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Original Research

Heavy Metal Accumulation in Dust and Workers' Scalp Hair as a Bioindicator for Air Pollution from a Steel Factory

Zhian Salih*, Farhad Aziz

Environmental Sciences Department, College of Science, Salahaddin University, Erbil, Iraq

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Abstract

The present study was carried out to detect some heavy metals such as Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co and Cd in fallen dust and the scalp hair of workers in a local steel factory, and people dwelling in rural areas 143 km away from the factory within Erbil Province. The study revealed a considerable accumulation of aforementioned heavy metals in dust and the hair of workers in the polluted zones as compared to the unpolluted rural districts. The concentrations of all the metals in the factory exceeded the standard limits of WHO. In a rural area, all metals except Ni are under the restrictions of WHO concentrations. The geo-accumulation index (I_{geo}) and pollution load index (PLI) values >1 indicated that the area pollution caused by the steel factory ranged from moderate to extreme contamination. The hair of the workers in the scrapyard and around the furnace part of the factory had a significantly higher content of metals compared with other parts of the workplace. A positive correlation was found between the concentration of dust and hair heavy metals. Also, 16 and more years of working showed a higher value of hair metals.

Keywords: steel factory, heavy metals, pollution load index, scalp hair, dust

Introduction

Air pollution is the emission of undesirable substances into the atmosphere such as gases, dust, heavy metals and fumes that could be harmful to the health or comfort of humans and animals [1]. One of the most critical pollutants is heavy metals. Unlike other pollutants, these metals are not degraded and persist for a long time in the environment [2]. Anthropogenic activities such as steel and iron industry, mining, cement, paper, leather and paint manufacturing, smelting procedures, traffic and agriculture activities are the most dangerous sources of heavy metals distribution in the environment [3].

Indoor and outdoor industrial air pollutants in the workplace negatively affect the health of workers [4]. Harmful pollutants such as gases, vapours, fumes and smoke may be produced during the melting, moulding, mould drying, furnace preheating, electric arc furnace processes and cooling in the iron and steel industry [5, 6]. Outdoors, the concentration of pollutants is lower compared with the level in the indoors of the industry due to fine size of emitted particulates [7]. In a furnace,

*e-mail: zhian.salih@su.edu.krd

different toxic metals such as lead, cadmium, mercury, zinc, nickel, chromium and manganese can be emitted as a fine dust, fume and vapour particulates [8].

The level of toxic metals is raised in urban dust [9, 10], causing threats to human life and ecological systems [11, 12]. In the urban areas, continuous deposition and accumulation of heavy metals may act as a source of air pollution. Moreover, ingestion of some amounts of dust via hand-to-mouth passageways and are thus more susceptible to contaminated dust [13, 14]. High concentrations of heavy metals are built up in our bodies and transported through a circulatory system and cause damage of our internal organs and nervous system [15, 16].

A different kind of body tissue can be used as environmental biomonitoring for air pollution [17]. Human hairs are one of the most important bioindicators that be used for environmental and workplace exposure to toxic elements [18]. The mineral content of hair offers a variety of information about the concentration of the elements in inner organs. The mineral contents of hair are higher than that of the other tissues in the body – especially urine and blood, so that the distribution of the metals in the hair reflect the concentration in the whole body [19, 20]. Furthermore, long-term exposure to toxic metals is mostly expressed through hair contents, while urine and blood give a picture of short-term exposure to toxic elements which might be helpful to see how exposure changed over time [21].

An important source of air pollution with heavy metals in Erbil, Iraq is a local steel factory, and due to the unavailability of reliable data and investigations regarding the biological monitoring of heavy metals contents in the human hair, the current study came to exist. The study intended to assess the accumulation of heavy metals such as Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co and Cd in fallen dust and scalp hair of workers in Erbil steel factory. Samples collected from the unpolluted rural area were exploited as control groups for comparison purposes and security. Having said this, the accumulation of metals was utilized as bioindicators for the level of air pollution. Also, the I_{geo} and pollution load index models were used for assessing the degree of contamination caused by heavy metal. Moreover, this study focused on the influence of workplace and years of working on the accumulation of metals in the hair of workers.

Materials and Methods

Study Sites

Erbil is located in northern Iraq and is situated 414 m above sea level at longitude 43º15′ E and latitude 35º11′ N. The Erbil climate is characterized by cold winters, mild in spring and hot summers, somehow similar to the Irano-Turanian type of the semi-arid zones [22]. In the present study, two different study sites were selected. The first site was a polluted area located within Erbil steel factory near Lajan and Turjan villages on the main road of Erbil-Gwer, 22 km southwest of Erbil and situated between 36º08′18.55″N longitude and 43º47′49.68″E elevation 347 m above sea level. The second site was an unpolluted mountain rural area within Akre District located 143 km from Erbil steel factory and situated between 36º44′27.90″N longitude and 43º52′51.11″E at an elevation of 675 m above sea level.

Sample Collection, Preparation and Analysis

Dust samples were collected from the polluted and unpolluted sites during June, July and August 2017. The specimens were put in clean plastic containers with a wide opening of 20 cm and a height of 30 cm. The mouth of each collector was fitted with a funnel to prevent dust from escaping to the atmosphere. The base of each containers was fixed to the earth by cement in order to support attachment and prevent it from moving due to winds or other reasons. Each collector was attached in a stand 100-150 cm above the ground. During dust collection months, the funnel was removed and the dust carefully collected by a small clean brush and transferred to a small clean plastic bag for weighing and calculating using the following equation:

$$\text{Amount of fallen dust} = \frac{\text{Weight of dust (mg)} \times 3}{\text{area (cm}^2\text{)} \times \text{time (days)}}$$

Area = area of the fallen dust container opening mouth (cm^2). The results were expressed in $mg/cm^2/month$.

After collecting the dust, the dusting powder was preserved at room temperature in order to determine the heavy metals. The powdered dust samples were analyzed for estimating Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co and Cd concentrations by using the XRF (X-ray fluorescence spectrophotometer) Sky Instrument Genius. XRF analyses were carried out at the laboratory of the Agriculture College of Salahaddin University using a handheld Thermal Scientific Genius 9000 XRF [23].

Human scalp hair samples were collected from the two sites (the polluted site of Erbil steel factory and the unpolluted site of the rural area of Akre located in the mountain region). In the unpolluted site, 25 healthy humans were selected, while in the contaminated site hair samples were taken from 100 expected healthy non-smoking workers aged 30-40 years with means 37±3 and divided into different groups as follows:

According to the workplace (factory parts or units) of workers: the administrative part (n = 25), inside factory part (n = 25), around the furnace part (n = 25) and the scrap yard part (n = 25).

According to the years of working: 1-5 years (n = 23), 6-10 years (n = 44), 11-15 years (n = 15) and 16 and more (n= 18; where the n= number of workers).

Freshly cut human hair samples were quickly put in a pre-coded polythene bag, sealed tightly and kept for pre-treatment. The hair samples were cut to about 200-250 mg using stainless steel scissors, then rinsed in ethanol, coded and stored. The stored samples were further split into approximately 0.3 cm pieces and mixed and washed according to the recommendation of the International Atomic Energy Agency (IAEA) [24], first in ethanol, then three times in distilled water, once again in ethanol and followed finally by distilled water. They were placed in crucibles and dried in an oven at 75ºC for 15-25 minutes. The hairs were analyzed for determining Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co and Cd by using XRF (X-ray fluorescence spectrophotometer) Sky Instrument Genius.

Pollution Assessment Models

In the present study, the geo-accumulation index (I_{geo}), contamination factor (CF) and pollution load index (PLI) were used to assist the level of heavy metals contamination in both polluted areas of the steel factory and unpolluted sites of the rural area. The following equation was used for the measure of I_{geo} of each heavy metal [25]:

$$I_{geo} = \log_2 [Cn / 1.5\ Bn]$$

…where Cn is the calculated heavy metal concentration in the dust sample and Bn is the geochemical background value for the metal n. For this study, Bn is the background value of local soil [26]. The constant 1.5 is the correction factor due to the variation of deviation in the background values. The I_{geo} for every heavy metal classified into $I_{geo}\leq 0$ (uncontaminated), $0<I_{geo}\leq$ (uncontaminated to moderately contaminated) $1<I_{geo}\leq 2$ (moderately contaminated), $2<I_{geo}\leq 3$ (moderately to heavily contaminated), $3<I_{geo}\leq 4$ (heavily contaminated), $4<I_{geo}\leq 5$ (heavily to extremely contaminated), and $I_{geo}>5$ (extremely contaminated) [25].

The contamination factor (CF) is the concentration of metal in the dust divided by the metal background value:

$$CF = C_{metals} / C_{background\ value\ of\ that\ metal}$$

Pollution load index (PLI) was used to evaluate the degree of heavy metals pollution in the studied areas [13] and was calculated by the following equation:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \ldots\ldots CFn}$$

…where CF = contamination factor of the metal and n = number of metals.

A PLI value<0 is considered to be no pollution while PLI>0 indicates that the area was polluted.

Statistical Analysis

Statistical analysis of the data was performed using SPSS (version 17). Results were expressed as means±standard error. Independent Student t-test was used for comparison of the heavy metals concentration in the dust and scalp hairs between the unpolluted and contaminated sites. Also, Pearson correlation was applied to find relationships between heavy metals concentrations in dust and hair. Analysis of variance (ANOVA) and Duncan post-hoc test was applied for comparison of the heavy metals in hairs of different groups of the workplace and years of working. A $p\leq 0.05$ was considered to be statistically significant.

Results and Discussion

Amount of Fallen Dust and Their Metals Concentrations

Today the ecosystem health life of the living organism and humans are at risk owing to exposure to toxic heavy metals [21]. The atmosphere of workers around the steel industry has attracted more attention to investigators to study the effect of pollutants that were released from the factories on human health [27].

The amount of fallen dust and its concentration of metals in the polluted and the rural control sites is represented in Fig. 1. The amount of fallen dust ranged from 0.296 in a rural area to 2.269 mg/cm^2/month in a polluted area with significant differences $p\leq 0.001$.

In the control area, the heavy metals in the dust from maximum to minimum concentration were as follows: Mn 233.33, Fe 222.33, Zn 198.12, Ni 89.33, Pb 35.14, Cr 33.33, Cu 27.88, Co 10.25 and As 4.48 mg/kg, while in the polluted site the concentration of metals follows the current graduations: Zn 13844.28, Mn 2125.46, Fe 1686.80, Pb 792.42, Cu 626.05, Cr 472.02, Ni 301.68, As 233.81 and Co 139.00 mg/kg. In the unpolluted area, the lower value of metal was As 4.48 and the higher concentration was Mn 233.33 mg/kg, while in the polluted area the results found that the concentration of Co 139.00 was lower and Zn 13844.28 mg/kg was higher among all studied metals. No Cd was detected in the fallen dust. Until now, there have been no guidelines for the concentration of metal in the dust. However, a great part of the dust comes from re-mobilization and re-suspension of the soil. Thus, it is important to compare the metal concentration in the dust with the permissible limits values in the soil.

According to WHO, the standard limits of concentrations of metals in soil are Cu 36 mg/kg, Ni 50 mg/kg, Cr 150 mg/kg, Zn 300 mg/kg, As 40 mg/kg, Pb 100 mg/kg and for Cd 3 mg/kg [28]. In the steel factory site, all of these metals but Cd exceed

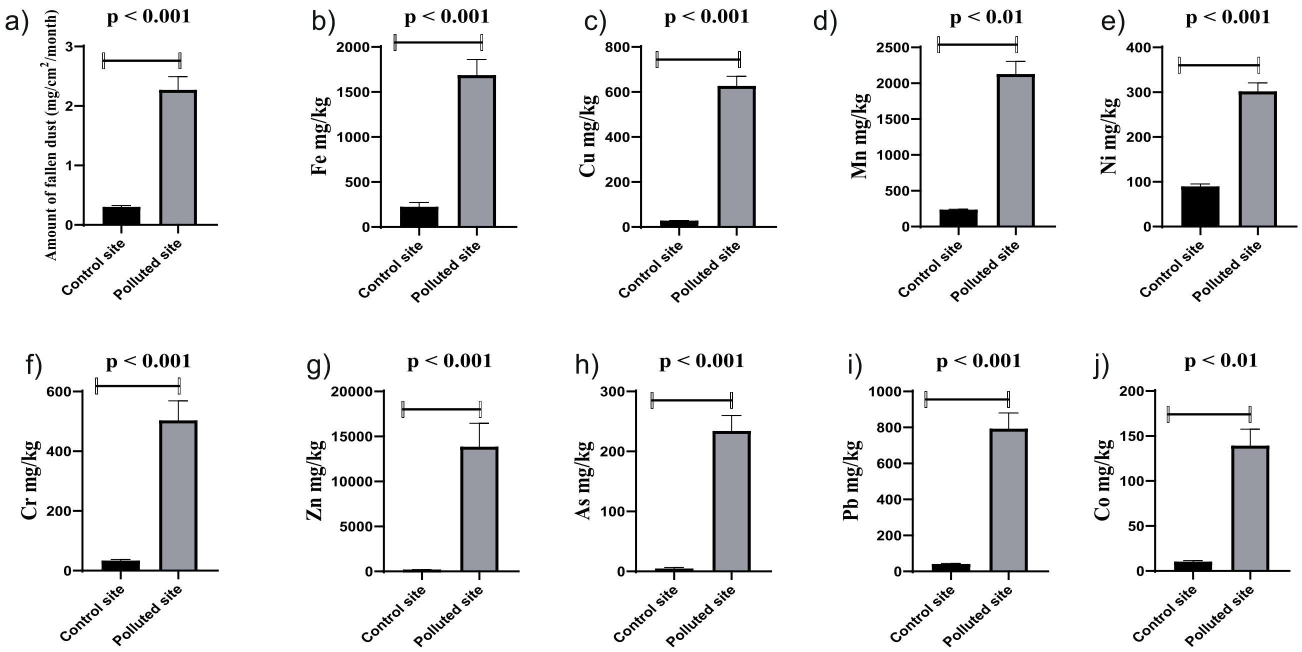

Fig. 1. Means±standard error of the amount of fallen dust and its concentration of metals in both controls rural and polluted sites. a) amount of fallen dust, b) Fe, c) Cu, d) Mn, e) Ni, f) Cr, g) Zn, h) As, i) Pb and j) Co.

the allowable limits of WHO, indicating high pollution of this area by heavy metals. While in the rural site and except for the concentration of Ni, the other studied metals are lower than the permissible limits of WHO, indicating that the area is clean and uncontaminated with metals.

The concentration of toxic heavy metals and chemical compound contents in the dust are emitted from factories and suspended in the air, and transported from the sources over long distances by the wind and cause contamination of the ecosystem [29]. Dust deposition in the respiratory tract through the opening of the mouth and nose affect human health by toxic metals contents. The risks to human health include difficulty breathing, blindness, body organ damage and death [30]. Consequently, the accumulation of large amounts of dust with more heavy metals contents will provide available data on the risks of them [31].

In the present study, the increases of the fallen dust and their heavy metals contents in the polluted site of the steel factory reflects the degree of pollutants released to the atmosphere and may negatively affect the health of the workers and people living around the factory. The results are supported with various studies that have reported and evaluated heavy metal pollution in dust [32-34], and have studied the sources of pollution [35] and human health risks [36, 37].

Pollution Assessment Index

The value of I_{geo}, contamination factor and pollution load index (PLI) for the studied metals are presented in Table 1. The value of I_{geo} for all metals in the rural control site is <1, which indicates that they are uncontaminated (Fe - 0.63, Cu - 1.51, Mn - 1.87, Ni - 0.13, Cr - 1.57, Zn − 0.42, As −1.68, Pb - 0.12, and Co - 0.92). Also, the PLI in the control site was 0.79, which is <1. In the polluted site, the values of I_{geo} for all metals are >1. The I_{geo} values for Mn 1.31 and Ni are 1.57 (moderately contaminated), while for Fe 2.28, Cu 2.97, Cr 2.24 and Co 2.83 (moderately to heavily contaminated). The I_{geo} of As 4.01 and Pb 4.01 (heavily to extremely contaminated, Zn 6.55 (extremely contaminated). The PLI in the steel factory site is 13.12>1. The I_{geo} and PLI values >1 in steel factory location indicate the high contamination of this area with heavy metals.

In different countries and locations, work on air pollution monitoring by dust and heavy metals contents has been carried out by other investigations; Han et al. found that the dust collected from parks and squares of Baotou industrial city in China were polluted by Cr, Co, Pb, Cd, and Hg according to the I_{geo} value. Depending on the pollution load index, it is contaminated by Ba, Co, Cr, Cu, Mn, Ni, Pb, V, Zn, Cd, As, and Hg [38]; Ghadimi et al., observed that Arak city is polluted with Pb, Cu, Ni, Zn, Cr, Hg and As on the basis of Igeo. The pollution is varying from a moderate to a very high degree of contamination [39]. These results are in agreement with the findings of our results.

Heavy Metals Concentrations in Scalp Hair

Hair has a vital role in the monitoring of heavy metals [40], and according to the U.S. Environmental Protection Agency (EPA), it is considered an essential biomarker [41]. The worldwide use of hair

Table 1. Geo-accumulation index, contamination factor and pollution load index of heavy metals in both rural and steel factory sites based on local soil backgrounds.

Metals (mg/kg)	The rural area of Akre (unpolluted control site)			Steel factory polluted site (polluted site)			Background value
	Means	I_{geo}	CF	Means	I_{geo}	CF	
Fe	222.33	−0.63	0.96	1686.80	2.28	7.33	230
Cu	27.88	−1.51	0.52	626.05	2.97	11.79	53.10
Mn	233.33	−1.87	0.41	2125.46	1.31	3.73	5.69
Ni	89.33	−0.13	1.32	301.68	1.57	4.46	67.60
Cr	33.33	−1.57	0.50	472.02	2.24	7.11	66.30
Zn	198.12	0.42	2.01	13844.28	6.55	140.67	98.41
As	4.48	−1.68	0.46	233.81	4.01	24.27	9.63
Pb	35.14	−0.12	1.37	792.42	4.36	30.91	25.63
Co	10.25	−0.92	0.78	139.00	2.83	10.69	13.00
Cd	ND			ND			0.35
PLI	0.79			13.12			

I_{geo} = Geo-accumulation index CF = contamination factor PLI = pollution load index ND = no detected
Background value of each metals = local soil concentration of metal [30].

in biomonitoring and biomarkers for heavy metals pollution is due to high metals storage and their longer lives. Also, a large number of people desire to donate a sample, with easy collection, storage and transportation [42, 43].

The results recorded from the present study and presented in Fig. 2 found significant differences in the concentrations of heavy metals in the hair of control men who live in the rural area far from the site of pollution and workers exposed to pollution inside a steel factory. The scalp hairs of the workers in a steel factory include significantly higher accumulations of Fe, Cu, Mn, Ni, Cr, Zn, As, Pb and Co (128.32, 166.38, 38.46, 18.34, 1.91, 490.35, 7.72, 30.09 and 2.08 mg/kg) compared with concentrations in the unpolluted rural site (50.98, 35.31, 23.84, 6.90, 0.00, 150.65, 1.06, 14.19 and 1.41 mg/kg). In the polluted site, and among the metals, higher concentrations of Zn and Cu (490.35 and 166.38 mg/kg) were observed, while Cr and Co (1.91 and 2.08 mg/kg) showed lower concentrations. No Cd was detected in the hair of workers in both control and polluted sites. These results are supported by the investigations of Mohmand et al., who observed lower concentrations of Mn, Ni, Cr and Co in hair scalp of low pollution of rural areas in comparison with more highly polluted urban areas [44]. Highly significant ($p<0.01$) concentrations of Cu, Cd and Pb were seen in hair samples of industrial workers in comparison to those controls which do not work in a metal-contaminated environment [45].

There is no acceptable data about the background, or reference value of the concentration of heavy metals in hair, and high differences were found between the studies. According to the results of Dongarra et al., who record a lower and upper reference range of the following metals Cr lower 0.001, upper 0.48 mg/kg; Co lower 0.01, upper 1.20 mg/kg; Cu lower 9.1, upper 59.7mg/kg; Mn lower 0.002, upper 0.91 mg/kg; Zn lower 96.86, upper 329.19; As lower 0.0003, upper 0.03 mg/kg; Cd lower 0.0004, upper 0.16 mg/kg; Pb lower 0.28, upper 3.03 mg/kg and Ni lower 0.036, upper 1.75 mg/kg in Italy [46]. On the other hand the study of Baran and Wieczorek in Krakow, Poland, who recorded the concentration of some metals in the hair of males as follows, Zn minimum 38.82, maximum 442.29 mg/kg; Pb minimum 0, maximum 14.36 mg/kg and Cd minimum 0, maximum 0.35 mg/kg [47]. In Nigeria, the results obtained from [48] show the following mean concentrations (mg/kg): Cd 27.8, Cr 2.70, Pb 73.8 and As 222.

According to the results of the great studies and due to the significant differences in the concentration of heavy metals in hair, it is challenging to select a background or reference value for metals in hair. It is appropriate to compare the results of the polluted industrial area with the rural uncontaminated site for determining the degree of contamination in the studied sites.

The accumulation of metals in the hair are tenfold higher than other biomarkers such as blood and urine [42, 49]. Moreover, the slower growth rate of hair (10mm per month) and the ability of the metal cations to bind with the keratin proteins present in the hair matrix indicate long-term exposure to heavy metals in the workplace [42].

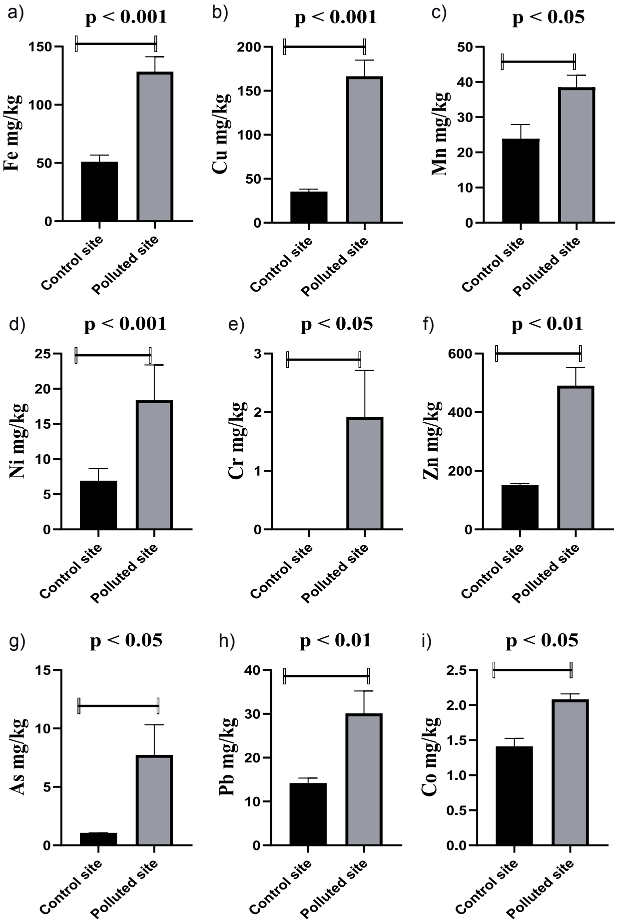

Fig. 2 Means±standard error of the concentration of metals scalp hair in both controls rural and polluted sites. a) Fe, b) Cu, c) Mn, d) Ni, e) Cr, f) Zn,g) As, h) Pb and i) Co.

The results presented in Table 2 revealed a positive correlation between heavy metal in fallen dust and scalp hair. Due to these results, the intensity of metals in the hairs depends on their level in the atmosphere (which is emitted from the chimneys and furnaces of the steel factory) and the amount of the inhalation and diffusion of these metals in the body tissues.

The concentrations of the metals in the scalp hair of workers found in different parts of the steel factory is presented in Table 3. The results observed after post hoc Duncan test application showed significant differences in the concentration of heavy metals in the hair of workers. The workers founding the scrap part of the factory have a significantly higher accumulation of Fe, Cu, Mn, Ni and Cr (156.82, 205.12, 45.92, 33.05 and 3.85 mg/kg) compared with control and other parts. Hair contents of Zn and Co are significantly higher in workers found in scrap (577.23 and 2.29 mg/kg) and around the furnace parts (608.60 and 2.07 mg/kg). The As and Pb metals significantly appear to be more accumulated (14.62 and 39.85 mg/kg) in the scalp hair of the worker's group founding around the furnace.

The concentration of the studied heavy metals in scalp hairs of the workers in the administrative part is significantly lower compared with others working inside the factory, around the furnace and scrap parts of the factory. The location of work has a significant role in heavy metal accumulation in the hair. In the present study the accumulation of metals in the scrap and around the furnace parts of the steel factory due to excessive exposure of workers to the pollutants because these two parts are the primary sources for emission of the heavy metals. The workers found in the administrative part are less exposed to the pollutants due to being far from the source of metals emission. Lack of adequate ventilation, working in closed spaces, less security and poor supervision in the iron and steel industry negatively affects the workers' health [50]. The fine particles found in the dust can transfer to the human body through ingestion, inhalation, and dermal contact [44, 51].

Table 2. Pearson correlation (r) between heavy metals in dust and scalp hair.

		In Hair							
		Fe	Cu	Mn	Ni	Zn	As	Pb	Co
In dust	Fe	0.924**							
	Cu		0.730**						
	Mn			0.765**					
	Ni				0.896**				
	Zn					0.920**			
	As						0.643*		
	Pb							0.878**	
	Co								0.720*

*Correlation is significant at 0.05 levels **Correlation is significant at 0.01 levels
A positive correlation was found between each heavy metal in dust and scalp hair. Increasing of metals in dust reflects the increase of them in the hair.

Table 3. Means±standard error of the accumulation of heavy metals (mg/kg) in scalp hair of control and different workplace of workers in the steel factory.

Workplace	Fe	Cu	Mn	Ni	Cr	Zn	As	Pb	Co	Cd
Control (n = 25)	50.98 d ± 10. 56	35.31 e ± 11.15	23.84 d ± 3.82	6.90 d ± 2.30	0.00	150.65 d ± 15.34	1.06 e ± 0.19	14.19 c ± 2.61	1.41 c ± 0.12	ND
Administrative unit (n = 25)	94.90 c ± 9.37	120.05 d ± 12.24	29.18 c ± 3.21	10.31 c ± 2.88	0.00 c	349.75 c ±20.69	2.86 d ± 0.65	15.75 c ± 2.72	1.90 b ± 0.06	ND
Inside factory (n = 25)	127.04 ab ± 13.18	155.76 c ± 15.37	39.19 b ± 4.18	14.39 b ± 2.60	1.56 b ± 0.09	425.83b ±22.66	8.60 b ± 1.44	31.53 b ± 3.27	2.06 a ± 0.09	ND
Around the Furnace (n = 25)	134.54 b ± 9.29	184.61 b ± 12.16	39.56 b ± 3.86	15.63 b ± 1.63	2.25 b ± 0.06	608.60 a ± 30.70	14.62 a ± 2.46	39.85 a ± 4.20	2.07 a ± 0.06	ND
Scrap part (n= 25)	156.82 a ± 8.60	205.12 a ± 18.85	45.92 a ± 4.01	33.05 a ± 4.31	3.85 a ± 0.11	577.23 a ± 25.43	4.83c ± 0.80	33.26 b ± 3.62	2.29 a ± 0.11	ND
p-value	0.001	0.05	0.001	0.001	0.05	0.001	0.001	0.001	0.05	

Post-Hoc Duncan- test: no differences between groups with the same letter. n = number of workers
Significant differences between groups with different letters. ND = no detected

Table 4. Means±standard error of heavy metals accumulation (mg/kg) in scalp hair of workers in different periods of working in the steel factory.

Years of working	Fe	Cu	Mn	Ni	Cr	Zn	As	Pb	Co	Cd
1-5 (n = 23)	113.84 b ± 9.56	128.89 c ± 11.75	29.40 b ± 3.68	10.32 b ± 2.41	0.40 c ± 0.07	390.58 c ± 35.61	5.48 c ± 0.19	17.57 c ± 2.06	1.97 b ± 0.06	ND
6-10 (n = 44)	115.46 b ± 8.45	146.94 b ± 10.73	30.17 b ± 3.79	10.55 b ± 1.47	1.61 b ± 0.06	502.33 b ±35.81	7.69 b ± 0.65	29.29 b ± 3.65	2.01 ab ± 0.08	ND
11-15 (n = 15)	140.25 a ± 13.18	189.96 a ± 19.01	46.64 a ± 11.54	25.36 a ± 3.26	2.53 a ± 0.06	510.71b ±27.65	7.60 b ± 1.10	35.75 a ± 2.22	2.13 a ± 0.11	ND
16 and more (n = 18)	143.75 a ± 15.25	199.75 a ± 13.30	47.64 a ± 4.21	27.15 a ± 1.03	3.12 a ± 0.08	557.79 a ± 66.43	10.14 a ± 1.46	37.78 a ± 5.86	2.21 a ± 0.09	ND
p-value	0.001	0.001	0.05	0.001	0.05	0.05	0.05	0.05	0.05	

Post-Hoc Duncan- test: no differences between groups with the same letter. n = number of workers
Significant differences between groups with different letters. ND = no detected

Period of work has an essential role in the accumulation of metals in the scalp hair of workers. The results tabulated in Table 4 observe that workers who have worked for 11 and more years in the steel factory have significantly higher concentrations of Fe, Cu, Mn, Ni, Cr, Pb and Co compared with those working for about 1-5 and 6-10 years. Moreover, 16 and more years of working showed a higher accumulation of Zn and As compared with fewer working years. The men who work for 1-5 years significantly have a lower concentration of Cu, Cr, Zn, As, and Pb compared with the higher period of working. The present work revealed that a high level of toxic metals is found in the hair of workers who are exposed for pollutants for an extended period. More periods exposed to pollutants mean more metals acumulating in the scalp hair. The structure of hair remains unchanged and more metals are accumulated and fixed, the hair widely used as a sample for metal analysis and it is the best choice when chronic exposure occurs [52]. The accumulation of metals in the body tissues reflect the biomedical and environmental history of the body as well as long-term metabolic changes [53].

Conclusions

High concentrations of heavy metals in the collected dust and scalp hair of workers was observed in the polluted site within the steel factory. A positive correlation was found in the concentration of the heavy metals between dust and scalp hair. The I_{geo} and pollution load index values in the steel factory site >1 indicates high contamination by heavy metals and it has value in the rural control site of Akre region <1, indicating an uncontaminated area. Moreover, the location of workers has an important role in the accumulation of metals in the scalp hair. Workers found near the emissions source of pollutants such as furnace and scrap yard area are more exposed to pollutants, causing more metals to accumulate in their bodies. Hair is a good indicator of air pollution caused by heavy metal deposition.

A longer period of working was reflected by more metal accumulation.

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Conflict of Interest

The authors declare no conflict of interest.

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