Prevalence of Lead Toxicity in Adolescents in Kuwait

Reem Jallad
Kuwait University College of Life Sciences
Muddanna Rao
Kuwait University Faculty of Medicine
Abdur Rahman (abdurrahman.ahmad@ku.edu.kw)
College of Life Sciences, Kuwait University https://orcid.org/0000-0002-5115-3053

Research

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Abstract

Background: Environmental lead (Pb) exposure is a public health problem in many developing and industrialized countries. Being a petrochemical industry-based economy, Pb levels are expected to be high in Kuwait but systematic data on population exposure are lacking. This study aimed at determining the prevalence of Pb toxicity in adolescents in Kuwait.

Methods: Adolescents (N=1385; age range 11-16 years) were cross-sectionally selected from public middle schools from all Governorates of Kuwait, utilizing multi-stage cluster random sampling. Pb in whole blood was analyzed by inductively coupled plasma mass spectrometry. Pb levels among Governorates and genders were compared by median test and the prevalence of Pb levels above the CDC cutoff (≥5 μg/dL) was estimated by x^2 test. Multiple logistic regression was used for association between prevalence of high Pb levels and Governorate.

Results: Median (IQR) Pb was 5.1(3.6 – 7.1) μg/dL [4.9 (3.8 6.5) μg/dL in males and 5.4 (3.3-7.6) μg/dL in females; p=0.001]. In the overall sample, 51% had Pb levels ≥5 μg/dL; 13% were ≥10 μg/dL and 3% >20 μg/dL. Prevalence of Pb ≥5 μg/dL was 47% in males and 56% in females (p<0.001). High Pb levels were clustered in Al-Asima and Al-Ahmadi (in both genders); Al-Jahra (in males) and Mubarak Al-Kabeer (in females) Governorates.

Conclusion: Pb exposure is a significant public health problem in adolescents in Kuwait. Urgent public health intervention is required in high Pb exposure areas and further research is needed to identify the sources of exposure in these areas for prevention.

Background:

Lead (Pb) is a toxic metal with quite serious and long-lasting health consequences, particularly in children. Due to its unique physical and chemical characteristic, Pb has been used in plumbing, mining and metals recycling; and until recently, it has been used in paint, pipes, batteries, cans, cables cover and gasoline (1). Due to its widespread use in many industries, Pb is present in our environment and humans are still exposed to it through food, water and inhalation (2). Once Pb enters the body, it is distributed in blood, soft tissues (liver, kidney, brain etc.), and bones. With time, and continuous exposure, Pb accumulates in bones, and thus becomes a source of internal exposure when it is mobilized from bones along with calcium due to abnormal calcium homeostasis or due to a physiological condition like pregnancy (3, 4).

The absorption of Pb in the human body depends on several factors such as Pb particle size, route of exposure (the gastrointestinal tract or respiratory tract), nutritional status, health and age of the human. The most common route of Pb exposure in non-occupationally exposed population is oral ingestion. In general, adults absorb approximately 20% of ingested Pb after a meal; however, on an empty stomach absorption can jump to 60–80%. In children absorption after a meal is approximately 50% and on an empty stomach it can reach to 100% (1). Other routes of exposure are inhalation and, to a lesser extent, skin contact. Inhalation and dermal exposure can be considered an important route mostly for occupationally exposed populations.

Pb is considered as a multisystem toxicant associated with neurological, nephrological, cardiac, gastrointestinal and hematological manifestations (2). Due to increased awareness of the toxic effects of Pb in children, particularly the neurological toxicities, the acceptable blood Pb level (safety limit) has been progressively decreased from 60 μg/dL in 960 s to 10 μg/dL in 1991 (5). Based on the reports of adverse health outcomes at levels below this safety limit, particularly in children, in 2012 the CDC established a new cutoff of 5 μg/dL at which intervention needs to be initiated and stated that no level of Pb exposure in children is safe (6). The debate continues, and recently some researchers in the field of Pb toxicity are arguing for reconsidering this level and are suggesting lowering this level to < 3.5 μg/dL (7).

Kuwait's economy is heavily based on petrochemical industry. Large oil installations are located in the country, where wastes from petrochemical industry are burnt and the smoke is released into the atmosphere. In addition, it is a country with one of heaviest traffic burden. As such, Pb pollution in the atmosphere is expected to be high. The atmospheric Pb can get into the food chain which is considered a major source of Pb exposure (8). The desert climate of Kuwait facilitates the spread of suspended Pb particles in the air and soil into residential areas (9, 10). Air samples collected from several urban areas of Kuwait showed high Pb content in the particulate matter (PM). The 10-micron size particle PM (PM10) Pb content on average was 12.67 mg/Kg, which was 2.4 times higher than corresponding background Pb levels in soil (11). Food could also be a source of Pb exposure. High levels of Pb have been reported in date fruits and tree leaves and bark, collected from different locations of Kuwait. Levels were particularly high in industrial areas and near highways (12). In addition, imported fruits, vegetables and rice were also found to have higher than reported levels of Pb (13). A recent study also reported higher than permissible levels of heavy metals (Pb, cadmium and mercury) in meat samples from Kuwait (14). Furthermore, drinking water was also reported to be a source of Pb in older reports (15); however, recent reports do not support water to be a major source of Pb contamination (16). Smoking tobacco, which is a source of Pb exposure, is also common in Kuwait (17).

Despite these facts, systematic data on the population Pb exposure from Kuwait is scarce apart from a few old sporadic studies (18, 19). Recent data on population Pb exposure is of interest to re-evaluate global prevalence of Pb exposure after the revision of the safety limit by the CDC in 2012. Majority of the data post-2012 available from most countries are from occupationally exposed groups or from those living near a source of Pb. Data on general population exposure, particularly on adolescents are meager. The adolescent population in Kuwait comprise approximately 1/4th of the total population. Based on a nationally representative sample, this study reports the prevalence of Pb exposure from the State of Kuwait. Thus, data reported here are not only locally relevant, but is also of global interest, as it will augment the limited data available on adolescent population Pb exposure.

Material And Methods:

Study Design and Protocol:

This school-based cross-sectional study was conducted in public middle schools selected from all the six Governorates of Kuwait. Study subjects, in the age range of 11 to 16 years, were selected from 12 schools using stratified multistage cluster random sampling, with probability proportional to size of schools. Thus, schools with a larger student population has a higher probability of being selected compared to schools with a lower number of students. The sample allocation in each Governorate was based on the relative size of that Governorate as judged by the total number of students. Details of the sampling, acquisition of data and the study subject characteristics are reported in detail previously (20). The study was approved by The Ethics Committee at the Ministry of Health, Kuwait (No: 2015/248) as well as The Ethics Committee of the Health Sciences Centre, Kuwait University (No: DR/EC/2338). The study was conducted in accordance with declaration of Helsinki ethical principles for medical research involving human subjects. A written informed consent from the parents and verbal ascent of each participant was obtained.

Blood collection and Pb analyses:

Blood samples were collected over a three-month period from February- April 2016. After obtaining written informed consent of the parents and verbal ascent of the subjects, 5 mL of venous blood was collected from each subject by a highly trained pediatric nurse. For Pb analysis, whole blood samples (0.5 mL) were digested in 5 mL of perchloric acid/nitric acid (1:5) solution. After complete digestion of the samples, the perchloric acid/nitric acid solution was evaporated and the residue dissolved in 5 mL of 1% nitric acid. Double-deionized water was used in all sample preparation steps to avoid contamination. Pb was analyzed with Inductively Coupled Plasma Mass Spectrometry (ICP-MS). For quality control check, lyophilized whole blood samples of known mineral content (Clin-Check- Control, Cat. # 884042; Recipe, Munich, Germany) were included in the analyses.

Statistics:

Data were double entered into a specifically designed database using Epidata Entry. Body mass index (BMI) was calculated as weight (Kg) divided by height squared (m^2), and weight status was classified based on the BMI-for-age z-scores (zBMI) calculated using WHO growth charts. Participants were divided into two Pb categories based on the cut off points of ≥ 5 µg/dL. Univariable logistic regression analysis were used to identify factors associated with Pb level ≥ 5 µg/dL. Factors that showed association with Pb (≥ 5 µg/dL) at less than 20% level of significance were considered in multivariable logistic regression analysis. Factors with $p < 0.05$ were deemed to be statistically significant. As Pb levels are not normally distributed, data are presented as median and interquartile range (IQR). Median and Chi-square tests were used to estimate the significance of difference in the prevalence of Pb levels ≥ 5 µg/dL. Data was analyzed with SPSS version 25.

Results:

Data were available for 1385 adolescents, of which 673 (48.6%) were males. The mean (SD) age was 12.48 (0.93) years. As the distribution of Pb levels was not normal, Pb levels are reported as geometric mean (GM) and standard deviation (SD) or as median and interquartile range (IQR). In the overall sample, GM (SD) and median (IQR) blood Pb levels were 5.4 (1.8) and 5.1 (3.6–7.1) µg/dL, respectively. Median (IQR) BPbL was significantly higher in females [5.4 (3.3–7.6) µg/dL] than in males [4.9 (3.8 6.5) µg/dL; $p = 0.001$] (Table 1). In the overall sample, 16 subjects (5 male and 11 female subjects) had BPbLs > 30 ug/dL. Prevalence of high Pb levels with various cutoffs are shown in Table 2. About 3% of the sample studied had Pb levels > 20 µg/dL. The distribution of Pb levels in subjects from different Governorates are shown in Fig. 1A; and with stratification by sex in Fig. 1B. Pb levels were significantly higher in the Al-Asima, Mubarak Al-Kabeer and Al-Ahmadi Governorates, as compared to the other three Governorates ($p < 0.001$). Significant sex-Governorate interaction was observed ($p < 0.001$). As shown, the entire distribution of male subjects in Al-Asima; and of female subjects in Mubarak Al-Kabeer and Al-Ahmadi Governorates were above the cutoff value of ≥ 5 µg/dL. Median (IQR) Pb levels were 5.3 (3.7–7.3), 4.9 (3.6–6.7) and 5.0 (3.6–7.6) µg/dL for the age groups of 11 to < 12 years, 12 to < 13 years and ≥ 13 years, respectively ($p = 0.07$). However, age-Governorate interactions were significant ($p < 0.001$; Fig. 1C).

Table 1
Pb levels in adolescents:

	Geometric mean (SD)	Median (IQR)	Range Low - High	High extreme values (N = 5)
Overall Sample (N = 1388)	5.35 (1.78)	5.10 (3.60–7.13)	1.31–75.67	58.14–75.67
Male (N = 674)	5.30 (1.67)	4.87 (3.78 6.49)	1.31–52.87	30.81–52.86
Female (714)	5.35 (1.87)	5.42 (3.25–7.58)	1.71–75.67	58.14–75.67

Table 2
Prevalence of high Pb levels in adolescents:

Pb Levels	Prevalence of high blood Pb levels N (%)		
	Overall sample	Male	Female
< 5 µg/dL	671 (48.4)	357(53)	315 (44.1)
≥ 5 to < 10 µg/dL	536 (38.7)	231 (34.4)	305 (42.7)
≥ 10 to ≤ 20 µg/dL	142 (10.2)	71 (10.5)	70 (9.9)
> 20 µg/dL	36 (2.7)	14 (2.1)	22 (3.2)
Total	1385 (100)	673 (49)	712 (51)

The proportion of subjects with various levels of blood Pb levels are shown in Table 2. Of the total sample, 713 (51.5%) had blood Pb levels ≥ 5 µg/dL [316 (47.0%) males and 397 (55.8%) females; $\chi2 = 10.87$; $p < 0.001$]. The proportions of subject with Pb levels ≥ 5 µg/dL and ≥ 10 µg/dL in different Governorates are shown in Table 3. The highest percentage was recorded in Al-Asima (78.6%), and the lowest in Hawally (10.4%). When stratified by sex, the highest percentage in male subjects was recorded in Al-Asima (92.9%), followed by Al-Ahmadi (53.7%), Jahra (47.5%), Mubarak Al-Kabeer (40.0%), Farwaniya (34.1%) and Hawally (13.0%). In female subjects the highest percentage was recorded in Mubarak Al-Kabeer (97.2%) and Al-Ahmadi (94.2%), followed by Al-Asima (62.9%), Al-Jahra (62.3%), Farwaniya (16.2%) and Hawally (7.4%). Of the total population, 12.9% had Pb levels ≥ 10 µg/dL. The association of Pb with Governorates was further explored by adjusting it with all the known covariates that are associated with high Pb levels. The results are presented in Table 4. In the adjusted model 2, the Governorates of Hawally and Farwaniya had significantly lower OR for Pb ≥ 5 µg/dL, compared to other Governorates.

Table 3
Percentage of subjects with high blood Pb levels in each Governorate

Pb cutoff > 5 µg/dL			
	Total[1]	Male[2]	Female[3]
Al-Asima	78.6	92.9	62.9
Hawally	10.4	13.0	7.4
Farawanya	22.6	34.1	16.2
Al-Jahra	55.0	47.5	62.3
Mubarak Al-Kabeer	68.0	40.0	97.2
Al-Ahmadi	73.7	53.7	94.2
χ^2	374.6	149.9	354.1
p-value	< 0.001	< 0.001	< 0.001
Pb cutoff > 10 µg/dL			
	Total	Male	Female
Al-Asima	27.8	20.4	36.0
Hawally	4.3	6.5	1.9
Farawaniya	3.9	2.4	4.7
Al-Jahra	7.1	11.9	2.5
Mubarak Al-Kabeer	24.5	9.3	40.3
Al-Ahmadi	15.7	19.2	12.1
χ^2	95.7	25.0	120.1
p-value	< 0.001	< 0.001	< 0.001

[1]Denominator is the total number of subjects from each governorate

[2]Denominator is the total number of male subjects from each governorate

[3]Denominator is the total number of female subjects from each governorate

Table 4
Association of high Pb levels with location (Governorates):

	N	OR	95% Confidence Interval	
			Lower Bound	Upper Bound
Model 1				
Capital	187	1.31	0.86	2.00
Hawally	231	0.04	0.03	0.07
Farawanya	230	0.10	0.07	0.15
Al-Jahra	240	0.44	0.31	0.62
Mubarak Al-Kabeer	147	0.76	0.50	1.16
Al-Ahmadi	350	1.00	Ref	
	$\chi^2 = 406.9$; $p < 0.001$; $R^2 = 0.340$			
Model 2				
Capital	185	1.20	0.75	1.92
Hawally	226	0.04	0.02	0.06
Farawanya	221	0.08	0.05	0.13
Al-Jahra	232	0.40	0.28	0.58
Mubarak Al-Kabeer	146	0.66	0.41	1.05
Al-Ahmadi	340	1.00	Ref	
	$\chi^2 = 425.8$; $p < 0.001$; $R^2 = 0.339$			
Model 1: unadjusted; **Model 2**: adjusted for sex, age, BMI categories, anemia status, and passive smoking in the household.				

Discussion:

Pb poising is a public health concern in many developing countries, as well as in some industrialized and developed countries (2). There is no known safe level of exposure, particularly in children. Most studies that have been published on population Pb exposure used the old cutoff of Pb safety level of ≥ 10 µg/dL. Therefore, there is a great need to reassess the population Pb exposure, particularly in areas where the average exposure level was ≥ 5 µg/dL. Several studies have been published from many countries since the revision of the safety limit of Pb exposure in children, but these studies are mostly based on populations living in high exposure environments and in those who are occupationally exposed to Pb. Kuwait, being a petrochemical industry-based economy with heavy traffic burden along with its associated industry (automobile repair workshops, etc.), is expected to have high level of Pb exposure (9). In addition, the excessive use of ammunition and the burning of oil wells during the 1991 Gulf war might also have its impact on the environmental Pb levels. However, studies on the population Pb exposure, using representative samples are non-existing. Studying Pb exposure in children and adolescents is particularly important due to the well-known and long-lasting adverse effects of low-level Pb exposure on brain development and function. Approximately, 25% of the population in Kuwait is under the age of 19 years. This study is based on a nationally representative sample of adolescent school children.

The median blood Pb was 5.1 µg/dL. However, a significant proportion of subjects (51%) had Pb levels above the CDC/WHO cutoff of ≥ 5 µg/dL, and this proportion was even higher (56%) in female subjects. About 13% of the subjects had Pb levels ≥ 10 µg/dL. Similar results have been reported in children and adolescents (age range 4–19 years) from Saudi Arabia, with mean Pb of 4.94 µg/dL and 50% with blood Pb level ≥ 5 µg/dL (21), and Indonesia, with 47% having Pb level ≥ 5 µg/dL (22). A study from Egypt reported mean Pb levels similar to ours (5.6 µg/dL) but in this study 57% of study sample had Pb levels ≥ 10 µg/dL (23). The prevalence of Pb exposure in our study was lower than many developing countries such as Senegal [61.7% >10 µg/dL] (24), Bangladesh [87.4% >10 µg/dL] (25), Nepal [84% >10 µg/dL] (26), India [47% >10 µg/dL] (27), Mexico [64% >5 µg/dL] (28) and South African countries [80–98% >10 µg/dL] (29). On the other hand, the average Pb levels from many developed countries were lower than the median Pb levels in this study. Examples are average blood Pb levels from the Unite States [1.9 µg/dL; 3.8% >5 µg/dL] (30), Sweden [1.4 µg/dL], Poland [1.63 µg/dL], Czech [1.55 µg/dL], Slovakia [1.9 µg/dL] (31), France [1.49 µg/dL] (32) and Canada [0.48 µg/dL] (33). Variations in sampling (whether from general population or high exposure environment), age and the degree of implementing legal restriction to minimize or restrict the use of Pb are possible reasons for these variations in the prevalence of Pb exposure (34, 35).

Striking differences were observed in the Pb exposure among the six Governorates, both in the median blood Pb levels and in proportions of subjects with Pb levels above the cutoff value. The differences among the Governorates remained significant after adjusting for several confounding variables that are known to be associated with Pb levels in the literature such as sex, age, smoking and anemia status. In terms of the median blood Pb levels, the entire distribution of males in Al-Asima and females in Mubarak Al-Kabeer and Al-Ahmadi were above the cutoff value (Fig. 1B). The Governorates of Al-Asima, Al-Ahmadi (both male and female schools), Al-Jahra (male school) and Mubarak Al-Kabeer (female school) stood out as the areas with the high proportions of subjects with high Pb levels, particularly above the cutoff of ≥ 10 µg/dL (Table 3). Two previous studies (36, 37) from Kuwait also have reported significant differences between the residents from residential and industrial areas.

Several factors could be responsible for the high exposure of Pb in these areas. For example, the schools that were selected from the Al-Asima Governorate, both male and female, are close to each other and are in close proximity to three major highways and one coastal road with a very heavy traffic burden. This is the oldest location in Kuwait, where most Kuwaiti people lived before the discovery of oil. It has old buildings, hundreds of automobile repair workshops, the main commercial port in the country and an industrial area. Another Governorate with high Pb exposure in both male and female subjects is Al-Ahmadi. Most oil fields, oil refinery and petrochemical industries are located in this Governorate. Soil and air sample from this Governorate have been reported to contain higher levels of Pb compared to other Governorates (10, 12). In addition, this Governorate has an agricultural site (Al-Wafra), where vegetables, fruits and dates are cultivated. The use of pesticides and fertilizers in these forms might also have contributed to the soil and air Pb content. Soil Pb content in samples from Al-Wafra was reported to be higher than the normal acceptable limits (38).

The high blood Pb levels in the governorates of Al-Asima and Al-Ahmadi is supported by a study on the indoor air quality in different schools; three from urban residential area and four from industrial area (39). Pb content in the dust particles (PM10) collected from air conditioner's (AC) filters in the classrooms was the highest (74.30 µg/g) in one school from the industrial zone (Bnediar boy's school). This school is located in Al-Ahmadi governorate near Mina Abdullah refinery. Pb content in PM10 dust particles form the three schools from residential area were also high (ranging from 40.3 to 50.0 µg/g), compared to the remaining three schools from industrial zone which were away from the oil refinery (ranging from 19.1 to 23.3 µg/g). The three schools from residential areas were from the Al-Asima governorate, and one of these schools is included in this present study. These data match with the BPbLs in schools from these Governorates and suggest that environmental air pollution from oil installations and industrial activity is the main source of Pb exposure in school children.

The Governorate of Mubarak Al-Kabeer is located next to the Al-Ahmadi Governorate and the spill-over of the environmental Pb contamination is suspected to be the reason for high blood Pb levels. In addition, this is a newly developed area with a lot of construction activity. The exhaust from the construction machinery, together with the rising dust from the soil might also contribute to the Pb exposure. The particularly high Pb exposure in the female school from this Governorate is of significant public health concern, as there might be a local source of contamination. It has been reported that in 2018, the Public Authority for the Environment, Kuwait asked the Ministry of Education to close drinking water supply in 13 different schools, as the water was not suitable for drinking (Al-Anba News Paper dated March 2, 2018). The reason mentioned for the closure of drinking water supply in these schools was the lack of maintenance of filters, internal water supply networks, reservoirs and chillers for drinking water. It is of interest to note that six out these thirteen schools were from Mubarak Al-Kabeer Governorate, although the school which was selected in this study was not specifically mentioned.

Flaring of the unwanted gases from the extracted crude oil is a common practice in oil extraction and refining and is considered a major source of emission and air pollution in oil producing countries like Kuwait (40). Heavy metals including Cd, Hg and Pb are found in crude oil and gas and are emitted to the environment from flaring (41). Middle East have the highest flaring rate with 80.99 metric ton (MT) in the year 2018 (42). The estimated emission of Pb from flaring is estimated to be 4.3 mg Pb/ton throughput from the associated gases and 5.4 mg/ton throughput from the non-associated gases (43). Thus, in Kuwait, emission of Pb into the environment from gas flaring is a potential source of environmental Pb exposure. This may be particularly relevant in the Ahmadi and Mubarak Al-Kabeer governorates, which are close to oil installations. The Kuwait National Petroleum Company (KNPC) has adopted several measures to curb emissions and to protect the nearby communities (44). It has recently (in 2018) installed a fully functional flare gas recovery unit to curb emissions. However, the Pb emitted from gas flaring in the past may still exist in the environment (air and soil), which may still be a source of environmental exposure.

In the Al-Jahra Governorate, the proportion of subjects with Pb $\geq$ 10 µg/dL was 12% in male subjects, compared with 2.5% in female subjects. The male school selected form this Governorate has several features that might have contributed to the high exposure of Pb. For example, this school is close to the major highway and is located in the middle of two major industrial zones (Jahra and Sulaibiya). It is in close proximity to a waste-water treatment plant, a cable and electrical appliances factory and an oil and pipe manufacturing unit. The female school is 16 Km away from this site. Lead-acid batteries are one of the major industrial sources of Pb accumulation and exposure. In Kuwait, there is one lead-acid battery recycling unit, which is located in Al-Jahra governorate, closer to the boy's school. Although, the Kuwait EPA has several regulations (Law Number 42; Decision No. 8, for example) to monitor and restrict the emission of toxic wastes, it is not clear to what degree these restrictions are implemented. Moreover, dust and Pb particles can be transferred to a wider community by workers, if they are not taking correct precautions and safety steps (45). In developing countries, unregulated lead-acid batteries recycling practices are a major source of Pb toxicity and environmental accumulation (22, 34). In the USA lead-acid batteries' manufacturing and recycling factories are still considered a source of contamination of the soil, air and water despite all the regulations and monitoring by the EPA (45). The Governorates of Hawally and Farwaniya are mostly residential and, although very congested with heavy traffic burden, have lower level of Pb exposure. This suggest that the source of Pb exposure in Kuwait is mostly from oil installations and industrial activity.

The median blood Pb was significantly higher in female subjects compared to male subjects, however, this relationship was not the same across all the Governorates. Significant sex-Governorate interaction was noted; in some Governorates, males had significantly higher Pb level than females and the opposite was true in others, and no difference in still others. Similar pattern was also observed in the proportion of subjects above the cutoff points, either at $\geq$ 5 µg/dL or at $\geq$ 10 µg/dL. In, Female sex was significantly associated with Pb $\geq$ 5 µg/dL in the univariate logistic regression, but this association did not remain significant in the multivariable analyses. This suggest that other factors might have confounded this relationship. Similar to ours, some studies also reported the lack of association with sex (23, 30); while others have reported significant differences between males and females in the same age group (21, 31, 46). Higher levels of Pb in female subjects in some Governorates could be due to certain differences in daily practices between boys and girls in Kuwait. Girls use Kohl and other cosmetics that may be contaminated with Pb (47). Anemia, which is associated with high Pb levels in some studies, is usually higher in females (48, 49). However, anemia in this population in female is considered moderate (11%), which can explain the lack of association between female sex and high Pb level in Kuwait.

To our knowledge, this is the first properly designed study utilizing a nationally representative sample of adolescents from Kuwait. We employed a very sensitive method of Pb estimation (ICP-MS) with strict quality control measures. Our method recovered 96.8% (S1) and 96% (S2) of Pb in the samples with known of Pb content (Seronorm). There are, however, a few limitations in this study. First, dietary history and food intake was not evaluated as a possible factor of Pb exposure. Second, father or mother occupational details were also not taken into account which could provide a clue to the exposure source. Third, subjects were selected from schools and Pb data from other members of the household was not available. As such it is difficult to discern whether the source of Pb is from household or from the school.

Conclusions:

In conclusion, we found that more than half of the adolescent population has blood Pb levels above the CDC safety limits (5 µg/dL), and almost 13% have levels above 10 µg/dL, suggesting that Pb exposure is of public health concern. Furthermore, exposure level was particularly high in some Governorates like the Al-Asima, Mubarak Al-Kabeer and Al-Ahmadi. More in-depth studies are needed to identify the exact source of exposure in these areas. Public health interventions are urgently required to reduce the exposure in these areas to protect children from the harmful effects of Pb toxicity. In addition, public awareness campaign should be launched in schools as a preventive measure to educate children, teachers and parents about Pb poising and its exposure risk factors.

Abbreviations:

BPbL: blood lead level; **EPA**: Environment Public Authority; **ICP-MS**: Inductively coupled Plasma Mass Spectrometry; **IRQ**: inter-quartile range; **MT**: metric ton; **zBMI**: BMI-for-age z-score.

Declarations:

Ethics approval and consent to participate:

The study was approved by The Ethics Committee at the Ministry of Health, Kuwait (No: 2015/248) as well as The Ethics Committee of the Health Sciences Centre, Kuwait University (No: DR/EC/2338). The study was conducted in accordance with declaration of Helsinki ethical principles for medical research involving human subjects. A written informed consent from the parents and verbal ascent of each participant was obtained.

Consent for publication:

Not applicable

Availability of data and materials:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests

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Authors' contributions:

AR designed the study, contributed to data collection and analysis, wrote the manuscript; also responsible for the overall supervision of the project. **RJ** contributed in Pb analysis, analyzed the data and wrote the manuscript. **MR** conducted Pb analysis and revised the manuscript.

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Figures

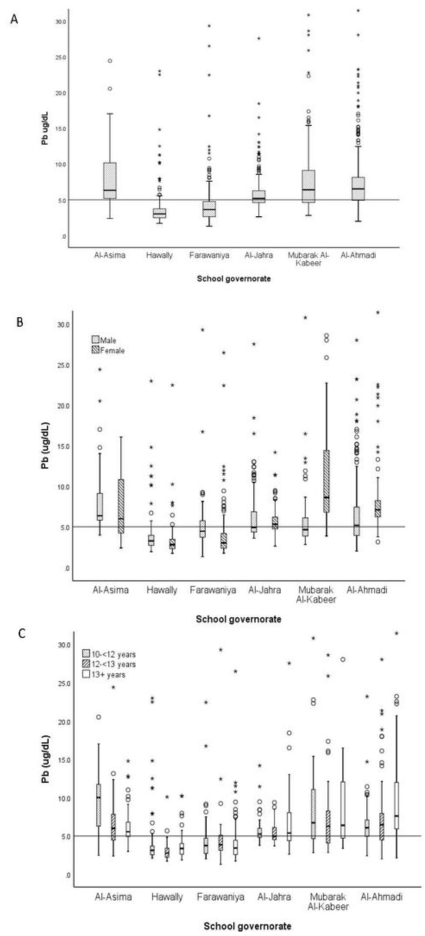
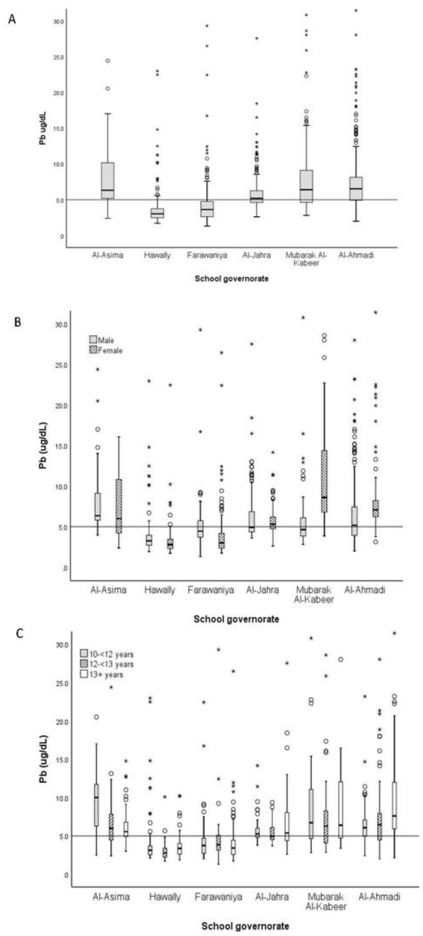


Figure 1

Boxplot showing distribution of Pb levels (µg/dL) stratified by Governorates (A), Governorates and sex (B), Governorates and age categories (C). Boxes show Pb distribution as median and interquartile range. Extremes values are shown above each box. For presentation, the maximum at Y-axis was set at 30 µg/dL. A total of 16 cases had blood Pb levels > 30 µg/dL. These are distributed as follows: Male; 1 in Hawally, 1 in Mubarak Al-Kabeer and 3 in Al-Ahmadi. Female; 1 in Al-Asima, 1 in Farwaniya, 1 in Al-Ahmadi and 8 in Mubarak Al-Kabeer. Statistics: A; Median test $p<0.001$; B; Governorate, x2=65.5, $p<0.001$; sex, x2 =15.3, $p<0.001$, Governorate*sex, x2 =94.5, $p<0.001$; C; Governorate, x2=149.2, $p<0.001$; age, x2=15.6, $p<0.001$, Governorate*age, x2=49.6, $p<0.001$



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