorescence excitation accomplished by the chromium target x-ray tube. The characteristic x-ray emissions of K, P, S, and Si were detected and analysed by the gas flow counter detector and LiF(200) crystal respectively.

A thin film standard was employed to calibrate the XRF [5,6]. A series of metal solutions were prepared from high grade salt solutions of the element of interest [7]. The standard calibration curves were constructed for each element in terms of x-ray intensities against the standard elemental concentration per filter area within a given elemental concentration found in the actual aerosol samples. Reliability checks were made by comparing the x-ray intensities of freshly prepared metal solutions of known concentration against the calibration curve. Results from these reliability checks agreed to within  $\pm 5\%$  for all the four elements. The elemental contamination from the filter background was also determined using 20 blank filters.

The bulk of the elemental analyses in this study were performed by neutron activation analysis, NAA (Reactor Triga Model Mk II). A total of 12 elements were routinely detected which include Al, As, Br, Ca, Cl, Co, Mg, Mn, Na, Sb, V, and Zn. The high background level of K and Fe in the filter substrate used in the study made it difficult to obtain reliable quantitative determinations of these elements in the analysis. Therefore, the more reliable data of K and Fe from the XRF and AAS analysis were used for these elements respectively.

The samples were analysed at an average neutron flux of  $3 \times 10^{12} \text{ n cm}^{-2} \text{ s}^{-1}$ . The samples were placed in polyethylene tubes prior to irradiation. Measurement procedures and nuclear characteristics of the various radionuclides determined by NAA method have been reported [8]. The gamma rays emitted by the nuclides in the radiated samples were detected by HPGe detector (resolution 1.9 KeV at 1332 KeV  $^{60}\text{Co}$ ). The detector was connected to a Nuclear Data-66 multichannel analyzer, and the computer code SAMPO-90 was used for spectral analysis (Nuclear Data, USA). Radionuclides were identified by their characteristics gamma ray energies after comparing them with the spectra of the standards. These standards were prepared by depositing mixtures of appropriate elements onto samples of a highly pure substrate (ashless filter paper) which were sealed in polyethylene tubes. Standard concentrations were adjusted to make counting rates of the samples

and standards of comparable magnitude. Similarly, blank filters were also irradiated using the same treatment. The accuracy and precision of the NAA were verified by analysing the NBS Reference Materials of Coal Fly Ash (SRM 1633a), Tomato Leaves (SRM 1573) and Vehicle Exhaust Particulate (NIES No 8). The differences between the analysed and certified values were relatively close, ranging from 0.1% to 20% for the elements of interest. The standard deviation of the determinations made using this technique ranged from 0.2% to 10% for Al, As, Ca, Mg, Mn and 1.8% to 17% for Br, Cl, Co, Na, Ti, V, and Zn.

Elemental Fe, Ni, and Pb were determined by the HGA-AAS (Perkin Elmer Model 5000). The sample was digested with 1.0 ml concentrated HNO<sub>3</sub> (BDH Analar) and heated in boiling water for at least 30 minutes to dissolve the residue. After cooling to room temperature, the sample was transferred and diluted with double distilled water in a 25 ml volumetric flask. The sample was analyzed by the AAS together with the standard stock solutions. Blank filters were subjected to a similar treatment. Recovery studies of the elements using certified standard solutions found that the average percentage recoveries of Fe, Ni, and Pb were 104%, 107% and 102% respectively.

### 3 RESULTS AND DISCUSSION

#### Elemental Concentrations.

Table 1 presents values of the mean, standard error of the means and the medians of the elemental concentrations determined for both fine and coarse aerosols. The mean and the median elemental concentrations do not differ appreciably, and thus the mean values are representative of the typical elemental concentration at the site.

Figure 2 illustrates the fine to coarse elemental concentration ratios determined in the study. As, Br, K, Na, Pb, S, and V were at least twice as dominant in the fine as in the coarse aerosols. The fine-to-coarse elemental concentration ratios of Ca, Cl, Fe, Ni, and Sb were between 1.10 and 1.80. Most of these elements are highly or moderately volatile and they are usually associated with anthropogenic sources. With the exception of Na and Cl, which are known to be associated with maritime aerosols. Another two naturally derived aerosols, Al and Si, were found to predominate in the coarse aerosols with average coarse to fine concentration ratios of 1.40 and 3.52 respectively. Both Al and Si are usually associated with soil weathering or abrasion of crustal materials.

Unexpectedly, Co and Zn were predominant among the coarse aerosols which are difficult to explain. However, Rashid *et al.* [9] found that Zn was highly enriched in the local urban road dust material and suggested that tyre wares (due to mechanical abrasion of tyres that generate coarse particles) was the source of Zn in their finding. A similar explanation is given in this study. Phosphorous seems to predominate in the coarse rather than in the fine aerosol fraction, while Mn was found to be equally distributed in the fine and coarse size fractions.

#### 3.1 Elemental Enrichment of Crustal Origin

To determine whether crustal weathering might be the source for a particular trace element, an enrichment factor (EF) for each element in the atmosphere relative to the average crustal rock was calculated as follows:

$$EF_{\text{crustal}} = (X/Si)_{\text{aerosol}} / (X/Si)_{\text{crustal}} \quad (1)$$

where X is the concentration of the trace element of interest and Si is the reference element used to represent the most abundant species in the selected crustal material [10]. An EF close to unity would indicate that a particular element, X, is present in the aerosol at the same relative abundance as in the crustal origin. Other associated crustal/soil elements, such as Fe, Sc or Al, have been used instead of Si [11-13] whilst Na is used as the reference element for sea-salt aerosol [14].

The mean elemental enrichment factors and their possible sources in the fine, coarse and total (fine + coarse) aerosols are presented in **Table 2** which reveals that As, Br, Cl, Co, Ni, P, Pb, S, Sb, and Zn are enormously enriched in both fine and coarse aerosols. In most cases, these elements (Cl is an exception) are related to industrial/anthropogenic source emissions as reflected by their high EFs in all three size fractions.

Both Br and Pb are traceable to automobile exhaust emissions, whilst Ni and S are usually related to oil combustion. The fertilizer industry is most probably responsible for element P, whilst As, Co, Sb and Zn could be related to anthropogenic sources. Sea sprays are known to be a frequent source of Cl.

In contrast, the elements Ca, Fe, K, Mn, Na, and V were enriched or slightly enriched in the fine aerosol fraction indicating that they are anthropogenic in origin, whilst in the coarse aerosol fraction, the low EFs indicate that they are related to normal soil weathering processes. These findings illustrate that the sources of these trace elements in the fine and coarse aerosols may be different and involve different mechanisms in their production. This means that Ca, Fe, K, Mn, Na, and V are soil related aerosols in the coarse size fraction, but in the fine fraction, they may be anthropogenically derived (Na is an exception) originating from processes related to high temperatures. Ca could possibly originate from the cement industry while Fe and Mn are related to the iron and steel industry in the region. The biomass burning which is common in the region could be a source for K, whilst fuel oil combustion is the main source for V. Sea-salt is suspected of being responsible for most of the Na in the region. As expected, the low EF for Al in all the aerosol size fractions strongly suggests that it is a soil derived aerosol.

It is noteworthy that the EFs for Ca, Fe, K, Mn, Na, and V in the total aerosol sample did not provide the means of deducing their origin, whereas the corresponding EFs in the segregated fractions did provide useful information in this respect. The EFs of Ca, Fe, K, Mn, Na and V in the total aerosol would suggest that these elements are only associated with soil sources (as their EFs are near to unity), and their non-soil sources (i.e. EFs  $\gg 1.0$ ) are therefore not revealed. This clearly indicates that the EF concept can be useful in revealing sources of the trace elements if it is applied to size segregated samples rather than to unsegregated samples of trace elements. In particular, the results of applying EF to those elements, which are known to be related to soil but also to anthropogenic sources, must be interpreted cautiously. Nevertheless, the degree of enrichment of Ca and Fe in the fine aerosols may not be high enough to prove that they are anthropogenically derived.

### 3.2 Elemental Enrichment of Marine Origin

An analysis of elemental enrichment with respect to a marine origin was also carried out in this study. As the site is within *ca* 30 km from the sea, the influence of sea-salt aerosol intrusions could be substantial and needs further investigation. Na is used as the reference element instead of Si in equation (1), and the elemental concentration in bulk seawater was taken from Pytkowicz and Kester [15].

Values of the mean  $EF_{sea}$  of the elements in the fine, coarse and total aerosol fractions, presented in **Table 3**, show that the EF of each element was consistent in all size fractions. As expected, Al, As, Co, Fe, Mn, Ni, P, Pb, Sb, Si, V, and Zn were found to be greatly enriched relative to their appearance in seawater. These elements are continental generated aerosols originating from anthropogenic or weathered mineral or soil dust sources. Very few of these trace elements are present in bulk seawater. Thus, their enrichments relative to the seawater strongly suggest that they are not exclusively marine related.

In contrast, values of the  $EF_{sea}$  Br, Ca, K, and S, although higher than unity, were found to be relatively much lower than those of the elements discussed above. Although Br, Ca, K, and S are known to be anthropogenically produced, they are also traceable to the marine aerosol, and are

present in bulk seawater. However, their presence in sea-salt in the region is insignificant compared to their component in the atmosphere as indicated by their  $EF_{sea} \gg 1.00$ .

Unlike other elements, Cl is believed to be predominantly associated with sea-salt aerosols as reflected by its consistently low mean  $EF_{sea}$  in all size fractions (Table 3). Both Cl and Na were found to be positively correlated ( $r = 0.32, p = 0.0001$ ), but with a low correlation coefficient value, suggesting that Cl is in some way depleted in the aerosol samples. A consistently lower mean Cl/Na ratio of 0.22 and 0.55 in the fine and coarse aerosol fractions respectively, compared to the value of Cl/Na = 1.80 in the seawater, supports the above statement.

### 3.3 Attribution of Trace Elements in Soil and Marine Components

Attempts were made to attribute these elements to soil and marine components. The importance of this exercise was to help understand the relative contribution of these two natural sources to the elemental pollution load at the site.

Tables 4-6 present the attribution of elemental concentrations to the soil and marine component along with the ratio of observed-to-calculated elemental concentration found in all aerosol size fractions. The calculated soil component (column 2 in the table) was based on the average crustal rock elemental ratio to Si multiplied by the Si found in this study. Calculation of the marine component (column 3) was based on the elemental ratio to Na in bulk seawater multiplied by the non-crustal Na derived from equation (2) below:

$$Na_{nc} = (Na)_{aerosol} - (Na/Si)_{crustal} (Si)_{aerosol} \quad (2)$$

where  $Na_{nc}$  is the non-crustal Na or "excess" Na which is assumed to be of marine origin,  $(Na)_{aerosol}$  and  $(Si)_{aerosol}$  are the elemental Na and Si concentration in the aerosol samples respectively, and  $(Na/Si)_{crustal}$  is the average crustal rock ratio of Na to Si. The ratio of observed-to-calculated (column 6) is the ratio of the measured elemental concentration to the total calculated soil and marine components.

As shown in Table 4, most of the elements (including As, Cl, Co, Mn, Ni, P, Pb, S, V and Zn) are attributable to soil, at least in a traceable quantity, even in the fine aerosol size fraction. Ca, Fe, K, and Na are attributable as soil component, while Br, Ca, K, and S are traceable to the marine component.

As revealed in Table 4, both Al and Fe are mainly of soil origin whilst Cl is exclusively of marine. Their low ratios of observed-to-calculated elemental concentration indicate that the atmospheric concentrations of these elements are accounted for respectively by the soil (Al and Fe) and the marine (Cl) components. Those elements (i.e As, Br, Co, K, Ni, P, Pb, S, Sb, V, and Zn) with increasingly high observed-to-calculated elemental ratio are anthropogenic and found predominantly in the fine aerosol fraction. A high observed-to-calculated ratio of these elements indicates that their associations with other sources are more significant than with soil or marine component. This is especially true for the urban aerosols where most of these trace elements are emitted by industries. The elements with moderately high observed-to-calculated ratio, such as Ca, and Mn, reveal that they may be associated with other sources besides soil or marine.

Similarly, in the coarse aerosol fraction (Table 5), most of the elements are traceable to the soil. Al, Ca, Fe, K, Mn, Na, and V were predominant in this component. Br, Ca, K, and S are traceable to the marine component with Cl exclusively accounted for by the marine source.

Conversely, Al, Fe, and V were exclusively attributed to the soil component and their low ratios of observed-to-calculated elemental concentration (i.e less than one) illustrate that these elements derived mainly from soil in the coarse size fraction. Although V is known to be of anthropogenic origin, its attribution to soil in the region has been reported [1].

In the total aerosol size fraction (**Table 6**), all the elements were also traceable to soil with Al, Ca, Fe, and Mn exclusively attributed to it. As in other aerosol fractions, Cl was mainly accounted for by the marine component. The high observed-to-calculated ratios of As, Br, Co, Ni, P, Pb, S, Sb, and Zn clearly demonstrate that the origin of these elements in sources other than soil or marine is discernible even in the total aerosol size fraction. Atmospheric Na is principally of marine origin, but also exhibits a significant though lesser concentration attributable to the soil component. Potassium has equally important contribution from both soil and anthropogenic sources in the total fraction.

#### 4 CONCLUSION

Studies on the elemental enrichment and attribution of segregated fine and coarse aerosols in Kuala Lumpur revealed that As, Br, Co, Ni, P, Pb, S, Sb, and Zn were strongly related to anthropogenic sources. Most of these elements were also more enriched in the fine than in the coarse aerosol size fraction. Furthermore, the EFs of these elements were at least seventeen times higher in all aerosol size fractions. Moreover, their large observed-to-calculated elemental concentration ratio suggested a strong association with sources other than soil or marine.

Elements like Ca, Fe, K, Mn, Na, and V could still be attributed to the soil, particularly in the coarse aerosol size fraction. The relatively high  $EF_{\text{crustal}}$  of these elements in the fine aerosol size fraction suggests that they are anthropogenically related aerosols (Na is an exception) arising from industrial processes. The enrichment of these elements in both fine and coarse aerosols reflects the importance of their origin in contributing to local pollution.

Al is predominantly soil originated since its enrichment from a crustal origin was consistently found to be less than one in all size fractions. As illustrated in this study, Al was exclusively attributed to soil in all aerosol size fractions. In a similar fashion, Cl was found to originate almost exclusively from the marine component.

The analysis of elemental enrichment was valuable in establishing a soil or marine origin, particularly in segregated aerosols. As illustrated in this study, the preliminary source classification of elements in a given aerosol sample can be simplified by using this approach.

#### 5 ACKNOWLEDGEMENT

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133	1.33	0.11	0.97	115	0.09	0.15	0.14
135	571	45.2	47.1	139	2016	461	1495
139	1.12	0.17	0.46	142	0.35	0.07	0.24
104	45.3	1.76	10.0	91	77.9	7.22	24.0

Note

The above data are for the period 1979-1980.

Figure 1 Location of the sampling site

The sampling site is located in the Pacific Ocean, approximately 1000 km south of Hawaii.

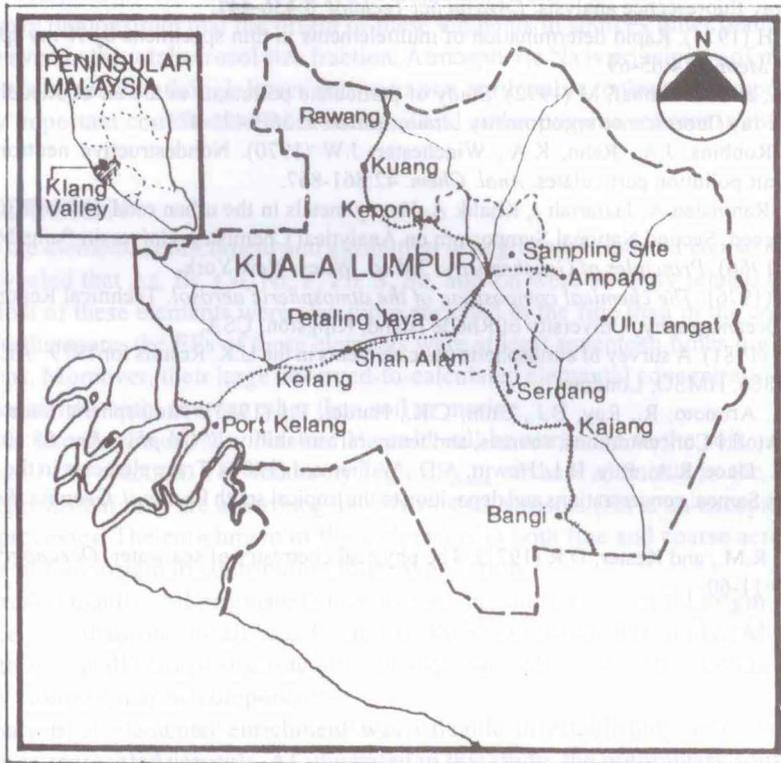


Figure 1 Location of the sampling site

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**Table 1** Concentrations of elements in the Kuala Lumpur aerosol, July 1988-December 1990

Element	N	Fine aerosol (ng m <sup>-3</sup> )			Total	Coarse aerosol (ng m <sup>-3</sup> )		
		Mean	S.E	Median		Mean	S.E	Median
Al	124	91.9	6.92	68.5	129	129	8.87	104
As	116	5.96	0.61	4.88	106	1.10	0.06	1.02
Br	129	25.4	1.46	21.0	107	6.49	0.53	4.46
Ca	79	190	16.9	164	101	171	10.8	153
Cl	76	109	6.40	102	93	95.2	9.66	55.0
Co	72	0.56	0.02	0.56	93	1.33	0.10	0.96
Fe	96	91.5	5.39	83.5	98	51.9	5.28	28.0
K	139	615	32.4	511	130	187	8.74	161
Mn	90	5.18	0.52	4.30	62	5.15	0.61	3.85
Na	137	484	21.1	456	97	172	13.8	149
Ni	84	23.4	2.54	16.5	58	16.2	1.35	13.0
P	133	68.6	12.3	44.0	138	118	7.29	99.0
Pb	138	160	4.81	163	99	30.3	2.70	24.0
S	139	3865	143	3744	135	1329	70.1	1425
Sb	95	1.35	0.18	0.97	115	0.99	0.18	0.34
Si	135	573	45.2	473	139	2016	143	1495
V	139	1.12	0.17	0.46	112	0.35	0.05	0.24
Zn	104	45.3	4.76	30.0	91	77.9	7.22	74.0

Note:

Fine aerosol: diameter  $\leq 2.5 \mu\text{m}$

Coarse aerosol:  $2.5 \mu\text{m}$  to  $10 \mu\text{m}$

S.E: standard error of the mean

N: number of samples actually detected

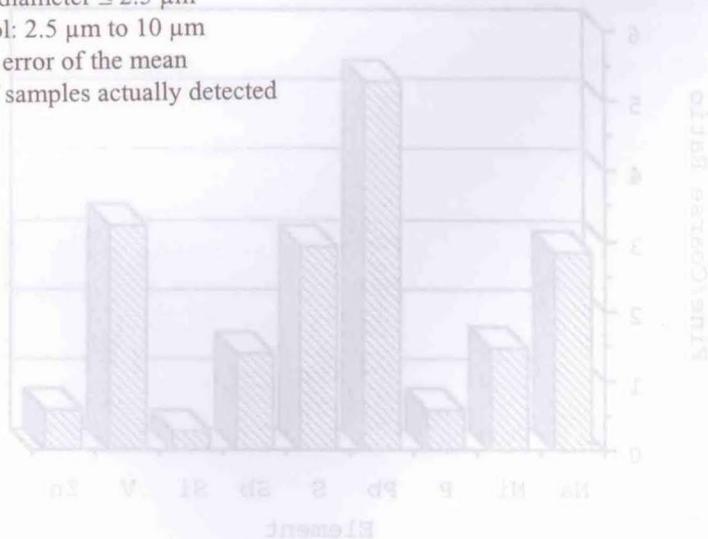


Figure 2 Elemental concentration ratio of fine to coarse aerosol in Kuala Lumpur

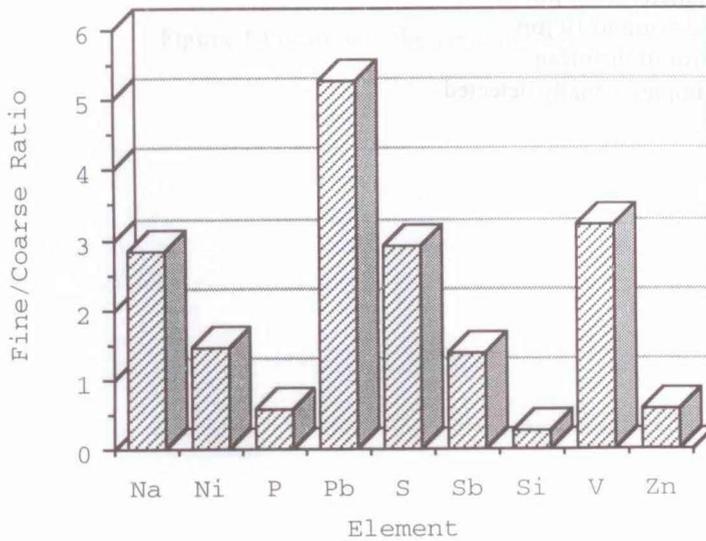
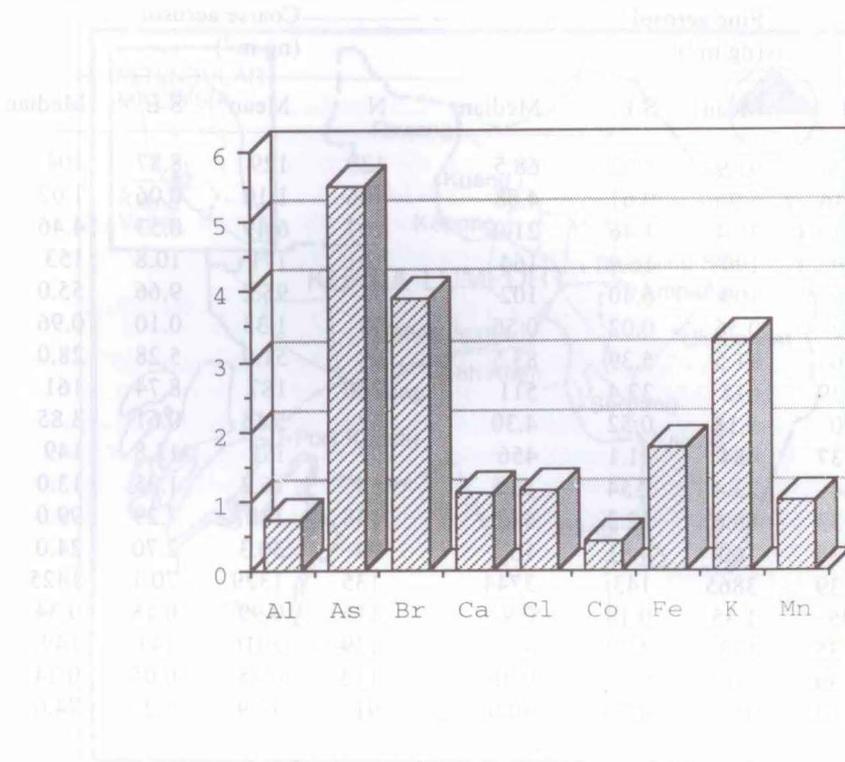


Figure 2 Elemental concentration ratio of fine to coarse aerosol in Kuala Lumpur

**Table 2** Enrichment factors calculated relative to crustal rock,  $EF_{\text{crustal}}$ , and possible sources for the elemental fine, coarse and total aerosols of Kuala Lumpur

Element	Fine	Coarse	Total	Possible Sources
Al	0.33	0.10	0.12	soil
As	3250	170	629	industrial
Br	11857	569	1860	auto-exhaust
Ca	6.15	0.81	1.06	cement/soil
Cl	989	105	129	sea-salt
Co	28.6	27.4	16.7	industrial
Fe	2.40	0.35	0.47	metallurgy/soil
K	23.6	1.65	5.19	biomass burning/soil
Mn	4.63	0.98	1.24	metallurgy/soil
Na	19.1	1.63	4.59	sea-salt/soil
Ni	416	65.0	67.3	oil combustion
P	56.7	22.0	26.4	fertilizer
Pb	12939	1192	2714	auto-exhaust
S	17649	1648	4102	oil combustion
Sb	6486	1056	1571	industrial
Si	1.00	1.00	1.00	soil
V	11.0	0.56	1.41	oil combustion/soil
Zn	716	365	2570	metallurgy/tyre wares

Note:

 $EF_{\text{crustal}}$  with Si as the reference element.

Total aerosols = Fine + coarse aerosols

**Table 3** Enrichment factors calculated relative to bulk seawater,  $EF_{sea}$ , for the elemental fine, coarse and total aerosols of Kuala Lumpur

Element	Fine	Total	Coarse	Total
Al	$1.85 \times 10^6$	1.0	$7.00 \times 10^6$	$2.60 \times 10^6$
As	$1.50 \times 10^4$	0.03	$1.00 \times 10^5$	$1.10 \times 10^5$
Br	15.0	1880	18.3	13.0
Ca	12.2	1.00	47.0	15.2
Cl	0.23	0.21	0.65	0.21
Co	$7.80 \times 10^5$	1.0	$5.00 \times 10^6$	$1.10 \times 10^6$
Fe	$1.10 \times 10^5$	0.03	$2.40 \times 10^6$	$8.10 \times 10^5$
K	64.4	1.0	65.0	52.0
Mn	$1.80 \times 10^5$	0.03	$5.90 \times 10^5$	$2.10 \times 10^5$
Na	1.00	1.00	1.00	1.00
Ni	$2.90 \times 10^5$	0.03	$1.20 \times 10^6$	$3.00 \times 10^5$
P	$8.10 \times 10^4$	0.03	$6.10 \times 10^5$	$1.60 \times 10^5$
Pb	$2.00 \times 10^8$	0.03	$1.40 \times 10^8$	$1.50 \times 10^8$
S	154	1.0	228	145
Sb	$1.90 \times 10^5$	0.03	$5.00 \times 10^5$	$1.40 \times 10^5$
Si	$7.50 \times 10^3$	0.03	$9.00 \times 10^4$	$2.20 \times 10^4$
V	$4.10 \times 10^4$	0.03	$3.00 \times 10^4$	$4.10 \times 10^4$
Zn	$5.20 \times 10^5$	0.03	$3.60 \times 10^6$	$7.30 \times 10^5$

Note:

$EF_{sea}$  with Na as the reference element.

Total aerosols = fine + coarse aerosols.



**Table 4** Elemental attribution ( $\text{ng m}^{-3}$ ) to soil and marine components with observed to calculated elemental concentrations ratios in the fine aerosol of Kuala Lumpur

(1) Element	(2) Cal Soil	(3) Cal Sea	(4) Total Cal	(5) Observed Conc	(6) <u>Observed</u> Total cal
Al	163	*	163	91.9	0.56
As	0.004	*	0.004	5.96	1490
Br	0.005*	2.66	2.66	25.4	9.55
Ca	73.1	16.3	89.4	190	2.12
Cl	0.26*	766	766	109	0.14
Co	0.050	*	0.050	0.56	11
Fe	101	*	101	91.5	0.91
K	52.1	15.8	68	615	9.04
Mn	1.91	*	1.91	5.18	2.71
Na (ref)	57	427	484	484	1.00
Ni	0.151	*	0.151	23.4	155
P	2.11	*	2.11	68.6	32.5
Pb	0.30	*	0.30	160	533
S	0.52	35.6	36	3865	107
Sb	0.0004*	*	0.0004	1.35	3375
Si (ref)	557	0.12*	557	557	1.00
V	0.003	*	0.003	1.12	373
Zn	0.141	*	0.141	45.3	321

Note:

The calculated elemental concentration was based on the elemental ratios to Si and Na in crustal and seawater respectively.

\* means the contribution is negligible.

**Table 5** Elemental attribution ( $\text{ng m}^{-3}$ ) to soil and marine components with observed to calculated elemental concentration ratios in the coarse aerosol of Kuala Lumpur

(1) Element	(2) Cal Soil	(3) Cal Sea	(4) Total Cal	(5) Observed Conc	(6) <u>Observed</u> Total cal
Al	327	*	327	129	0.39
As	0.007	*	0.007	1.10	157
Br	0.01	0.82	0.83	6.49	8.0
Ca	146	5.03	151	171	1.13
Cl	0.52*	236	236	95.2	0.40
Co	0.10	*	0.10	1.33	13.3
Fe	201	*	201	51.9	0.26
K	104	4.90	109	187	1.72
Mn	3.82	*	3.82	5.15	1.35
Na (ref)	114	132	246	246	1.00
Ni	0.30	*	0.30	16.2	54
P	4.20	*	4.20	118	28
Pb	0.052	*	0.052	30.3	583
S	1.04	11	12	1329	111
Sb	0.001	*	0.001	0.99	990
Si (ref)	1116	0.04*	1116	1116	1.00
V	0.54	*	0.54	0.35	0.65
Zn	0.28	*	0.28	77.9	278

Note:

The calculated elemental concentration was based on the elemental ratios to Si and Na in crustal and seawater respectively.

\* means the contribution is negligible.

**Table 6** Elemental attribution to soil ( $\text{ng m}^{-3}$ ) and marine components with observed to calculated elemental concentration ratios in the total aerosol of Kuala Lumpur

(1) Element	(2) Cal Soil	(3) Cal Sea	(4) Total Cal	(5) Observed Conc	(6) <u>Observed</u> Total cal
Al	642	*	642	204	0.32
As	0.014	*	0.014	6.04	431
Br	0.020	2.70	2.72	31.0	11.4
Ca	287	16.6	303	266	0.88
Cl	1.03*	781	783	106	0.13
Co	0.20	*	0.20	1.43	7.15
Fe	395	*	395	105	0.26
K	204	16	220	790	3.60
Mn	7.51	*	7.51	7.28	0.97
Na (ref)	223	436	659	659	1.00
Ni	0.59	*	0.59	27.9	47.3
P	8.30	*	8.30	183	22.0
Pb	0.10	*	0.10	181	1810
S	2.05	36.3	38.4	5156	134
Sb	0.002	*	0.002	1.78	890
Si (ref)	2190	0.12*	2190	2190	1.00
V	1.07	*	1.07	1.40	1.31
Zn	0.55	*	0.55	87.4	159

Note:

The calculated elemental concentration was based on the elemental ratios to Si and Na in crustal and seawater respectively.

\* means the contribution is negligible.