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An Evaluation of Loading Rate of Dust, Pb, Cd, and Ni and Metals Mass Concentration in the Settled Surface Dust in Domestic Houses and Factors Affecting Them

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Key Words

Surface dust · Domestic houses · Interior · Exterior · Loading rate · Mass concentration · Pb · Cd · Ni · Location · Age · Tobacco smoke

Abstract

Interior and exterior measurements of surface loading rates for settled surface dust in domestic houses and the content of three metals – lead (Pb), cadmium (Cd) and nickel (Ni) – were conducted weekly during the autumn of 2007 in an urban area of Giza, Egypt. Surface mass concentrations of the metals were also calculated. Results revealed that the interior and exterior surface loading rates averaged 1.58 and 8.18 $g\,m^{-2}$ per week, respectively. The interior surface mass concentrations of Pb, Cd, and Ni averaged respectively 311.18, 33.09 and 53.51 $\mu g\,g^{-1}$, and their interior surface loading rates averaged 533.17, 54.78 and 87.84 $\mu g\,m^{-2}$ per week, respectively. The interior surface loading rates of dust were higher at the side streets than at main streets although the interior surface mass concentrations and loading rates of the metals were higher at the main streets than at side streets. Levels were higher in older homes and smoking homes than in new homes and non-smoking homes. Surface Pb per area in all homes exceeded the US EPA and US HUD guidelines (40 $\mu g\,ft^{-2}$) of interior floor Pb dust wipe. Significant positive correlation coefficients were found between interior surface loading rates of metals and dust; among surface loading rates of metals; and among metals' surface mass concentration.

Introduction

House dust from both exterior and interior sources can be the source of exposure to many environmental pollutants when deposited on indoor surfaces [1,2].

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House dust is a complex mixture of particulate material from outdoors as well as generated and anthropogenic sources from indoors including particles from skin, hair, mites, fibres from clothing and furnishings, cigarette smoke, cleaning products, cooking and heating emissions, building materials and many other materials found indoors [3,4]. A considerable fraction of interior dust can be derived from exterior soil. Various estimates of the contribution have been proposed, ranging from 20–30% [5,6] to 30–45% [7,8] of the interior dust.

Many indoor air pollutants can be adsorbed onto suspended particulate matter and later settle out on indoor surfaces. The composition of settled house dust can differ considerably between rooms of a given house and among geographic locations [2,9]. Indoor settled dust can include biological and chemical contaminants, combustion products and others [10]. This dust is also potentially an important route of exposure to heavy metals [11]. For example, interior dust and exterior soil are recognised as possible sources of lead (Pb) exposure, particularly through children's play and hand-to-mouth transfer of Pb-contaminated dust [2,12]. The Pb in the atmosphere comes from a variety of sources, particularly leaded gasoline and paint as well as refuse burning and waste incineration [13–17]. Another toxic metal is cadmium (Cd) from a variety of sources, particularly, indoors, tobacco smoking. Cadmium is also used in the accumulators of motor vehicles or in carburettors as an alloy and it is released after combustion [18,19]. The third metal examined here is nickel (Ni). Unlike Pb and Cd, contributions from mobile sources to Ni-emission inventories are small and derived primarily from engine wear and impurities in engine oil and fuel additives [20]. The combustion of oil and incineration of waste contribute more than 70% of total Ni to the atmosphere [21].

In the indoor environment, besides the penetration of outdoor particulate matter that contains the heavy metals, leaded paints used for interior decoration have a remarkable influence on Pb levels in house dust [22]. Tobacco smoke is also an important source of Pb and Ni as well as Cd in the indoor environment [23,24]. Metal concentrations are often higher in house dust than in the soil outside [7,25].

Pb is dangerous to human health and its effects include blood enzyme changes, anaemia, hyperactivity and neurological disorders, while both Cd and Ni are toxic metals and probably carcinogenic to humans [13,26–30]. The settled surface dust in domestic houses and its metal content are mostly still unstudied in Egypt and the present study aims to remedy this, looking at levels of the three metals, Pb, Cd and Ni, in household dust and their potential effects on health.

This study had two goals: first, to evaluate the levels of interior and exterior surface loading rates of the settled surface dust in domestic houses and the content of the three metals noted and their mass concentration in an urban area (El Haram) of Giza; and, second, to investigate the influence of three important factors (home location, home age and tobacco smoke) on the levels found.

Materials and Methods

Sampling Site and Period

Giza is located on the west bank of the River Nile, some 20 km southwest of the centre of Cairo. It lies between two huge industrial areas: Shoubra El-Khiema in the north and Helwan in the southeast. Roads in and around Giza are characterised by high traffic density. The study was conducted at eight different homes that occupied the second floor in a block that used liquefied petroleum gas, had natural ventilation, and were located in an urban area (El Haram) of Giza. These homes were carefully selected based on the differences in their location, age of the buildings, and tobacco smoking in the home. A smoking home was defined as one in which there was at least one smoker. Table 1 gives details of the homes in the study: location, age (when the house was built, in years), size (total area of home in m^2), and information as to whether they were smoking or non-smoking homes.

Interior and exterior surface dust samples were taken weekly during the autumn months of 2007 (September, October and November). The interior samples of dust were collected at 75 cm above the floor in the living rooms, at least 1 m from the nearest door or window, and at least 20 cm from the nearest wall. Simultaneously, the exterior samples were collected nearby from a balcony of the same home.

Sampling and Analysis

Samples of interior and exterior surface dust were collected using glass plates having a measuring area of $1\,m^2$ according to the method described by Caravanos et al. [31]. Dust deposited on each glass plate was collected once per week by careful wiping. The samples were packaged in plastic 50 mL centrifuge tubes and then transferred to the laboratory. After weighting, dust samples were digested in a mixture of HCl and HNO_3, according to Harrison and Perry [32]. Atomic absorption

Table 1. A statistical summary of interior and exterior surface loading rates of settled surface dust in domestic houses (g m^{-2} per week) in Giza

Ser. no.	Type	Location	Size (m^2)	Age (year)	Interior					Exterior				
					Min.	Max.	Median	Mean	SD	Min.	Max.	Median	Mean	SD
1	Non-smoking homes	Main St.	105	2\3	0.49	0.99	0.75	0.74	0.14	4.18	8.79	6.61	6.53	1.13
2			115	16	0.55	1.52	1.05	1.08	0.32	4.88	9.49	7.31	7.23	1.14
3		Side St.	85	1	0.75	1.70	1.10	1.20	0.30	5.68	10.29	8.11	8.03	1.12
4			75	18	1.18	2.35	1.63	1.72	0.41	6.10	11.71	8.53	8.45	1.32
5	Smoking homes	Main St.	120	1\2	0.70	1.86	1.14	1.23	0.41	5.48	10.09	7.91	7.83	1.12
6			80	20	1.06	2.26	1.70	1.67	0.42	5.50	11.91	8.31	8.25	1.48
7		Side St.	100	2	1.35	3.05	2.16	2.18	0.57	6.30	12.91	9.23	9.15	1.53
8			65	22	2.05	3.77	2.88	2.90	0.57	6.90	13.51	9.83	9.65	1.55
All homes					0.49	3.77	1.45	1.58	0.77	4.18	13.51	8.22	8.18	1.60

spectrophotometry was used to quantify Pb, Cd and Ni in the samples.

Results

Surface Loading Rate of Dust

Table 1 gives a statistical summary of the interior and exterior surface loading rates of dust in these domestic houses (in g m^{-2} per week) in Giza through the study period. From this it can be seen that levels of the exterior surface loading rates of dust were much higher (5.2 times) than those indoors. The highest values of interior and exterior surface loading rates of dust (2.90 and 9.65 g m^{-2} per week, respectively) were found in the oldest home (22 years) located in a side street, categorised as a smoking home and the smallest of those studied (65 m^2). Meanwhile, the lowest values (0.74 and 6.53 g m^{-2} per week, respectively) were found in the newest home (8 months), which was located on a main street, categorised as a non-smoking home and was of a larger size (105 m^2). Overall the results showed that the average values of the surface loading rates of dust ranged from 0.49 to 3.77 g m^{-2} per week indoors and from 4.18 to 13.51 g m^{-2} per week outdoors. Differences in interior and exterior measurements were statistically significant ($p < 0.001$) and a significant positive correlation coefficient ($r = 0.85$, $p < 0.001$) was found between them.

Mass Concentration and Loading Rate of Metals in the Settled Surface Dust

Table 2 shows a statistical summary of the interior and exterior surface mass concentrations (in μg g^{-1}) and surface loading rates (in μg m^{-2} per week) of Pb, Cd and Ni detected in the settled surface dust in the examined homes. The levels of the interior surface mass concentrations of Pb, Cd and Ni averaged respectively, 311.18, 33.09 and 53.51 μg g^{-1} and were relatively lower than the exterior levels (averaged 323.38, 35.19 and 56.30 μg g^{-1}, respectively). Differences in interior and exterior measurements were not statistically significant for the three metals. A significant positive correlation coefficients were found between interior and exterior surface mass concentrations of Pb ($r = 0.72$, $p < 0.001$), of Cd ($r = 0.84$, $p < 0.001$) and Ni ($r = 0.85$, $p < 0.001$). Showing the same trend, levels of the interior surface loading rates of Pb, Cd and Ni (averaged respectively 533.17, 54.78 and 87.84 μg m^{-2} per week) were much lower than the exterior levels (averaged 2657.75, 290.75 and 465.17 μg m^{-2} per week, respectively). Differences in the interior and exterior values were statistically significant only for Pb ($p < 0.001$) and not statistically significant for Cd and Ni. Significant positive correlation coefficients were found between interior and exterior surface loading rates for Pb ($r = 0.69$, $p < 0.001$), Cd ($r = 0.82$, $p < 0.001$) and Ni ($r = 0.86$, $p < 0.001$). The average of interior/exterior (I/E) ratios of surface loading rates of metals was of order of 0.20 for Pb and 0.19 for both Cd and Ni.

In addition, the correlations among surface loading rates of dust; surface loading rates of the three metals; and metals' surface mass concentration in the interior settled surface dust in domestic houses were studied and a general picture of their correlation coefficients are reported in Table 3. The data indicate that, the interior surface loading rates of the metals were significantly correlated with the interior surface loading rate of the collected dust (Pb: $r = 0.92$; Cd: $r = 0.81$; and Ni: $r = 0.73$). Significant positive correlation coefficients were found between surface mass concentrations of Pb and Cd ($r = 0.89$), Pb and Ni ($r = 0.84$) and Cd and Ni ($r = 0.98$). Significant positive correlation coefficients were also found between surface loading rate of Pb and Cd ($r = 0.95$), Pb and Ni ($r = 0.90$) and Cd and Ni ($r = 0.98$).

Table 2. A statistical summary of the interior and exterior surface mass concentrations (μg g^{-1}) and surface loading rates (μg m^{-2} per week) of Pb, Cd and Ni found in the settled surface dust in domestic houses in an urban area of Giza

Pollutant	The measured parameter	Interior					Exterior				
		Min.	Max.	Median	Mean	SD	Min.	Max.	Median	Mean	SD
Lead	Surface mass concentration	110.00	525.00	315.00	311.18	97.59	160.00	508.00	310.00	323.38	88.06
	Surface loading rate	68.50	1753.05	407.59	533.17	378.45	1068.80	5542.30	2599.80	2657.75	884.44
Cadmium	Surface mass concentration	12.00	67.00	30.50	33.09	13.35	16.00	65.00	34.00	35.19	10.73
	Surface loading rate	7.00	158.34	43.93	54.78	37.81	106.90	709.15	283.31	290.75	109.52
Nickel	Surface mass concentration	18.43	127.92	45.91	53.51	24.97	25.60	104.00	54.40	56.30	17.17
	Surface loading rate	10.82	289.10	71.73	87.84	62.41	171.00	1134.64	453.29	465.17	175.21

Min.: minimum; Max.: maximum; SD: standard deviation.

Table 3. Correlation coefficients between loading rates of dust, mass concentrations and loading rates of Pb, Cd and Ni in the interior settled surface dust in domestic houses

		Surface mass concentration Pb	Surface mass concentration Cd	Surface mass concentration Ni	Surface loading rate Pb	Surface loading rate Cd	Surface loading rate Ni
Surface mass concentration	Pb	1					
	Cd	0.89*	1				
	Ni	0.84*	0.98*	1			
Surface loading rate	Pb	0.78*	0.89*	0.84*	1		
	Cd	0.87*	0.73*	0.69*	0.95*	1	
	Ni	0.88*	0.80*	0.77*	0.90*	0.98*	1
	Surface dust loading rate	0.53*	0.24**	0.18	0.92*	0.81*	0.73*

*Significant ($p<0.001$); **Significant ($p<0.05$).

Possible Influencing Factors

The interior surface loading rate of dust in domestic houses and its metal content varied largely depending on many considerations such as exterior pollution levels, interior–exterior air exchange rate, interior air recirculation rate, ventilation rate, interior activities, deterioration and erosion procedures, cleaning regimes and environmental and seasonal parameters. Therefore, the current study was concerned with three important factors: home location, home age and environmental tobacco smoke (ETS), which includes some of the factors previously considered that were thought to have a potential influence on the surface loading rate of dust in domestic houses and its metal content.

Home Location: Data analysis revealed that levels of the exterior surface loading rates of dust at main and side streets were much higher (6.3 and 4.4 times, respectively) than the interior levels. Interior and exterior surface loading rates of dust in the side streets were higher (1.7 and 1.2 times, respectively) than their main street values. In contrast, levels of the interior surface mass concentrations and surface loading rates of metals from the main streets were higher (~1.61 and 1.2 times, respectively) than their corresponding levels in the side streets. The differences were statistically significant ($p<0.001$) for the mass concentration measurements and not statistically significant for loading rate measurements for all metals. The highest I/E ratio of surface mass concentrations of the metals were found in homes located on the main streets. Additionally, the average results summarised in Figure 1 exhibit the influence of home location on surface mass concentrations and loading rates of the metals in the interior settled surface dust in the study homes. The interior surface mass concentrations of Pb, Cd and Ni averaged, respectively, 304.04, 31.53 and 49.43 μg g^{-1} at the main streets and 189.26, 19.00 and 30.18 μg g^{-1}, respectively, at the side streets, while levels of the interior surface loading rates of Pb, Cd and Ni averaged, respectively, 314.35, 32.19 and 50.5 μg m^{-2} per week at the main streets and 270.54, 26.88 and 43.35 μg m^{-2} per week, respectively, at the side streets.

Home Age: Data summarised showed that levels of the exterior surface loading rates of dust at new and old homes were much higher (9.1 and 4.8 times, respectively) than the interior levels. The interior surface loading rates of dust were higher in older homes than in new homes and differences in their measurements were statistically significant ($p<0.001$). For non-smoking and smoking

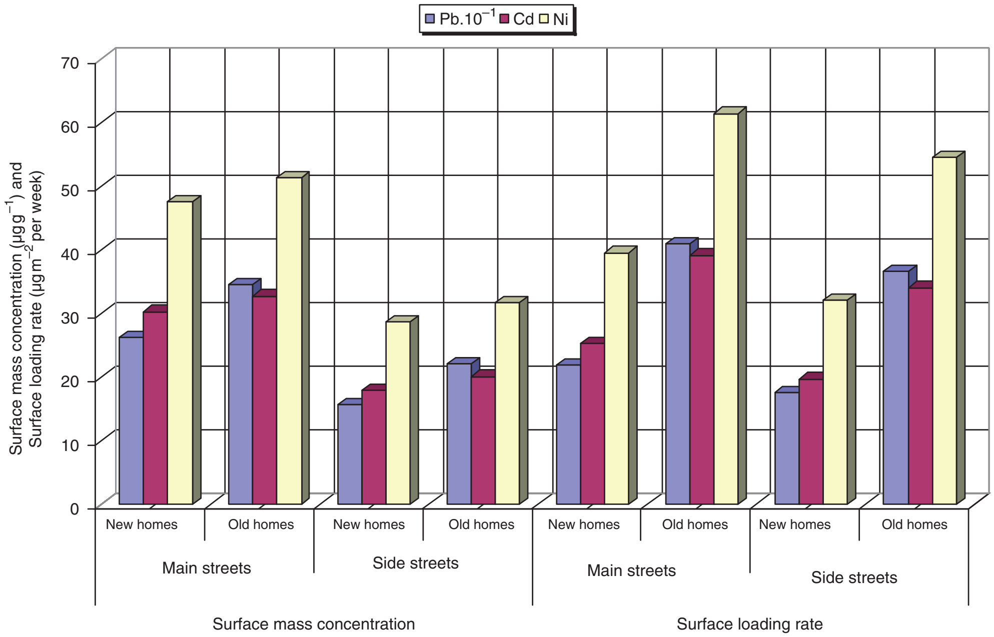

Fig. 1. A comparison of averages of interior surface mass concentrations ($\mu g\,g^{-1}$) and interior surface loading rates ($\mu g\,m^{-2}$ per week) of Pb, Cd and Ni in new and old non-smoking homes located on the main and in side streets. Pb levels are scaled differently: Pb values to be multiplied by 10^{-1}.

homes, the highest values of interior surface loading rate of dust and lead besides Pb mass concentrations were found in the oldest home while the lowest values were observed in the most recent home. The average results summarised in Figure 1 also illustrate that levels of the interior surface mass concentrations and loading rates of the three metals were higher in older homes than in new homes at both main and side streets. Differences in the corresponding values at new and older homes were statistically significant for Pb only ($p < 0.001$ for mass concentrations measurements and $p < 0.01$ for loading rates measurements), and not statistically significant for Cd and Ni. To be more precise, the average interior surface mass concentration and loading rate of lead at the main streets were respectively, $346.17\,\mu g\,g^{-1}$ and $409.31\,\mu g\,m^{-2}$ per week in older homes and $261.92\,\mu g\,g^{-1}$ and $219.38\,\mu g\,m^{-2}$ per week in new homes. Meanwhile, at the side streets, their values averaged, respectively, $221.10\,\mu g\,g^{-1}$ and $366.32\,\mu g\,m^{-2}$ per week in older homes, and $157.42\,\mu g\,g^{-1}$ and $174.76\,\mu g\,m^{-2}$ per week in new homes.

Environmental Tobacco Smoke: Output results displayed that the average values of exterior surface loading rates of dust at non-smoking and smoking homes were much higher (6.7 and 4.4 times, respectively) than their interior average. The interior surface loading rates of dust were higher in smoking homes (1.7 times) than in non-smoking homes. Similarly, levels of the surface mass concentrations and loading rates of the metals were higher (~1.6 and 2.7 times, respectively) in smoking homes than in non-smoking homes. Differences in the corresponding measurements of dust and metals in non-smoking and smoking homes were statistically significant ($p < 0.001$). I/E ratios of surface mass concentrations of metals averaged 0.76 for non-smoking homes and 1.13 for smoking homes. The highest I/E ratios of surface loading rates of metals were recorded in smoking homes. The average results recapitulated in Figure 2 reveal the influence of tobacco smoke on the interior surface mass concentrations and loading rate of the three metals. The average interior surface mass concentrations of Pb, Cd and Ni were, respectively, 246.65, 25.27 and $39.80\,\mu g\,g^{-1}$ in non-smoking homes and 375.71, 40.92 and $67.23\,\mu g\,g^{-1}$ in smoking homes. While the average interior surface loading rates of Pb, Cd and Ni were, respectively, 292.24, 29.53 and $46.92\,\mu g\,m^{-2}$ per week in non-smoking homes, they were 773.14, 80.04 and $128.76\,\mu g\,m^{-2}$ per week in smoking homes.

Discussion

The results presented in this study show that the interior settled surface dust in domestic houses may be derived from exterior sources, although interior sources might contribute as well. The penetration of outdoor

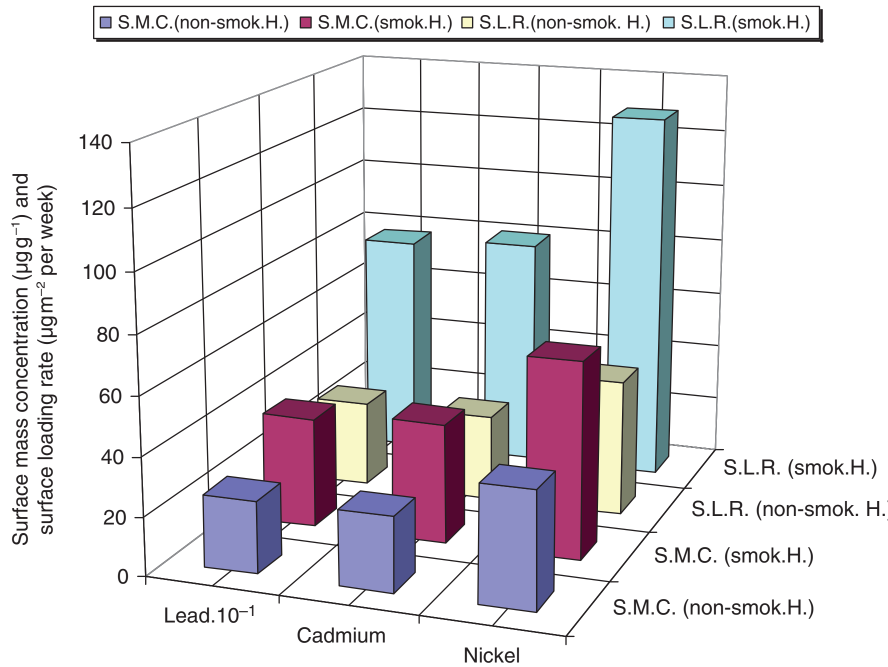

Fig. 2. A comparison of averages of interior surface mass concentrations ($\mu g\, g^{-1}$) and interior surface loading rates ($\mu g\, m^{-2}$ per week) of Pb, Cd and Ni in non-smoking and smoking homes. S.M.C.: surface mass concentration; S.L.R.: surface loading rate; smok. H.: smoking homes. Pb levels are scaled differently: Pb values to be multiplied by 10^{-1}.

particles into the indoor environment has been shown to be a significant source of indoor dust loads [33,34]. It has been estimated that as much as 85% of indoor dust is from outside the home [35]. Existence of high levels of interior surface loading rates of dust in homes located at the side streets, in older homes and in smoking homes could be attributed to the nature and characterisation of the study area and also the homes investigated, for example, where most of surroundings side streets of the study area are unpaved. Consequently, the re-suspension of street dust from these streets leads to an increase in loading rates of dust in the side streets. Whereas, in older homes it could be a consequence of the deterioration and erosion that usually occur in the old homes causing an increase in the interior surface loading rate of dust. While in smoking homes, cigarette smoke increases the levels of interior suspended particulate matter that later settled or adsorbed on or attached to interior surfaces, posing an enhancement in the interior levels of surface loading rate of dust. Smoking was the predominant activity associated with elevated concentration of particles [3]. Smoking can add $\sim 20\, \mu g\, m^{-3}$ (24 h mean) of particles per smoker to a household [36], with short-term peaks of $300\, \mu g\, m^{-3}$, which can persist for up to 30 min after a cigarette is finished [37].

The average values of the exterior surface loading rates of Pb detected in the settled surface dust in domestic houses at Giza was much higher ($\sim$5 times) than its interior average. However, 18.75%, 77.09% and 47.91% of the surface Pb per area in non-smoking homes, smoking homes and all homes, respectively, exceed the interior floor Pb dust-wipe guideline ($40\, \mu g\, ft^{-2}$) set by US HUD [38] and US EPA [39]. Moreover, the average interior surface loading rates of Pb at Giza was much higher (6.7 times) than the corresponding average found in New York homes as reported by Caravanos et al. [31]. Exposure to high levels of Pb in surface home dust at Giza may pose a great health risk by increasing the blood Pb levels and children's body burden of Pb. The potential hazard effect of Pb on health is confirmed by Gulson et al. [40], Kimbrough et al. [41] and Roy et al. [42] who all concluded that blood Pb concentrations and children's body burden of Pb are associated with house dust Pb.

In general, the high levels of Pb monitored in the Giza atmosphere corroborate the proposal that accumulated Pb particles in both vehicle exhaust system and street dust (Pb-bearing dust), from the extensive past use of leaded gasoline, could be considered as an indirect Pb source particularly at El Haram, considered as the area with the highest congestion of traffic at least in Giza, if not in Egypt. Furthermore, the El Haram area is characterised by numerous and different anthropogenic activities and some of these activities extend late into the night. Meanwhile in domestic interior environments, Pb is derived from interior Pb-based paint, tobacco smoke and cooking emissions in addition to that which comes from exterior sources. Exterior sources are widely known to contribute to Pb in residential dust via transfer from the exterior into the house [1,2,14,31,43–45].

Levels of the interior surface mass concentrations and loading rates of the three metals were higher in main streets than in side streets. Living close to a main road leads to increases in Pb and Cd levels in house dust [46]. Associations between Pb and Cd levels in interior dust and traffic density and/or distance from roads have been found in several studies [7,47]. The amount of Pb in interior dust was shown to be affected by the age of the house [46]. Consistent with the observations of previous investigators, a relationship between Pb concentrations in house dust and the age of housing has been found in many other studies [5,47,48] and it is considered to be due to the prevalence of Pb-containing paints in older houses. Significant higher dust Pb levels were found in older homes [22,49]. Use of Pb pigments, especially in interior paints, may significantly influence Pb levels in house dust [50].

The significantly higher levels of Cd, Pb and Ni in smoking homes show that tobacco smoking increases the levels of the three metals [29,51,52]. Smoking is a known indoor source of Pb [53] and Cd [54]. Also, a significant association between number of smokers in the household and an elevated dust Cd loading rate has been found [55].

In the light of the correlation study results, it could be assumed that Cd and Ni were derived mainly from exterior sources, although interior sources of these metals might be important as well. The highly significant correlations found among the three metals in the interior settled surface dust may denote that all of them share the same sources. The interior mass concentrations and loading rates of both Cd and Ni in the settled surface dust were not significantly associated with home age.

Finally, the data presented in this paper show certain factors, such as home location, home age and condition, which affect the amount of dust in domestic houses and its metal content. Also, differences in activities, habits, behaviour and cleaning regimes, can affect the amount of dust and metals accumulating over time in individual homes and have a significant impact on loading rate of dust and metals. A home in which Pb dust is removed daily from surfaces will have a lower Pb loading than a home in which Pb dust is removed weekly from surfaces, even if both homes had the same Pb loading rate [56]. The impact of cleaning regime on Pb loading can be quite significant, with some new regimes reducing indoor Pb and dust levels from 50% to 98% [57–59].

Recommendations

In the light of these results, we make the following suggestions to mitigate lead exposure to young children: Remove settled surface home dust daily. Use paints that are not lead-based. Stop tobacco smoking, particularly indoors. Pave the side streets, particularly in residential and commercial areas. The scientific community, especially in developing countries, which suffers from serious pollution-related health problems, should pay more attention to the potential health effects of settled dust in domestic houses.

Conclusions

It is worth noting that the atmosphere in Giza is still contaminated by lead despite a decade of using unleaded gasoline. The lead is found in surface dust in houses and it was noted that although loading rates of the settled dust in homes were higher in side streets than main streets, levels of metals were higher in dust from main streets and consequently, this poses the greater hazard. Measurements of interior surface loading rates of dust and metals and also metals' surface mass concentrations were significantly associated with home location and tobacco smoke. Except for Cd and Ni measurements, the same finding was observed related to the age of the home.

Overall, this study may shed some light on the risks from settled surface dust and those arising in part from unpaved streets which may be a particularly Egyptian problem.

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