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Health risk assessment of metal fumes in an Iranian Mineral Salt company

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ABSTRACT:

Introduction: Salt is a crucial mineral for human health, however, workers of salt factories may be exposed to hazardous pollutants such as heavy metals. Heavy metal fumes are considered toxic for human health. This study aimed to investigate concentration and assess health risks posed by toxic fumes in a salt factory.
Materials and methods: Three units in the factory including salt laboratory, maintenance and metalworks were sampled for Arsenic (As), chromium (Cr), cadmium (Cd), cobalt (Co) and lead (Pb) according to the National Institute for Occupational Safety and Health, NIOSH7300 method, and analyzed using Inductively Coupled Plasma-Atomic Emission Spectrometers (ICP-AES).
Results: All hazardous levels of fumes were below the permissible limit. The highest concentration of toxic fumes (Cr) was found in the maintenance unit. With 0.0758 mg/m^3, the highest total concentrations of heavy metals (tHM) was found in the maintenance unit (tHM for Salt laboratory=0.0281 mg/m^3 and metalworks=0.0103 mg/m^3). In salt laboratory, the metal fumes concentrations were ordered as Pb>As>Cd>Cr>Co; in maintenance unit: Cr>Pb>As>Co>Cd; in metalworks: Cr>As>Pb>Co>Cd. The total hazard quotient (tHQ) and Life Time Cancer Risk (LCR) in salt laboratory unit were 5.11 and 4.93E-01, respectively; in maintenance the tHQ=9.35E+01 and Life Time Cancer (LCR) =5.90E-01; in metalworks tHQ=6.57 and LCR=4.95E-02.
Conclusion: The pollutant levels were below the acceptable limit. Yet, the non-carcinogenic and carcinogenic risks that they pose are not negligible. Therefore, enhancing the efficiency of the ventilation system and additional monitoring on wearing protective equipment as preventive strategies are proposed.

Introduction

Salt is a mineral consist of NaCl and is the most used food seasoning and food preservative in human history and sodium found in salt is a key factor in many reactions of the body from balancing volume of plasma and balancing acid and base levels, transmitting nerve impulses and cellular functionality of the body1]]. In general, salts are produced in two ways: Seawater evaporation or mining salty rocks. Seawater salts are mainly consist of Na, K, Mg, Ca, Cl, SO_4 and H_2O, while the composition of salt extracted from rocks varies depending on geological features of the mining location which can change the amounts

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and type of trace elements in composition of the extracted salt [2, 3]both based on laser ablation sampling, can be employed simultaneously to obtain different chemical fingerprints from a sample. We demonstrated that this analysis approach can provide complementary information for improved classification of edible salts. LIBS could detect several of the minor metallic elements along with Na and Cl, while LA-ICP-MS spectra were used to measure non-metallic and trace heavy metal elements. Principal component analysis using LIBS and LA-ICP-MS spectra showed that their major spectral variations classified the sample salts in different ways. Three classification models were developed by using partial least squares-discriminant analysis based on the LIBS, LA-ICP-MS, and their fused data. From the cross-validation performances and confusion matrices of these models, the minor metallic elements (Mg, Ca, and K. Salt may contain heavy metals such as copper, nickel, cobalt, manganese, lead, cadmium, zinc, iron and aluminum that can be harmful upon exposure [4, 5].

It is reported that salt factory workers may experience negative health effects through dermal and inhalation routes and exposure to heavy metal fumes via inhalation has been considered as the prevalent route. Heavy metals have been frequently reported as possible carcinogens by International Agency for Research on Cancer (IARC) and are one of the extensively researched topics, especially in industrial settings [6]. Therefore, the health status of workers in salt industry might be compromised by exposure to various hazardous substances [7].

According to literature, inhalation of metal fumes can lead to elevated risk levels of cancer and due to adverse effects of some metal fumes, the U.S. Occupational Health and Safety Administration (OSHA) has set permissible limits to, hexavalent chromium Cr (VI) (5 $\mu g/m^3$) as a case in point, concentration of heavy metal fumes in workspace air [8]. A researcher stated that occupational exposure to heavy metals might lead to kidney failure [9]. Occupational Health and Safety (OHS) measures are efforts to improve the of protection level of workers and workspaces to reduces hazardous events.

With regard to occupational hazards surrounding the workspace of salt factory workers and lack of previous investigation on air pollutants in the salt industry, especially in Iran, this study was conducted to determine metal fumes including As, Cr, Co, Cd, Cd and Pb in the workspace of an Iranian salt factory and assess the health risks.

Materials and methods

Site description

This cross-sectional study was conducted in 2019 in an Iran Salt Mineral company that produces sodium sulphate and recrystallized refined salt. 219 workers are currently work in the factory. The production capacity of sodium sulfate powder and salt capacity is 190,000 tons and 65,000 tons/year. As a result of various production processes in different units of this company, metal fumes can release into the workplace air. Five hazardous pollutants including Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr) and Lead (Pb), were investigated in salt laboratory, maintenance and metalworks units.

Air sampling method, sample preparation and analysis

Personal monitoring in the breathing zone of the workers was conducted during shiftwork in the mentioned units according to NIOSH 7300 method for measuring fumes As, Cd, Co, Cr, and Pb [10]. The air of breathing zone in exposed workers was collected on filter (0.8 µm, cellulose ester membrane in cassette filter holders) using calibrated personal sampling pump (with flow rate of 1.5 L/min). The samples were immediately transferred to the laboratory for sample preparation, and instruments calibration and quality control was performed. Measurement of each analyte was done by inductively coupled argon, plasma atomic emission spectroscopy (ICP-AES) technique after analyzing of standard samples and setting spectrometer to conditions specified by manufacturer. Finally, concentration calculation was determined using Eq. 1

$$C = \frac{Cs\,Vs - Cb\,Vb}{V}, \frac{mg}{m^3} \quad (1)$$

Where, C (mg/m^3) is the concentration of each element in the air volume sampled, V (L) is the volume of the sampled air, Cs is solution concentrations of sample (µg/mL), Cb is the average media blank (µg/mL), Vs is the solution volume of the sample (mL) and Vb is media blank (mL).

Occupational exposure limit (OEL)

In general, the occupational exposure limit (OEL) represents the maximum airborne concentration of a toxic substance to which a worker can be exposed over a period of time without suffering any harmful consequences. The result of pollutants measurement were compared to their threshold limit values. These values apply for 8-h workday and 40-h workweek. When working shifts longer than 8 h, the exposure time is increased and the recovery period between exposures is decreased. In these situations, the threshold exposure limit should be so adjusted that in the end the peak body burden does not exceed the one that would occur during a normal eight-hour shift. In this study we used the Brief and Scala model that recommended by American Conference of Governmental Industrial Hygienists (ACGIH) as a simpler model which reduces the TLV by a factor that takes into account the hours worked daily and the periods of rest between them.

Health risk assessment

Health risk assessment focuses on chronic exposure to pollutants that may cause cancer or other toxic effects. The main exposure route was inhalation of contaminated indoor air. Therefore, respiration health risk of pollutants exposure was calculated via United States Environmental Protection Agency (USEPA) method as follows (Eq. 2): [11]

$$I=(C \times ET \times EF \times ED)/AT \quad (2)$$

Where, I is the average daily inhalation intake over the exposure period (mg/m^3), C is the concentration of the related compound in the personal air monitoring sample (mg/m^3), ET is the exposure time (h/day), EF is the exposure frequency (days/year), ED is the exposure duration (years), and AT is an average lifetime (days). Next, n non-carcinogenic health of the toxic fumes was determined by calculating the hazard quotient (HQ) (Eq. 3):

$$HQ=I/RfD \quad (3)$$

Where RfD is inhalation reference dose of the pollutant (mg/m^3). The interpretation for THQ value is as follows: (exposed population are at risk of a non-carcinogenic adverse health effect) 1>HQ>1 (exposed population are not likely at risk of a non-carcinogenic adverse health effect) [4]. Additionally, an HQ>10 suggests high chronic risk [3]. Risk characterization requires combining the estimated exposure concentrations with toxicity data to provide a quantitative estimate of the potential health impacts. The lifetime cancer risk (LCR) was estimated using the following equation [12]:

$$LCR = CDI \times CSF \quad (4)$$

Where CSF is cancer slope factor in mg/m^3, CDI (mg-m^3/d) is chronic daily intake was calculated using following equation:

$$CDI = (C \times IR \times ED \times EF) / (AT \times BW) \quad (5)$$

Where IR is inhalation rate (m^3/working hour.) and BW is body weight (kg). All parameter for pollutants and their toxicity factors were summarized in Table 1 and Table 2.

Results and discussion

Metal fumes

All the levels of hazardous fumes were below the permissible limit [10] in all sampled units. The highest concentration of toxic fumes (Cr) was found in the maintenance unit. Collectively, with 0.0758 mg/m^3 the total concentrations of heavy metals (tHM) was highest in the maintenance unit (tHM Salt laboratory=0.0281 mg/m^3 and metalworks=0.0103 mg/m^3). It was also found that Cr had the highest total concentration in the studied units compared to other heavy metals. In salt laboratory, the metal fumes concentrations were ordered as Pb>As>Cd>Cr>Co; in maintenance unit as Cr>Pb>As>Co>Cd; in metal works

Table 1. Exposure parameters used for the health risk assessment

Parameter	Unit	Value	Source
Body weight (BW)	Kg	70±13	[13, 14]
Exposure time (ET)	h/day	12	
Exposure frequency (EF)	Days/year	300±10	
Exposure duration (ED)	Years	30	
Inhalation Rate (IR)	m^3 working/h	6.64 ± 0.6	
Average time (AT)	Days		
For carcinogens		365 × 70	
For non-carcinogens		365 × ED	

Table 2. Reference doses (RfD) in (mg/kg-day) and inhalation Cancer Slope Factors (CSF) for the different heavy metals

Pollutant	RfD (mg/m^3)	CSF (mg/m^3)	Source
Cd	5.7 E-05	6.30E+00	[13]
Cr	2.86E-05	4.20E+01	[15]
Co	5.71E-06	9.80E+00	[15]
Pb	3.52 E03	4.20E´02	[13]
As	3.00E´04	1.50E+01	[13]

as: Cr>As>Pb>Co>Cd. Levels of metal fumes are shown in Table 3.

Health risk assessment

In salt laboratory unit, the values of HQ for Cd, with the highest HQ value (2.78), and Co (1.30) were greater than 1 and total hazard quotient (tHQ) was 5.11 which indicates that workers of the laboratory unit are at the risk of resultant adverse health effects. Also, the total LCR value of metal fumes in salt laboratory were in the high-risk zone (i. e. greater than E-04) with Pb having the highest value. In salt laboratory, the daily exposure to heavy metals (CDI) was as follow: Pb>As>Cd>Cr>Co. The hazard quotient of the studied toxic metals was Co>Cd>Cr>Pb>As. Also, the cancer risk posed by the heavy metals was as follow: Pb>Cr>As>Cd>Co. Table 4 shows the results of health risk estimations for salt laboratory unit.

In the maintenance unit, the HQ values of Co (5.55E+01) and Cr (3.75E+01) were greater than 1 and tHQ was 935 thus indicating high level of adverse effect may occur as a result of exposure to the studied fumes in this unit. The LCR assessments of all pollutants, except for Cd, yielded to values greater than E-04 (with total LCR=0.59) demonstrating a high potential for cancer risk in lifetime for workers in the maintenance unit. In the maintenance unit, the CDI was ordered as Cr> Pb>Co>As>Cd; HQ was ordered as Co>Cr>Pb>Cd>As; LCR was ordered as Pb>Cr>As>Co>Cd. Table 5 provides the findings in detail.

The HQ values of Cd, Co and Cr were greater than 1 and tHQ=6.75, indicating high probability of adverse health effect following the exposure in the metal-works unit. Also, the total LCR values of all pollutants, save Cd, were greater than E-04 with total LCR=0.0495) which shows a potential risk of cancer during the lifetime for workers of metalworks unit. the CDI was ordered as Cr>As> Pb>Co>Cd; HQ was ordered

Table 3. concentration of metal hazardous metal fumes in the sampled units

Fumes	Permissible limit (mg/m^3) [10]	Mean ± SD (mg/m^3)		
		Salt Lab	Maintenance	Metal works
Cd	0.005	0.0014 ± 0.0018	0.0002 ± 0.0001	0.0002 ± 0.0001
Co	0.01	0.0003 ± 0.0001	0.006 ± 0.0028	0.0003 ± 0.0001
Cr	0.25	0.0008 ± 0.0004	0.0426 ± 0.035	0.0041 ± 0.0032
Pb	0.025	0.022 ± 0.0042	0.022 ± 0.0042	0.0017 ± 0.0002
As	0.005	0.0036 ± 0.0019	0.005 ± 0.0001	0.004 ± 0.0014

Table 4. Results of health risk assessment of metal fumes for salt laboratory unit

Fumes	CDI (mg-m^3/d)	HQ	LCR
As	1.90E-04	6.34E-08	2.85E-03
Cd	7.40E-05	1.30E+00	4.66E-04
Co	1.59E-05	2.78E+00	1.55E-04
Cr	4.23E-05	7.05E-01	1.78E-03
Pb	1.16E-03	3.30E-01	4.88E-01
total	1.48E-03	5.11E+00	4.93E-01

as Cr>Co>Cd>Pb>As; LCR was ordered as Pb>Cr>As>Co>Cd. Table 6 shows the analysis results in the metal-works unit.

By comparing the results of assessment on the three units, it can be found that HQ values in the maintenance unit, saving Cd in the salt laboratory, were higher than the other units. Also, the cumulative HQ of the maintenance unit (tHQ=93.52) was greater than the other two This means that workers in the maintenance unit are more prone to adverse health effects after exposure to fumes. Additionally, the cumulative values of LCR in the maintenance unit was also greater than salt laboratory and metalworks units.

Analysis of the heavy metal fumes in three units of the salt factory showed that fume levels were below permissible limits recommended by NIOSH. The measurements of the current study were comparable with measurements in other industries. The levels of Pb and Cd in the current study were lower than levels of Pb (0.045 mg/m^3) and Cd (0.0015 mg/m^3) in smelting unit of an alloy steel industry determined by some researchers, however, Cr levels in maintenance and metalworks of the current study was higher than theirs (2017) [14]. To assess the health risk of workers in the smelting unit of an alloy steel factory to long term exposure to heavy metals, a simple, fast and less expensive method was used for evaluation with the combination of suspended dust analysis and PM10 measuring. The results showed that the highest and lowest concentration value was respectively recorded for Pb and Cd. Although, the average concentrations of heavy metals were lower than the recommended levels of occupational exposure, their occupational carcinogenic risks were different. The carcinogenic risk of Pb, Ni and Cd was low and acceptable, but was higher and unacceptable for Cr; therefore, using protective respiratory equipment and more efficient local ventilation was recommended.

Additionally, the levels of toxic fumes in our study were greatly lower than the determined

Table 5. Results of health risk assessment of metal fumes for maintenance unit

Fumes	CDI (mg-m^3/d)	HQ	LCR
As	2.64E-04	8.81E-08	3.96E-03
Cd	8.81E-06	1.54E-01	5.55E-05
Co	3.17E-04	5.55E+01	3.11E-03
Cr	2.25E-03	3.75E+01	9.45E-02
Pb	1.16E-03	3.30E-01	4.88E-01
total	4.00E-03	9.35E+01	5.90E-01

Table 6. Results of health risk assessment of metal fumes for metal works unit

Fumes	CDI (mg-m^3/d)	HQ	LCR
As	2.11E-04	7.05E-08	3.17E-03
Cd	8.45E-06	1.48E-01	5.33E-05
Co	1.59E-05	2.78E+00	1.55E-04
Cr	2.17E-04	3.62E+00	9.13E-03
Pb	8.81E-05	2.50E-02	3.70E-02
total	5.41E-04	6.57E+00	4.95E-02

levels in the studies conducted in the welding and waste recycling industry [6, 16]. Other researchers found concentrations from 0.17 to 237.78 mg/m^3 for toxic metals of Cr, Co, As and Pb whereas in our study, toxic metals were very low compared to the standard levels [6]. This may also indicate that the studied units benefit from an appropriate ventilation system.

Cr was found to be the most ubiquitous toxic metal in all units combined. This finding was in line with findings of other studies in which high concentrations was reported for Cr in welding and steel industries and waste recycling [6, 14, 16-18]. The toxic gaseous generated from welding process contained heavy metals that induce various cancers and diseases. Exposure to this toxic fume is associated with the occurrence of lung cancer and worker that exposed to this situation is considered as a high-risk group. This study aims to investigate the amounts of heavy metals concentration in the breathing zone and toenail samples of 36 individuals from automotive related industries in Malaysia that were classified as an exposed group (welders. Chromium has been frequently characterized as a carcinogen in various studies conducted in occupational settings [19]most notably chromate production workers exposed to high concentrations of Cr(VI. Therefore, special attention should be given to maintain Cr levels low in the workspace.

Comparison of the units in terms of total HQ values (Table 4 to 6) puts them in the following order: mai ntenance>metalworks>laboratory; in terms of LCR values as: maintenance>laboratory>metalworks. Estimation of total HQ values showed that workers of the maintenance unit are at high risk of adverse health effects caused by heavy metal fumes than other units. However, in terms of lifetime cancer risk, workers of the maintenance unit are at higher risk. Studies indicate that heavy metals such as Cr, Cd and Pb were recognized as elements with the highest toxicity, especially via inhalation [16, 20]. Therefore, finding their emission sources in the units are necessary for subsequent actions.

Conclusion

In this study, both non-carcinogenic and carcinogenic risks were assessed. It was found that toxic metal fumes pose great risk to workers operating at the investigated units although the all the levels of pollutants below their respective acceptable limits. This shows that efforts are needed to further reduce pollutant levels in the workspace and to determine pollution sources. As a recommendation, enhancing the efficiency of the ventilation system and additional monitoring on wearing protective equipment is proposed.

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Competing interests

The authors declare that there are no conflicts of interest.

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Ethical considerations

The authors declare that ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed.

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