Evaluation of lead pollution risk assessment in the air and dust (A case study: Shiraz-Fars)

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Abstract

Lead as heavy metal is one of the pollutants in the air of large cities. It can enter the human body system through the inhalation of polluted air and cause many environmental and health problems due to its accumulative property. Shiraz is a famous tourist city located in Southwestern Iran. This study tries to evaluate the risk of lead, as a heavy metal in the air and dust of Shiraz in summer and spring. Sampling has been carried out from 12 stations, and dust samples were sieved below 63 microns. All samples were diluted with $HCl–HNO_3–H_2O$ to determine the concentration of lead and concentration was determined by atomic absorption. The concentrations used in ecological risk assessment were obtained from analysis of lead in dust; health risk assessment was calculated according to the concentration of lead in the air. Hakanson's method was used to determine the ecological risks. The average of lead concentrations were 1.29 µg/m^3 in air and 125.5 mg/kg in outdoor dust. As the Hazard Quotient (HQ), in most parts of the investigated zone was higher than 1, ecological risk of lead was considerable for entire city. The highest concentrations were recorded in spring and summer for air and dust respectively. This amount has been higher than standard value of 0.5 mg/m^3 proposed by World Health Organization (WHO) in most studied cases. These results are important for the development of proper management strategies to decrease non-point pollution sources by various remediation ways.

Keywords

heavy metal, lead, air pollution, dust, risk assessment, Shiraz

Résumé

Le plomb appartient à la catégorie des métaux lourds qui se trouvent dans l'air des grandes villes. Il peut pénétrer dans le corps humain par inhalation et, en raison de ses possibilités d'accumulation, il peut provoquer des dommages sanitaires comme il peut avoir des effets négatifs sur l'environnement. Cette étude tente d'évaluer le risque causé par le plomb contenu dans l'air et dans la poussière de la ville de Shiraz, en été et au printemps. L'échantillonnage a été réalisé grâce à l'installation de 12 stations de mesure filtrant les poussières au niveau de 63 microns. L'évaluation des concentrations par absorption atomique a été réalisée après dissolution des échantillons avec des solutions d' $HCl–HNO_3–H_2O$. C'est à partir des niveaux de plomb contenu dans les échantillons de poussière qu'une analyse du risque écologique a été possible avec la méthode d'Hakanson, tandis que l'évaluation du risque sanitaire est effectuée à partir des niveaux de plomb contenu dans l'air. En moyenne, les concentrations observées sont de 1,29 µg/m^3 dans l'air et 125,5 mg/kg dans la poussière de l'air extérieur. Le risque écologique est élevé pour l'ensemble de la ville puisque le coefficient de hasard (Hazard Quotient (HQ)) est, la plupart du temps, supérieur à 1. C'est au printemps et en été que les concentrations sont les plus élevées ; elles dépassent largement la norme de 0,5 mg/m^3 proposée par l'OMS. Ces résultats sont importants à prendre en compte pour développer des stratégies pour diminuer cette pollution diffuse par tous les moyens.

Mots-clés

métaux lourds, plomb, pollution atmosphérique, poussières, évaluation du risque sanitaire, Shiraz

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1. Introduction

The growth of population, industries and transportation has increased air pollution in cities, especially large cities (Jiries, 2003; Al-Khashman, 2007). Heavy metals have been considered as the main pollutants, with their destructive effects that can result from heavy traffic, industries, building erosion, erosion of tires and parts used in cars, mining activities, and the combustion of fossil fuels (Manasreh, 2010; Yongming et al., 2006). Numerous studies have tried to point out certain various aspects of this problem, both for house and street dust: the amount and size of dust particles in the home/outdoor environment, rate of deposition on to household/urban surfaces, the rate of transfer to the human organism, the sources and chemical composition of house/street dust, the behavioral effects on children living in urban areas with high levels of toxic chemicals, etc. (Fergusson et al. 1991; Akhter and Madany, 1993; Edwards et al. 1998; Gulson et al., 1998). Some studies focused on the difference between some city functional areas show that the highest concentrations of heavy metals in dust are mainly found in industrial area (Han et al., 2008; Liu et al., 2012), especially Pb^{2+} and Zn^{2+}, with nearly twice higher than in other functional area (Li et al., 2013). While some studies on health risk have been conducted according to the heavy metal concentrations in whole city urban dust (Fang et al., 2010; Li et al., 2013), Faiz et al. found that the average concentration of Cd, Cu, Ni, Pb and Zn were 5 ± 1, 52 ± 18, 23 ± 6, 104 ± 29 and 116 ± 35 mg/kg, respectively in dust samples collected from the Islamabad Expressway (Faiz et al., 2009). Highest concentration of Cd, Cr, Cu, Ni, Pb and Zn in most areas of Haidian District, Beijing were 0.28-1.31, 57.9-154, 68.1-142, 25.8-78.0, 73.1-222 and 264-664 mg/kg, respectively (Zhao, 2010).

Shiraz, the present study case, is surrounded by mountains, lacks sustained winds with appropriate speed, has low rainfall and air pollution and particular matter have increased in recent years. By considering arrival of large masses of dust from Iraq borders and their adverse effects on the health of citizens, it seems necessary to assess the concentration of heavy metals in the crowded city of Shiraz. The selection of wide areas, assessing the concentration of considered metal in outdoor air and dust in different stations, and the effects of seasonal change can be considered as a new perspective in assessing the lead concentration. The final achievement of this study is to measure and assess lead in the air and outdoor dust of Shiraz, and evaluate the health risk resulting from inhalation and the ecological risk of this metal.

2. Material and method

2.1. Scope of study

Shiraz is the center of Fars province and it is one of the country's metropolis. Geographically, Shiraz is located in southwestern of Iran and in the central part of Fars. Its geographical coordinates are 29º 36´, and 52º 32´ and its height above sea varies from 1480 to 1670 m in different parts of the city. Shiraz population is over 1,460,665 people and this figure increases to 1,700,687 people by considering the population living in the suburbs. Shiraz has a moderate climate with an annual rainfall of 338 mm. This city is prone to environmental problems due to the following reasons: being surrounded by mountains, lack of winds with appropriate speed, low rainfall, and human factors such as crowded population and abundance of the cars, and most importantly, the arrival of large masses of dust from neighbor countries.

2.2. Selection of sampling points and time

As assessment of risk is a method based on the residents' health, those squares and areas were selected as sampling points in which the population and traffic are high (Figure 1). Shiraz rainfall usually occurs in autumn and winter. Therefore, sampling was conducted in dry and warm seasons of spring and summer.

2.3. Sampling method and chemical analysis

Outdoor air and dust sampling was conducted to determine the concentration of heavy metal of lead during the spring and summer of 2015. Air sampling rate has been done by high-pressure air pump of SKC-Leland Legacy using PTFE filter in 6 hours, with flow of 15 liters per minute at 12 stations. The collected filters were transported to laboratory through special holders. Dust sampling was also conducted at 12 stations by broom and vacuum. After transporting to the laboratory, it was screened through #10, #35, #60, #230 by sieves for particle size analysis. Particles smaller than 63 microns in diameter (the size of the diameter of holes of sieves scored 230), that are easily suspended and spread in the air and penetrating into respiratory system and creating risk to human health, were measured and assessed (Zhou et al., 2003). Finally, to measure the concentration of heavy metal of lead, The 0.5 g analytical samples were diluted with 3 ml of a 2:2:2 mixture of $HCl–HNO_3–H_2O$ at 95ºC for 1 hand diluted to 10 ml with distilled water (Ordonez, 2003).The concentration of lead was measured using atomic absorption device, Sen SAA model made in Australia.

Figure 1. Sampling points in Shiraz

2.4. Control of analysis quality

To determine the quality of analysis methods, the accuracy was examined and at least one sample was analyzed twice at in each stage (duplicated sample). The difference between obtained results indicates that analysis method is accurate. The difference percentage (accuracy) was 6% to measure the lead, which it was within the acceptable instructions of the US Environmental Protection Agency (U. S-EPA-SW-846) (Chambers, 1983; Nabi and Pardakhti, 2011). In order to determine the accuracy of analysis method in each period, one spike sample and one blank sample were prepared. To prepare spike sample, a certain amount of pollutant was added to the sample and it was analyzed so that the accuracy of methods was determined by comparing the ratio of mentioned concentration to actual concentration. It was observed that, duplicate samples of lead matched 90 percent of the instructions provided by Environmental Protection Agency (U. S-EPA-SW-846) (Chambers, 1983).

2.5. Ecological risk of one element

The method of potential ecological risk assessment was first introduced by (Hakanson, 1980) and then widely used in the pollution assessment of sediment (Caeiro, 2005), soil and dust (Tang, 2013). The potential ecological risk of toxic metals was defined as:

$$C_f = C_s / C_n \quad (1)$$
$$E_r = T_r \times C_f \quad (2)$$

Where *Cf* is the pollution factor of sampled metal, Cs is the concentration of sampled metal, *Cn* is the background values of element, and *Er* is ecological risk of each element.

Hakanson (1980) has proposed the Tr value as 5 for lead. Tr is known as toxic index of heavy metals. In this study, *Cn* is the average concentration of lead in the earth's crust (14 ppm).

To analyze the obtained values, four different groups were defined as follows:

1. Low ecological risk ($15 < E_r$)
2. Moderate ecological risk ($15 \leq E_r < 30$)
3. Considerable ecological risk ($30 \leq E_r < 60$)
4. High ecological risk ($60 \leq E_r$)

2.6. Health risk assessment

After determining the concentration of lead in the air, the instructions defined by the US Environmental Protection Agency, published in a program of harmonized information system of risk, were used so that the concentration value that every individual has contact with this hazardous material in the air to be determined. The value of exposure was calculated and determined separately through inhalation. Information system of IRIS has provided factors such as average life expectancy, average weight, absorption coefficients and contact time during extensive studies. By using this system, it was found how much each person has inhaled air and how much heavy metal of lead has penetrated into his body by measuring the concentration of pollutants in the air (IRIS, 2005; Schwarzenegger, 2008; U.S-EPA, 2005). Lead has only non-cancerous effects. In non-cancerous effects group, there is no probability of the emergence of non-cancerous effects in a person or it is very low until the contact of the person with pollutant did not reach to certain threshold. Considering the pollutants in the inhaled air, the concentration of reference inhaled air is defined as the value of pollutant that people have contact with it during the day to cause non-cancerous effects in humans. The Hazard Quotient is derived by dividing the contact value in reference concentration. If the result was greater than one, people who have contact with pollutant are exposed to non-cancerous pollution risks. Chronic reference concentration for lead is 0.5 mg/m³ (U.S-EPA, 2005). The Hazard Quotient (HQ) was measured and calculated as follows (U.S-EPA, 2005):

HQ inhalation = CDI inhalation / RFD inhalation (3)

2.7. Contact value assessment

Methods of contact with assumed pollutants in this study include the following cases:

The inhalation of air polluted to heavy metal of lead, the rate of 20 m³ per day, with assumption of using absorption coefficient through lung. For this purpose, three groups of people were defined in terms of type and value of their contact with heavy metal of lead (Hanna, 1985):

1. Permanent residents in the area: 24 hours per day, 350 days per year (assuming 15 days of absence in a year)

2. Employees and vendors: 8 hours per day, 6 days per week

3. Customers and students: exposure hours assuming 5 hours per day and 4 days per week Daily intake of pollutant caused by inhalation (U.S-EPA, 2005):

$$CDI_{inhal} = \frac{C_{air}.EF.ED.(\frac{ET}{24})}{AT} \quad (4)$$

Where, CDI_{inhal} is daily intake of pollutant caused by inhalation; C_{air} is heavy metal concentrations (mg/m³); EF is contact days; ED is number of days in which there is possibility of being ill. Additionally, ET is number of hours a day in contact with pollutants (24 hours for permanent residents); AT is human life span in which one has contact with pollutant for non-cancerous diseases.

3. Results and discussion

3.1. Results of lead concentration

Concentration changes of lead in spring and summer are shown in Table 1.

Air concentration was higher than standard value of 0.5 µg/m³, presented by WHO, in spring at all locations. It was also higher than 0.5 µg/m³ in summer at all locations, except in Maali Abad and Sanayei. Higher concentration of air in spring than summer could be due to the presence of dust during harvest time in spring and during school holidays and reduced traffic in summer. Higher concentration of dust in summer than spring may be due to deposits of dust, lack of wind and low level of rainfall. In both spring and summer, the highest concentration of air observed in station No.1 and the highest outdoor concentration observed in station No.2. Both of them are considered as the busiest and most crowded parts of Shiraz, and most of the shops and universities are located around these squares. The lowest concentrations were observed in station No.11 and station No.12. Considering the presence of green space and their location in the windy limit of Shiraz, it is acceptable.

3.2. Results of ecologic risk assessment

The average concentration of lead in the earth's crust is 14 ppm (Niencheski et al., 2002). In various studies, the calculated values of heavy metals in previous studies were selected as background value (Zheng et al., 2010; Kartal et al., 2006). The measurement of concentration of heavy metals in outdoor dusts of Shiraz was conducted for the first time in this study. Hence, due to the lack of prior knowledge and information and lack of presentation of background values of concentrations for different parts of the country by relevant organizations (while these values were produced and presented by many countries) (Wei et al., 2010), average values in earth's crust were used as background concentration of lead.

The ecological risk of stations was calculated using equations (1) and (2), and results are shown in Table 2.

For spring, ecological risk is very high in one station, considerable in seven stations, moderate in four stations, and it was considerable in the city. For summer, the ecological risk was very high in four stations, considerable in six stations, moderate in two stations, and it was considerable in the city.

In both spring and summer, the highest risk was observed in station No.2, which is one of the busiest and most crowded parts of the city, and most offices, shops and schools are located within this station. In both seasons, the lowest risks were observed in station No.11 and station No.12 that it is acceptable due to less car traffic and large green space in these locations.

3.3. Results of non-cancerous health risk assessment

To investigate the non-cancerous health risks, daily intake resulting from inhalation was obtained firstly by equation (3). Then, Hazard Quotient or non-cancerous health risk was obtained by equation (4). Results for each of the three groups are shown in Table 6 and 7.

As can be seen from the table above, the Hazard Quotient is higher than 1 for group 1 in all points in spring, the Hazard Quotient for group 2 is higher than 1 in station 1 and station 2 in spring. It indicates that people, who have contact with lead, are exposed to non-cancerous health effects of lead. As the Hazard Quotient is lower than 1 in all points for group 3 in spring, it indicates that people, who have contact with lead, are not exposed to non-cancerous health effects of lead.

As can be seen in the table above, the Hazard Quotient is higher than 1 for group 3 in all points, except Sanayei and Maali Abad Squares in the summer. It indicates that people, who have contact with lead, are exposed to non-cancerous health effects of lead. As the Hazard Quotient is lower than 1 in all points for group 2 and 3 in summer, it indicates that people, who have contact with lead, are not exposed to non-cancerous health effects of lead.

Dust contaminated by metals is becoming an important threat to urban environment and ecosystem because of the possible transmission of metals in dust to water systems by urban runoff (Zhao, 2010) and to atmosphere by re-suspension in the wind (Ferreira-Baptista and De Miguel, 2005). As Shiraz is not considered as an industrial city, this difference is mainly due to dust coming from the Southern border of the country (Iraq). Shiraz's street lead dust contamination in this study was compared to Tehran – Iran (Saeedi et al., 2012) and Beijing-China (Zheng et al., 2015). 2013 – January 2014

The concentrations of lead in Shiraz street dusts are lower than in Tehran, but higher than in Beijing. Note that in Iran, there is still no background or reference recommended value of contaminants for soil and solid elements. Shiraz is less industrialized than Tehran and Beijing, in terms of population and vehicle volume. This indicates that there may be serious health and environmental impacts related to the uptake of lead in Shiraz.

4. Conclusion

The aim of this study was to measure and assess the ecological and health risk of lead as a heavy metal in outdoor air and dust of Shiraz. As it can be seen from the results, the lead concentration is higher than standard value of 0.5 micrograms provided by WHO for most areas (Table II). In average, Shiraz has considerable ecological risk for lead. Additionally, among three studied groups, the first group is exposed to non-cancerous risks resulting from the presence of lead in air in most parts, while other groups are not exposed to non-cancerous risks resulting from the presence of lead. Due to the high concentration of dust in the air in spring samplings and lower concentrations in summer samplings, it is likely that the source of increase in the concentration of lead is inhaled air since one of the transporter factors of heavy metals is dust particles. Other possible factors include the heavy traffic of cars and the combustion of fossil fuels that have been reduced due to school holidays in summer. Based on obtained concentrations, identifying critical points and contributing to short-term and long-term urban planning, as well as providing a strategy to reduce them are considered as implications of these study. Some recommendations to complete this study include: measuring and assessing the risk of all heavy metals simultaneously, identifying the pollutant factors that release and transfer lead, finding appropriate ways to reduce the adverse effects of lead in the air, measuring the total risk for lead and other heavy metals that include total inhalation risk, ingestion, and skin contact for individuals.

Table I. Parameters required for risk assessment assumed to groups

Parameter	Group 1	Group 2	Group 3
EF(DAY/YEAR)	350[a]	282[b]	218[c]
ED(YEAR)	30[a]	25[a]	4
ET(HOUR/ DAY)	24	8	5
AT(YEAR)	30[a]	25	4

a: U.S.EPA 1991a pg.15
b: 6 days in a 52-week of year, minus 30 day off and holidays
c: 4 days in a 52-week of year

Table II. Lead concentration

		Spring		Summer	
	Location	Concentration in air µg/m^3	Concentration in dust mg/kg	Concentration in air µg/m^3	Concentration in dust mg/kg
1	Namazi Square	2.78	120.0	1.90	140.0
2	Setad Square	2.38	185.0	1.80	210.0
3	Shohada Square	1.62	142.5	1.40	180.5
4	Valiasr Square	1.16	130.0	1.00	140.0
5	Modarres Boulevard	1.16	110.0	1.00	130.0
6	Adabiat (Golestan Boulevard)	1.39	150.0	1.10	190.0
7	Sibouyeh Boulevard	1.85	142.5	1.40	165.0
8	Basij Square	1.16	75.0	0.90	100.0
9	Amir Kabir Square	1.16	75.0	0.70	90.0
10	Moallem Square	1.39	125.0	1.10	150.0
11	Shariati Boulevard	0.93	60.0	0.30	75.0
12	Sanayei Square	0.93	62.5	0.35	80.0
	Mean in Shiraz	1.49	113.5	1.08	137.5

Table III. Results of ecologic risk assessment

		Spring		Summer	
	Location	E_r	Concentration in dust mg/kg	E_r	Concentration in dust mg/kg
1	Namazi Square	120.0	43	190.0	68
2	Setad Square	185.0	66	210.0	75
3	Shohada Square	142.5	51	180.5	64
4	Valiasr Square	130.0	46	140.0	50
5	Modarres	110.0	39	130.0	46
6	Adabiat	150.0	54	190.0	68
7	Sibouyeh	142.5	51	165.0	59
8	Basij Square	75.0	27	100	36
9	Amir Kabir	75.0	27	90	32
10	Moallem Square	125.0	45	150	54
11	Shariati	60.0	21	75	27
12	Sanayei Square	62.5	22	80	29
	Mean in Shiraz	113.5	41	137.5	49

Table IV. Results of non-cancerous health risk assessment in spring

Station	**Namazi**	**Setad**	**Shohada**	**Valiasr**	**Modarres**	**Adabiat**	**Kazeroun**	**Basij**	**Amir Kabir**	**Moallem**	**Shariati**	**Sanayei**	**Mean of Shiraz**
C µg/m³	2.78	2.38	1.62	1.16	1.16	1.39	1.85	1.16	1.16	1.39	0.93	0.93	1.49
CDI Group 1	2.67	2.28	1.55	1.11	1.11	1.33	1.77	1.11	1.11	1.33	0.89	0.89	1.43
CDI Group 2	0.72	0.61	0.42	0.30	0.30	0.36	0.48	0.30	0.30	0.36	0.24	0.24	0.38
CDI Group 3	0.35	0.30	0.20	0.14	0.14	0.17	0.23	0.14	0.14	0.17	0.12	0.12	0.19
HQ Group 1	5.34	4.56	3.10	2.22	2.22	2.66	3.54	2.22	2.22	2.66	1.78	1.78	2.86
HQ Group 2	1.44	1.22	0.84	0.60	0.60	0.72	0.96	0.60	0.60	0.72	0.48	0.48	0.76
HQ Group 3	0.70	0.60	0.40	0.28	0.28	0.34	0.46	0.28	028	0.34	0.24	0.24	0.38

Table V. Results of non-cancerous health risk assessment in summer

Station	Namazi	Setad	Shohada	Valiasr	Modarres	Adabiat	Kazeroun	Basij	Amir Kabir	Moallem	Shariati	Sanayei	Mean of Shiraz
C µg/m³	1.90	1.80	1.40	1.00	1.00	1.10	1.40	0.90	0.70	1.10	0.30	0.35	1.08
CDI Group 1	1.82	1.73	1.34	0.96	0.96	1.05	1.34	0.86	0.67	1.05	0.29	0.34	1.04
CDI Group 2	0.49	0.46	0.36	0.26	0.26	0.28	0.36	0.23	0.18	0.28	0.08	0.09	0.28
CDI Group 3	0.24	0.23	0.17	0.12	0.12	0.14	0.17	0.11	0.09	0.14	0.04	0.04	0.13
HQ Group 1	3.64	3.46	2.68	1.92	1.92	2.10	2.68	1.72	1.34	2.10	0.60	0.68	2.08
HQ Group 2	0.98	0.92	0.72	0.52	0.52	0.56	0.72	0.46	0.36	0.56	0.16	0.18	0.56
HQ Group 3	0.48	0.46	0.34	0.24	0.24	0.28	0.34	0.22	0.15	0.24	0.08	0.08	0.26

Table VI. Comparison of concentration of lead in street dust

City	**Min concentrations of lead (mg kg⁻¹)**	**Max concentrations of lead (mg·kg⁻¹)**	**Mean concentrations of lead (mg·kg⁻¹)**	**Number of samples**	**Sampling time**
Shiraz-Iran	60.0	210.0	125.5	24	April 2015 – August 2015
Tehran-Iran	64.7	764.9	257.4	50	August 2010
Beijing-China	40.26	174.39	107.98	48	November 2013 – January 2014

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