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CHEMICAL CHARACTERIZATION OF HOUSEHOLD DUST IN TWO MAJOR CITIES: COLOMBO, THE CAPITAL AND KANDY, THE HILL CAPITAL, SRI LANKA

Amarasooriya PITAWALA[1], Dilmi HERATH[1,2] & Nadeeka PIYATUNGA[2]

[1]*University of Peradeniya, Department of Geology, Peradeniya, Sri Lanka e-mail; apitawala@pdn.ac.lk*

[2]*University of Peradeniya, Postgraduate Institute of Science, Peradeniya, Sri Lanka*

Abstract: Household dust is an important environmental medium that affects human health. In this study, the levels of several heavy metals and other major elements in household dust in two cities of Sri Lanka were analyzed for the first time to interpret the possible sources and the factors controlling the chemical characteristics of household dust. Fifty four (54) dust samples from Colombo, the capital of Sri Lanka, located in the west coast and from the city of Kandy, located in central highlands were collected. Acid digested samples were analyzed by Atomic Absorption Spectrophotometry (AAS). The average concentrations of Pb, Cr, Mn, Cu, and Zn were found to be 2.3, 0.8, 191, 2, and 18.1 ppm respectively, in the household dust samples of Colombo city. The average concentrations of the above elements in the household dust of Kandy urban area were 3.5, 0.7, 347, 94.2 and 738 ppm respectively. Fe, Na and Ca concentrations in both areas show higher values; 3.2, 0.3 and 0.05 wt. % respectively, in Colombo and 3.2, 2.8 and 2.6 wt. % respectively, in Kandy. The levels of concentrations of measured elements of Colombo samples are relatively low compared to those found in Kandy though the Colombo city is heavily urbanized. The influence of wind pattern, high humidity and flat land area may have caused the low concentrations of measured metals in Colombo area while wind circulation and comparatively low humidity in Kandy which also is a valley area, may have accumulated those elements in dust. The present study reveals that urbanization and related anthropogenic activities are not only the main factors controlling the contamination of urban dust, but also natural conditions such as morphology, overburden soil cover and hydro meteoric conditions are also important factors contributing to the heavy metal pollution in dust samples.

Key words: household dust; heavy metals; urban environment; morphology, wind patterns

1. INTRODUCTION

The development of science and technology leads to environmental problems in both developed and developing countries. The world's most populated cities are in developing countries with a low per capita income. Main cities of these countries have high concentrations of poor residents who are suffering from social and environmental problems including severe air pollution (Soubbotina & Sheram, 2000). According to the United Nation Organization (UNO), more than 1 billion people are annually exposed to outdoor air pollution. Also, urban air pollution is linked up to 1 million premature deaths and 1 million prenatal deaths each year. The estimated cost for treating the patients who suffer from outdoor pollution related diseases is approximately 2% of GDP in developed countries and 5% of GDP in developing countries.

Natural processes such as overburden soil cover and volcanic eruption can emit dust particles into the environment (Singh, 2009). In the downstream areas, the air parcels encounters marine air masses with abundant water vapor and the dust contains accumulated sea salts (Zhang et al., 2005). Other than the natural dust, the land is characterized by dust derived from industries and biomass burning (Akimoto, 1994). The rate of dust distribution is controlled by the land use pattern, climatic conditions, wind direction, atmospheric temperature and the vegetation (Pereira et al., 2007; Pey et al., 2008). These dust particles deposited in houses or other buildings are referred to as household dust. Possibility for dust deposition in inside of houses is higher in tropical countries than in cold countries, because the houses of tropical countries are more open for wind flow than those in temperate countries. In urban soils and dusts, the anthropogenic sources of heavy metals include traffic emission (vehicle exhaust particles, tire wear particles, weathered street surface particles and brake lining wear particles), industrial emission (power plants, metallurgical industry, auto repair shop and chemical plants, etc.), domestic emission, weathering of building and pavement surface and atmospheric depositions (Thornton, 1991; Wei & Yang, 2009). Heavy metals in soils and household dusts can accumulate in the human body *via* direct inhalation, ingestion and dermal contact absorption (Ahmed & Ishiga, 2005; Wei & Yang, 2009). Excess heavy metal accumulation in household dust is toxic to humans as well as to other animals (Ongeri et al., 2010). Problems associated with long-term heavy metal exposures are: mental lapses, skin poisoning, problems for kidney, liver, gastrointestinal tract and central nervous system (Sherameti & Varma, 2010).

The interest in the levels of contaminants associated with urban dust has risen in the last two decades, particularly on sources and distribution of Pb, Cu, Zn, Fe and Cr. Many studies have been conducted in urban dust in developed countries (Charlesworth & Lees, 1998; Kabadayi & Cesur, 2009; Kim et al., 1998; Li et al., 2001). However, a limited number of studies have been carried out to understand the chemical and mineralogical nature of dust and soils in developing countries (Ahmed et al., 2006; Ahmed & Ishiga, 2005; Banerjee, 2002; Srivastava & Jain, 2005). The urban atmosphere can easily be subjected to pollute by anthropogenic contaminants arising from both stationary and mobile sources.

Recent studies have revealed that the respiratory diseases in Sri Lanka have become a major health problem (Senarath, 2003). Colombo Metropolitan Region (CMR) may experience high levels of metal contamination due to heavy traffic congestion and unplanned industrial and domestic waste deposition. Road deposited sediments (RDS), household dust and soil are useful probes to understand the pollution condition of an area. Although there may be many sources contributing to the pollution of the urban environment in Sri Lanka, the level of pollution in dust has not yet been studied.

Therefore, the present study was focused to determine the chemical composition of household dust in two major cities of Sri Lanka, (a) to identify the possible sources of the heavy metals, and (b) to interpret the factors controlling the chemical characteristics of household dust.

2. STUDY AREA

Colombo Metropolitan Region and Kandy city (Fig. 1) are highly populated and urbanized areas in the country. Population of Sri Lanka is of 19.7 million, of which more than 15% live in urban areas. The population of the country has an annual growth rate of 1.3 (Asian Development Bank report, 2006). Colombo is the capital city of Sri Lanka and lies in the flat coastal plane on the western part of the island.

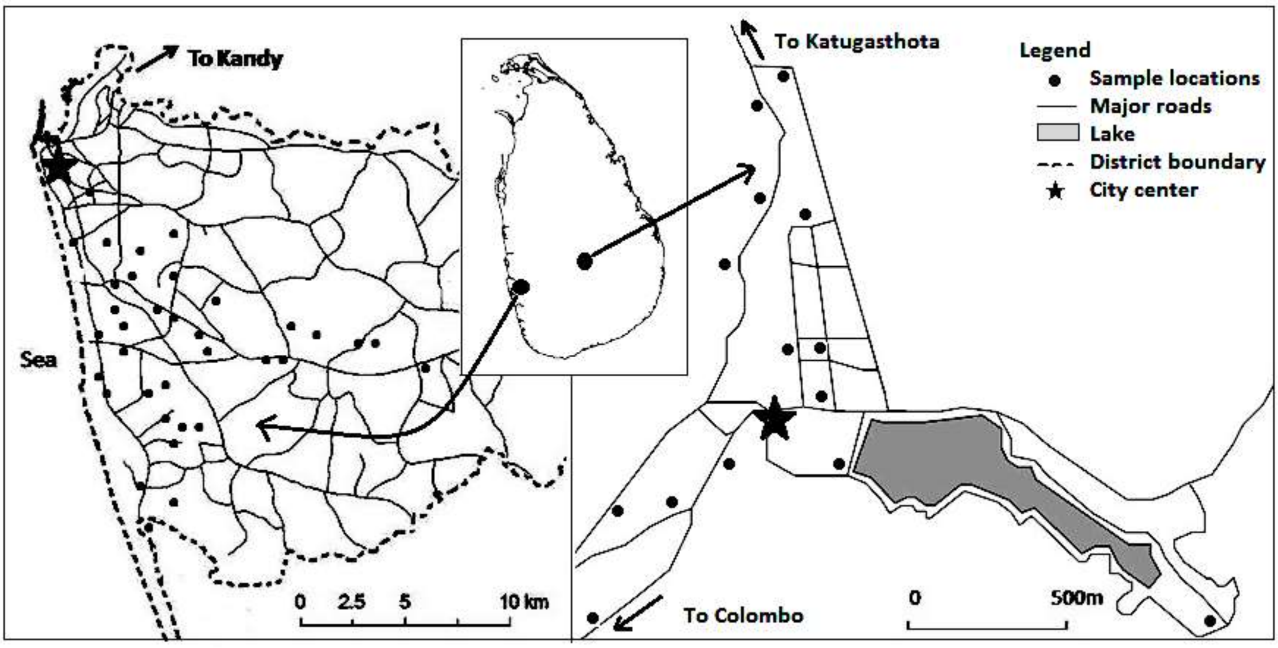

Figure 1. Sampling location map of (a) Colombo and (b) Kandy urban areas.

The city covers an area of 37.29 km^2. More than 80% of industries of the country operate in close proximity to the city of Colombo (Asian Development Bank report, 2006). Although large-scale industries are not common, there are many small- and medium-scale industries within the city limits. Multistory buildings are not common as in other developed cities of the world. High population density, large number of daily commuters, city center -oriented traffic flows and traffic congestions are very significant in the city. Humidity in Colombo varies from 75–95 % and receives an average annual rainfall of approximately 2,400 mm, in about 140 rainy days. The mean annual temperature in Colombo is approximately 25 to 28 ^{o}C with a small variation in the mean monthly temperatures. The wind flow into the city varies depending on monsoonal conditions.

Wind mainly flows from the Northwestern direction and moves across the city towards the interior parts of the country. Lateritic soil cover is predominated in the Colombo area (Cooray, 1984).

Kandy city is situated nearly 500 m above mean sea level, lies among the central hills of the island and possesses a basin-like morphology. It is a narrow city which covers an area of nearly 27 km^2. The urban area is mainly reserved for commercial purposes and social activities. The mean annual rainfall in Kandy is about 2250 mm and the mean annual temperature is around 24^{o}C. Although the humidity of the city is around 85% it is always less than that of Colombo area due to its high elevation. Due to the basin like morphology of the area, wind circulates within the city. The overburden soil cover of the area is different from that of the Colombo area and is made from the weathering of underlying rocks such as hornblende biotite gneiss, crystalline lime stone and charnockitic gneiss (Almond, 1994).

3. METHODOLOGY

3.1. Sample collection

A total of fifty four (54) household dust samples were collected from selected locations in Colombo (40) and Kandy (14) urban areas (Fig. 1) during sunny days from March to July 2011. Dust gathered on window panes and on tops of furniture was wiped carefully on to a white paper by a well cleaned brush with smooth fibers (avoiding paint, cement, lime or rust on surfaces) and stored separately in labeled air-tight polythene bags and were transferred to the laboratory for analyses.

3.2. Chemical analysis

Samples were treated with 50% hydrogen peroxide to remove organic matter and were oven dried overnight at 105 ^{o}C. Approximately 1.0 g of each sample was accurately weighed and digested for heavy metal analysis using aqua regia (3:1 HCl/HNO_3, v/v). The solutions were stored in sealed plastic bottles prior to analysis. The extracts were analyzed by Atomic Absorption Spectrophotometry (AAS-Perkin Elmer, Model 2380) to determine the total concentrations of Zn, Cu, Cr, Fe, Mn, Pb, Na, K, Ca and Mg. The accuracy of determination was controlled by means of duplicates, reagent blanks and reference materials. Analysis errors were maintained below 5–10%.

Mineralogical composition of selected dust samples were studied using X-Ray Diffraction (XRD) analysis on Siemens D 5000 X ray diffractometer. Organic matter and coated iron of samples were removed prior to analysis by treating with 50% hydrogen peroxide (Kunze & Dixon, 1986) and Citrate Bicarbonate Dithionite (CBD) (Jackson, 1969) respectively.

4. RESULT AND DISCUSSION

The most dominant element in the dust of both study areas is Fe (Table. 1). Iron (Fe) concentration in the dust of Colombo varies from 0.1 to 9.5 wt. % while that of the Kandy area shows from 0.3 to 10.6 wt. %. The second most abundant element is Na. Average Na concentration in Kandy dust is 2.8 wt. % whereas that of the Colombo dust is 0.3 wt. %. Ca concentrations are also considerably high in the dust of Kandy (average = 2.6 wt.%), compared to that of Colombo (average = 0.05wt. %). Among the measured heavy metals, Zn is the most abundant heavy metal. Cu concentration in Kandy dust is also significant and all the other heavy metals are present below the threshold levels.

There are many different sources for the presence of heavy metals in the environment; both natural and anthropogenic (Wei & Yang, 2009). The major cause for high accumulation of Fe in household dust of studied samples may be a result of rusting and due to dust accumulation from soil cover (Charlesworth & Lees, 1998). The higher concentrations of Fe in dust of both cities may have derived mainly from the basement soil covers since lateritic soil cover in Colombo contains 26302 ppm of Fe (Dissanayake, 1986) and soils derived from gneisses with Fe-Mg minerals contain about 86000 ppm of Fe (Sharma & Rajamani, 2000). Therefore, it can be assumed that the extent of Fe accumulation in dust due to anthropogenic influence has been masked by the natural processes.

Table 1. Elemental concentrations of dust samples from the study areas. Major oxides (Fe, Na and Ca) are in wt. % and trace elements are in ppm

Element	Colombo (n= 40)				Kandy (n= 14)			
	Maximum	Minimum	Average	SD	Maximum	Minimum	Average	SD
Cu	17.2	0.2	2.0	2.6	132.5	5	94.2	29.8
Cr	3.1	0.1	0.8	0.6	2.5	b.d[*]	0.71	1.1
Pb	11.2	0.3	2.3	2.3	15.5	b.d[*]	3.5	4.7
Mn	370.9	98.5	191.0	79.3	565	30	347.5	145.9
Zn	150	0.2	18.1	28.3	2,475	82.5	738.9	611.7
Fe	9.5	0.1	3.2	2.4	10.6	0.3	3.9	2.3
Na	1.5	0.04	0.3	0.2	12.2	0.2	2.8	3.2
Ca	0.3	0.01	0.05	0.06	4.1	1.0	2.6	1.1

[*]b.d-below detection limits; n- sample number

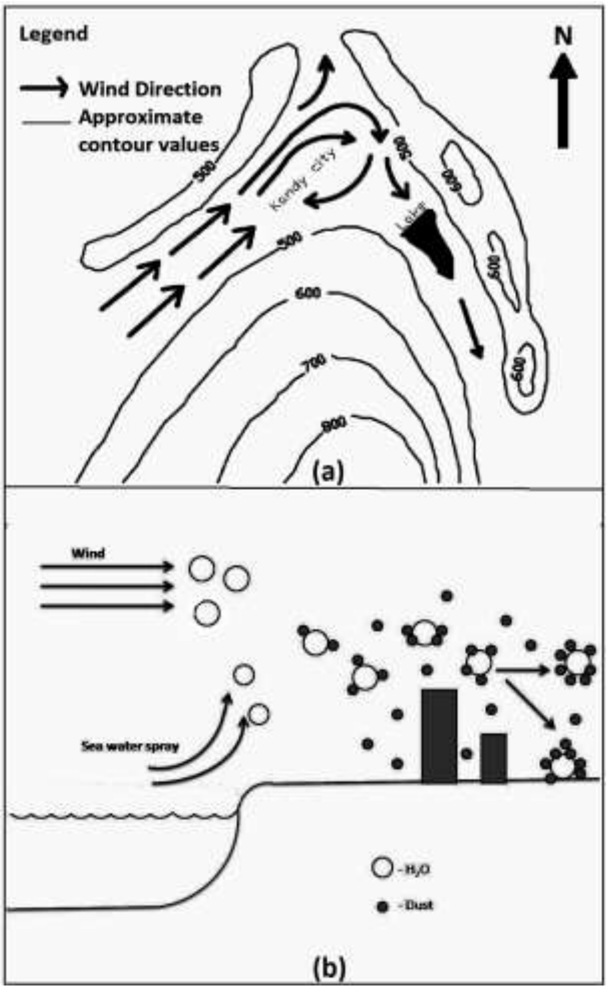

Figure 2. (a) Wind flow pattern within Kandy city (not to scale) and (b) Influence of sea water spray and wind on the dust deposition in Colombo

The major sources for high levels of Zn in the household dust of Kandy area could be mainly from motor traffic related activities and their combustion exhaust (Kim et al., 1998) because the area has no significant industrial activities. The wear and tear of vulcanized rubber tires, lubricating oils and corrosion of galvanized vehicular parts are the sources for Zn associated with vehicles (Charlesworth & Lees, 1998). Despite the heavy traffic congestion, higher vehicle density and the presence of large number of medium scale industries (Asian Development Bank report, 2006), the level of Zn is remarkably low in the dust of Colombo city. Also the concentrations of Pb, Cu and Cr in Colombo samples are relatively low compared to those of Kandy.

Higher values of major ions, especially Na and Ca can be expected in Colombo samples because it is located along the western coast of the island. However the concentrations of Na and Ca are relatively high in Kandy. Levels of these elements in soils of Kandy area can be high as soil derived from charnokitic gneiss contains Na_2O and CaO, 2.65 wt. % and 2.76 wt. % ppm, respectively (Pohl & Emmermann, 1991). Therefore, it can be assumed that dust from the soil cover is the main source of household dust of the area.

Despite Colombo having intense traffic, poor maintenance of roads, improper waste disposal practices and rapid construction activities (Senarath, 2003), the levels of heavy metals in the household dust is relatively low compared to those in Kandy as well as those of different cities of the world (Kim et al., 1998; Wei & Yang, 2009). Dust in Kandy is heavily polluted in terms of heavy metals such as Cu and Zn in addition to containing higher amounts of Fe, Na and Ca.

Basin-like morphology in the Kandy area can act as a barrier to flow the wind and favors to circulate within the city (see Fig. 2a). This can increase the accumulation of dust particles together with heavy metals within the city area. Since the city of Colombo is situated close to the coast, wind flow and wind velocity is high. Therefore, the suspended dust particles disperse over a large area and reduce the concentration of accumulation. Also the high humidity combined with particles in air enhance the fall down of the suspended particles from the air (see Fig. 2b), especially during nights with dew.

Although population density in Kandy is low compared to Hong Kong and Istanbul cities (Li et al., 2001; Kabadayi & Cesur, 2009), the lack of pollution control practices as well as poor maintenances of vehicles and road conditions may be the reasons for comparatively higher accumulation of Zn in dust samples in Kandy. Sharp bends and steep slopes of the roads due to morphological conditions may also increase the wearing of tires. Present study implies us that not only urbanization, but also other factors such as morphology and climatic conditions are also important aspects in controlling dust and heavy metal accumulation in the dust of the area.

Colombo urban area and its suburbs are underlain by peaty lateritic formations which were formed during the quaternary period (Cooray, 2003).

Average concentrations of Cu, Zn, Mn, and Cr in these formations are 20, 67, 104 and 41 ppm respectively (Dissanayake, 1986). Only Mn concentrations obtained by this study shows a high value while all other elements show relatively low values than the underlying formation. Weight percentages of Fe, Na and Ca in peaty lateritic formations are 2.6, 0.2 and 0.3 wt. % respectively, (Dissanayake, 1986) while results obtain from this study shows higher concentrations for all these major elements in the household dust. Higher Fe in dust may be due to intense rusting in the costal environment.

Kandy urban area is underlain by high grade metamorphic rocks such as hornblend biotite gneiss and charnockitic gneiss with small bands of marble. Concentrations of Cu, Zn, Mn and Cr in these rocks are 11, 68, 800 and 16 ppm respectively, in charnockitic gneiss (Pohl & Emmermann, 1991). Cu and Zn concentrations of samples in Kandy show higher values than those present in the basement rocks. However, Cr and Mn show relatively low values. Iron (Fe), Na and Ca concentrations in basement charnockitic rocks are 0.96, 2.65 and 2.76 wt. % respectively (Pohl & Emmermann, 1991). Except Na, other major elements show lower values in the samples compared to those in the basement rocks. Mineralogical study on dust samples of Colombo show that they do not contain any crystalline materials (See Fig. 3A). It is possible that the crystalline materials that may contain in Colombo dust samples are heavily coated with organic materials and as such the crystalline materials are not visible in mineralogical studies. The XRD studies of Kandy dust samples (see Fig. 3B(1)) indicate the presence of quartz (Q), calcite (Ca) and sulphur (S).

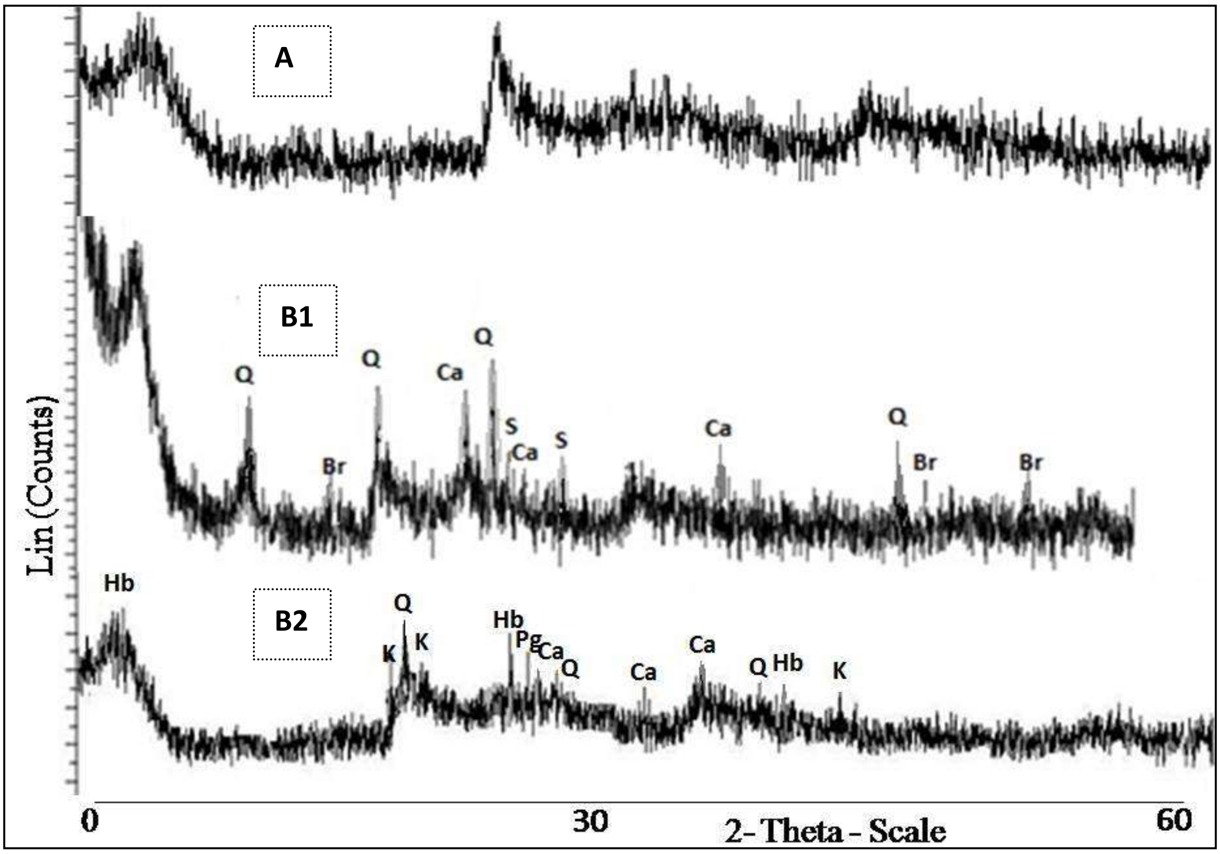

Figure 3. X-Ray Diffraction analysis plots for the dust samples collected from Colombo (A) and Kandy (B1 and B2) (abbreviations - quartz (Q), calcite (Ca), sulphur (S), hydrated biotite (Hb), kaolinite (K), plagioclase (Pg), hematite (H))

Presence of sulphur in samples indicates the anthropogenic influence, becouse sulphur is a constituent in vehicle exhausts. The figure 3B(2) reveals the presence of hydrated biotite (Hb), kaolinite (K), quartz (Q), plagioclase (Pg), calcite (Ca) and hematite (H).

Therefore, the household dust in Kandy has been derived mainly from the basement soil.

5. CONCLUSIONS

Although Colombo is heavily urbanized compared to Kandy, heavy metal and other major element concentration in household dust is higher in Kandy than that in Colombo. Out of measured heavy metals, Zn, Cu, Mn and Fe are notably high in Kandy dust.

Further, dust of Kandy city area is heavily polluted in terms of heavy metals such as Cu and Zn compared to the dusts of other cities in the world. Mineralogical composition of samples from Kandy implies us that input of overburden soil is high on the accumulation of dust.

Obtained data illustrate that natural conditions such as wind pattern, overburden soil cover, morphology of the area and the atmospheric humidity conditions may have controlled the chemical characteristics of household dust in addition to the anthropogenic sources in the area concerned. Also the sea water spray can increase the levels of Ca and Na in dust.

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