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Determination of Suspended Particulate Matter Concentration and Assessment of Inhalation Risk in the Ambient Air of Ahvaz City, Iran

Saeed Karimi* and Nima Rezayani[1]
Faculty of Environment, University of Tehran, Iran
[1]Department of Environmental Engineering, University of Tehran, Iran
✉ karimis@ut.ac.ir

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Abstract: Air pollution due to the presence of particulate matter (PM) in the ambient air is assumed to be the leading cause of many diseases in different metropolitan and industrial regions throughout the world. Based on WHO's report on the classification of different cities of the world in terms of the amount of fine particles in the air, Ahvaz is one of the most polluted cities among a sample of more than 1100 cities around the world. Heavy metals attached to the inhalable particulate matters having a size of less than 10 microns can penetrate more deeply into the lungs, form sediments, and cause many health problems. In the present study, concentrations of arsenic, nickel, lead, aluminium and magnesium, with two particle sizes of $PM_{2.5}$-PM_{10} and PM_{10} and larger, in the ambient air of different districts of Ahvaz city have been measured. Their related carcinogenic and non-carcinogenic risks have been assessed to quantify the amount of pollution. The results showed that the measured concentrations of arsenic, nickel, lead, aluminium and magnesium in the ambient air of Ahvaz were 0.542 µg/m, 0.59 µg/m, 1.65 µg/m, 33.94 µg/m and 0.833 µg/m, respectively. Non-carcinogenic risk assessments for arsenic, nickel, aluminium and magnesium due to their inhalation from the ambient air of Ahvaz were 3.39×10^{-2}, 1.13×10^{-2}, 1.73×10^{-2} and 1.59×10^{-2}, respectively, which indicates that the health of people in Ahvaz is not adversely affected by the non-carcinogenic factors.

Key words: Air pollution, non-carcinogenic risk assessment, carcinogenic risk assessment, Ahvaz city.

Introduction

Air pollution due to the existence of suspended particulate matter in the ambient air is the main cause of many diseases in industrial and metropolitan cities. Epidemiological studies conducted in the last decade demonstrated a close relationship between the particulate matter of $PM_{2.5}$ and PM_{10} (particulate matter with particle sizes of 2.5 and 10 microns respectively) and incidence of different respiratory, cardiovascular and cancer problems and mortalities (Fernández-Camacho, 2011). The urban environment is exposed to a great volume of pollutants caused by humans due to many different stable and mobile sources (Melaku et al., 2008). WHO has reported that around 800,000 individuals throughout the world face an early death due to lung cancer, cardiovascular diseases and respiratory problems caused by the increased pollution in the ambient air (Ashrafi et al., 2011). Particulate matter (PM) plays an important role in our daily life and in the control of various air processes (Preining, 1996).

Since particulate matter has the potential to affect public health, these particles have recently been the focus of scholarly attention. Besides, these particles

*Corresponding Author

need to be appropriately controlled. These particles can be produced by different sources and can also have highly variable sizes. Finer particles (especially $PM_{2.5}$) have a higher potential to penetrate the lungs and reach the alveoli region. Therefore, they are likely to produce further effects such as untimely death, increased respiratory symptoms and diseases, decreased efficiency of the lungs and variations in the pulmonary tissues. The various health effects of the particulate matter depend on their chemical combination and physical properties (Sharma and Maloo, 2005; Koch, 2000; Schwartz et al., 1996; Borja-Aburto et al., 1998).

According to the literature, a logical relation exists between the inhalation of $PM_{2.5}$ and PM_{10} and an increase in human mortality and a decrease in pulmonary performance (Costa and Dreher, 1997). Besides, exposure of $PM_{2.5}$ and PM_{10} via inhalation from PM scattered by vehicles is regarded as a health problem and plays a role in increased respiratory risks and diseases (Lough et al., 2005). Heavy metals attached to the inhalable PM_{10} can penetrate deeply into the lungs, remain there, and cause many health problems (Chaudhari et al., 2012).

Long-term exposure to toxic metals such as nickel, arsenic, lead, copper, zinc, cadmium and mercury—even at low concentrations—can adversely affect human health (Swietlicki et al., 1996). Increasing development in human societies and economic and industrial growth have caused the most important environmental problem—air pollution (Rezayani, 2012). Due to the existence of different industrial centres in Ahvaz, this city has faced this serious problem with air pollution. Besides, according to a World Health Organization (WHO) report on the classification of 1100 cities in the world in terms of the amount of PM in the ambient air, Ahvaz city is recognized as one of the most polluted cities worldwide (WHO, 2012).

Due to its dense population and adverse climatic conditions, Ahvaz is among the most polluted cities in Iran. This study aims to determine the concentration of arsenic PM and to assess the non-carcinogenic and carcinogenic risks of the ambient air of Ahvaz. Arsenic is an element which is naturally found in the Earth's crust and is classified as a semimetal due to having both metallic and non-metallic properties. Arsenic is found in the rock, soil, water, air, and biosphere of the Earth. Furthermore, arsenic has different types which can broadly be categorized into mineral and organic forms (ATSDR, 2007; Brown and Zeise, 2004; EFSA, 2009; Francesconi and Kuehnelt, 2004; Aitio and Becking, 2001).

Occupational encounters with arsenic mainly occur among copper smelter factory workers (Järup et al., 1989). It is also encountered in power plants where the combustion of coal rich in arsenic (Jacobson et al., 1984) results in the production of arsenic, in the application of arsenic-containing pesticides (Ishinishi et al., 1986) and in the extraction of the metallic ores (Taylor et al., 1989). Previous studies have shown that exposure to nonorganic arsenic through breathing can lead to lung cancer in humans (Atsdr, 2007; Jacobson et al., 1984). There is sufficient evidence that nonorganic compounds are carcinogenic, causing human skin and lung cancers (International Agency for Research on Cancer, 1980; IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, and World Health Organization, 1987).

Many studies have demonstrated that exposure to the mineral compounds can increase the risk of lung cancer among smelter factory workers, metal ore miners, and those involved in the production and uses of arsenic-based pesticides (Järup et al., 1989; Lee-Feldstein, 1986; Bencko et al., 1979; Lee-Feldstein, 1983). Some demographical studies have also shown an increase in the average mortality due to lung cancer for human populations living in the vicinity of copper smelter factories and other arsenic-emitting sources (Blot and Fraumeni, 1975; Pershagen, 1985; Matanoski et al., 1981).

The main effects of exposure to arsenic include headaches, vomiting, stomach ache, hemolytic anaemia, hemoglobinuria and jaundice, which may result in renal failure (EPA, 1994). The International Agency for Research on Cancer (IARC) has classified the mineral arsenic in Group I of the carcinogenic substances for humans (IARC, 2004). On the other hand, the United States Agency for Environmental Protection has classified nonorganic arsenic in Group A of the carcinogens in humans (EPA, 1998).

Foodstuffs may naturally contain nickel and are generally the main source of human exposure to nickel. Average nickel consumption by adults has been estimated to be between 100 and 300 micrograms per day (ATSDR,1997; U.S. Environmental Protection Agency. Health Assessment Document for Nickel, 1986). Nickel is one of the metals used in the plating industry. Long and continuous exposure to nickel can result in dermatitis and respiratory disorders (Razos and Christides, 2010). Breathing in nickel increases the chances of laryngeal cancer and lung cancer.

People who are exposed to nickel gas may experience lethargy and dizziness. Other effects include respiratory problems, reduction in reproductive capacity, asthma, chronic bronchitis, allergies such as itching, and heart failure (CalEPA, 1997; ATSDR, 1997). According to the National Toxicology Program of America (NTP), nickel and its combinations are among the carcinogenic substances. Moreover, according to the International Agency for Research on Cancer, nickel compounds are categorized in Group I of carcinogens (Sheihki, 2010).

Lead is suspended in the air in the form of fine particles with dust and smoke and is absorbed by the human digestive system, respiratory system, and skin. Lead is one of the four metals that have the most effect on the human health. Previous works have reported that the negative effects of lead on human health includes hemoglobin biosynthesis disorder, anaemia, hypertension, renal damage, increased risk of miscarriage and premature death of the child, neural system disorder, male infertility and cancers (ATSDR, 2007a; ATSDR, 2007b; EPA, 2006).

High concentrations of aluminium have serious effects on human health. If an individual is exposed to high concentration of aluminium for a long time, the following symptoms may occur: degeneration of the central nervous system, dementia, decline in memory, state of inaction and lethargy, intense shivering, and convulsions. Furthermore, breathing in aluminium or aluminium oxide results in pulmonary sclerosis and damage to the lungs (Sheihki, 2010).

Chronic effects of the inhalation of magnesium by humans are coughing, bronchitis, shortness of breath during exercise, and increased sensitivity to infectious diseases of lungs (ATSDR, 1997; EPA, 1999).

The Region under Study

Ahvaz city, the capital of the Khuzestan province, south-west Iran, is situated between 48 degrees 40 minutes and 49 degrees 29 minutes east of the Greenwich meridian, and 30 degrees 45 minutes to 32 degrees latitude north of the equator. According to the census of the year 2011, the population of Ahvaz is 1,186,880. The city is 18 metres above sea level and covers an area of 7,848 kilometres. Due to the inclusion of different industrial estates and manufacturing companies such as the Khuzestan Steel Company, the Iran National Steel Industrial Group, carbon black companies, asphalt and brake factories, gas and oil production sites, and power plants, Ahvaz is presumed to be one of the main industrial centres in Iran (Sheihki, 2010; Sakipur, 2010).

Methodology

To conduct this work, the concentration of arsenic PM in the air of Ahvaz was first measured. Then, based on the existing relations, the non-carcinogenic and carcinogenic risks due to the inhalation of arsenic and nickel were measured. Moreover, GIS software, version 10.2.2, was utilized to differentiate the suspended particle concentrations and assess their related non-carcinogenic and carcinogenic risks.

Positioning of Sampling Stations

With regard to the wind rose of Ahvaz city and the dominant wind direction from the west and north-west to east and south-east and by considering the congested and populated sites in proximity to the industrial sites in the city, five sampling stations have been determined, as shown in Table 1. Figures 1, 2 and 3 represent the wind rose of the region, location of different stations and population density, respectively.

Table 1: Stations in the study

Row	*Station*	*District*	*Population*
1	Baharestan	4	178162
2	Naderi	1	113533
3	Issar Street	8	117904
4	Kian-Pars	2	80329
5	Daneshgah Square	4	178162
Total Population			**668090**

Sampling Time and Iteration

Sampling was performed in the six months of June, July, August, September, October and November in two particle size ranges of $PM_{2.5}$ to PM_{10} and PM_{10} and larger. Concerning each station, the sampling was carried out six times a month.

Sampling of PM in the Ambient Air of Ahvaz and Calculation of Their Concentrations

In order to measure the concentration of arsenic and nickel in the ambient air of Ahvaz, a high volume sampler device having two holders and several filters made of fibreglass was used. Based on the ASTM D4096 standard, sampling was undertaken for 24 hours with a specific volumetric flow rate while the device was placed at a height of three metres from the ground (ASTM, 2001). After sampling, in order to calculate the concentrations of the metals in the air, first the acidic digestion of the samples must take place.

To this end, the Iranian Environmental Protection Organization's guidelines, extracted from such

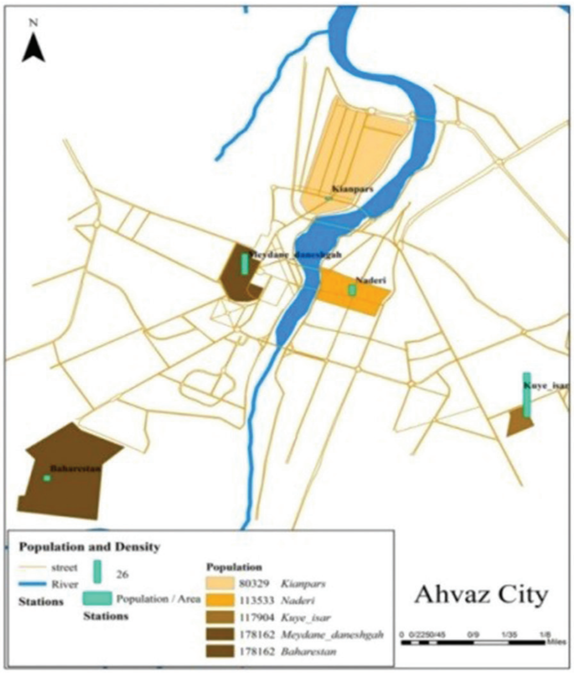

Figure 1: Population of the stations under study and diagram of the covered population density.

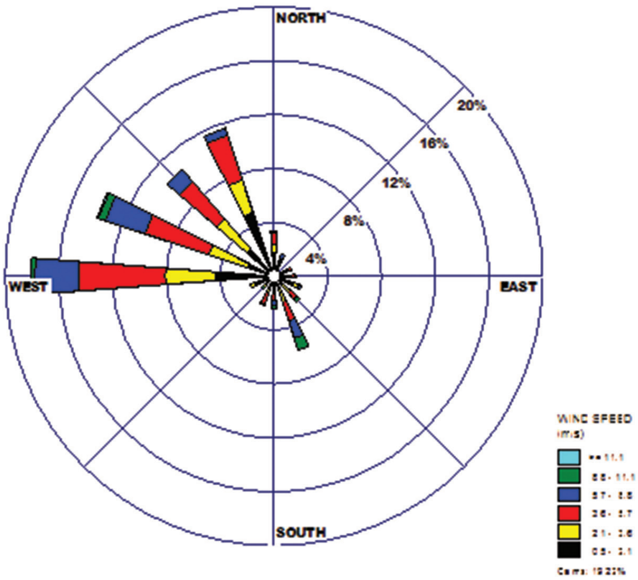

Figure 2: Wind rose of Ahvaz.

international standards as the Manual of Oceanographic Observation and Pollutant Analyses Method (Moopam), National Institute for Occupational Safety and Health (NIOSH), and Environmental Protection Agency (EPA), were employed. Then, the resulting solution from the acidic digestion was analysed by atomic adsorption spectroscopy to obtain the concentrations of arsenic and nickel metals in the solution. Using the following relation, the metal concentration in the air samples was

Figure 3: Location of stations on the map of Ahvaz.

calculated (Environmental Protection Organization, 2009):

$$C = \frac{Gs \times V}{t \times D} \quad (1)$$

where C shows metal concentration in air sample (µg/m^3); Gs is metal concentration in metallic solution obtained from digestion (µg/L); V shows the dilution volume (50 mL); t is the time duration of filter exposure to the air (min); and finally D shows the volumetric flow rate (L/min).

Averaging the Daily Exposure of Citizens to Each Element through Inhalation

In order to average the citizens' daily intake of each particulate matter through inhalation, relations (2) and (3) are used for carcinogenic and non-carcinogenic states. Besides, the variables used in the process of averaging the daily exposure are given in Table 2.

$$CDI_{nc-inh}\left(\frac{\mu g}{m^3}\right) = \frac{C \times \left(\frac{0.001\ mg}{\mu g}\right) \times EF_r\left(\frac{350\ days}{year}\right) \times ED_r(30\ years) \times ET_{rw}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right)}{AT_r\left(\frac{365\ days}{year}\right) \times ED_r(30\ years)} \quad (2)$$

$$CDI_{ca-inh}\left(\frac{\mu g}{m^3}\right)=\frac{C\times EF_r\left(\frac{350\text{ days}}{\text{year}}\right)\times ED_r\ (30\text{ years})\times ET_{rw}\left(\frac{24\text{ hours}}{\text{day}}\right)\times\left(\frac{1\text{ day}}{24\text{ hours}}\right)}{AT_r\left(\frac{365\text{ days}}{\text{year}}\times LT_r(70\text{ years})\right)} \quad (3)$$

Table 2: Variables used in the process of averaging the daily exposure (RAIS, 2010)

Quantity	*Input variables*
350	EF_r (exposure frequency) d/yr
30	ED_r (exposure duration–resident) years
70	LT (lifetime–resident) years
24	ET_r (exposure time) hours/day

Risk Assessment

Noncancerous Risk Assessment

In the group of noncancerous effects, unless the exposure of a typical person to a considered pollutant reaches a determined threshold, the emergence of the noncancerous health problems will be impossible or highly improbable. The Hazard Index can be obtained through the division of the average value of exposure by the reference concentration of inhalation. If the obtained value is greater than one, this means that the individuals suffering from exposure to this pollutant are susceptible to the noncancerous health problems (Pardakhti, 2010). The reference concentration for determining the noncancerous hazard index of arsenic and nickel can be observed in Table 3.

Table 3: Reference concentration for determination of the noncancerous hazard index

Chronic reference concentration (milligrams per cubic metre)	*Particles under study*
1.50E-05 (CalEPA,1997)	Arsenic
5.00E-05 (CalEPA,1997)	Nickel
5.00E-03 (PPRTV,2006)	Aluminium
5.00E-05 (IRIS, 2009)	Magnesium

Hazard quotient (HQ) due to inhalation can be obtained from relation (4).

$$HQ = CDI/RfC \quad (4)$$

Cancerous Hazard Assessment

Concerning the group of cancerous effects, even the smallest amount of human exposure to the aforesaid pollutants may result in the increased risk of incidence of cancer in humans. With regard to the air pollutants, the reference unit risk is expressed in micrograms per cubic metre. Values of the inhalation unit risk for the assessed pollutants are given in Table 4.

Table 4: Reference concentrations for cancer risk assessment (IRIS, 2009)

Inhalation unit risk (micrograms per cubic metre)	*Particles under study*
4.30E-03	Arsenic
2.40E-04	Nickel
1.20E-05	Lead

Cancerous risk assessment is given by relation (5).

$$\text{Cancer risk} = CDI \times UR \quad (5)$$

Results

Concentrations of arsenic, nickel, lead, aluminium and magnesium in five sampling stations are represented in Tables 5 and 6.

Table 5: Average particulate matter in five sampling stations for particle sizes between $PM_{2.5}$ and PM_0 $\left(\frac{\mu g}{m^3}\right)$

Sampling stations →	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*
Arsenic	0.06	0.05	0.03	0.040	0.025
Nickel	0.09	0.02	0.02	0.06	0.013
Lead	0.06	0.24	0.05	0.09	0.17
Aluminium	2.47	3.41	2.67	2.14	2.61
Magnesium	0.14	0.04	0.06	0.02	0.04

Table 6: Average of particulate matter in five sampling stations for particle sizes of PM_{10} and larger $\left(\frac{\mu g}{m^3}\right)$

Sampling stations →	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*
Arsenic	0.078	0.079	0.063	0.063	0.041
Nickel	0.14	0.04	0.03	0.15	0.027
Lead	0.11	0. 43	0.11	0.16	0.23
Aluminium	4.08	4.63	4.18	3. 6	4.15
Magnesium	0.17	0.08	0.10	0.04	0.14

Concentrations of arsenic, nickel, lead, aluminium and magnesium in five sampling stations are represented in Figures 4 and 5.

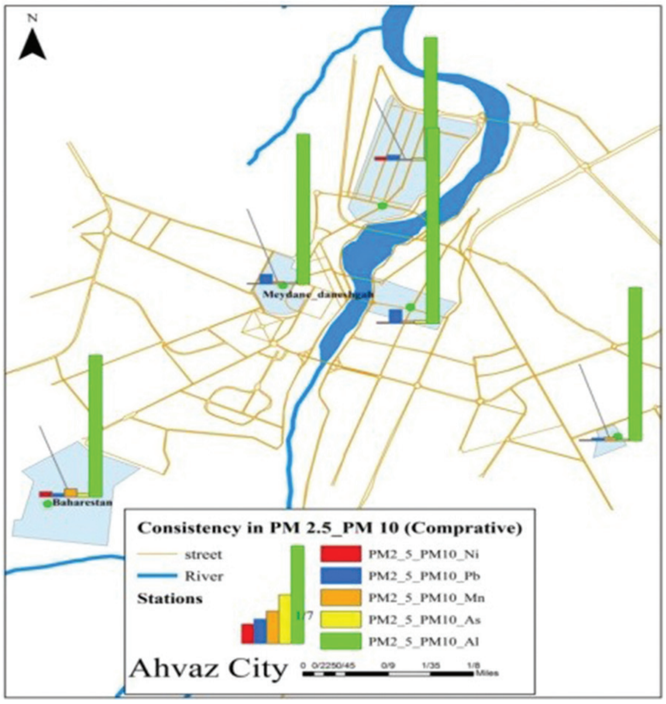

Figure 4: Average of particulate matter in five sampling stations for particles between $PM_{2.5}$ and PM_{10}.

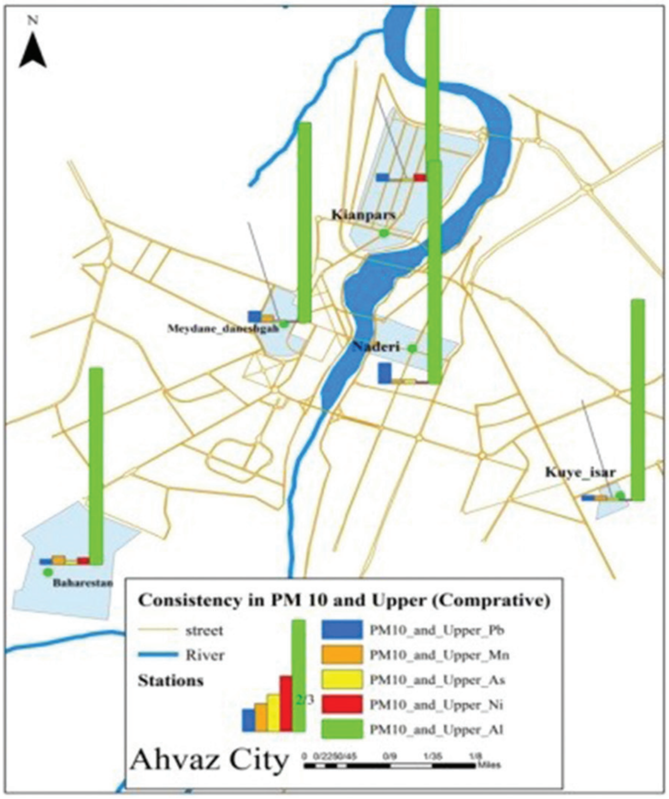

Figure 5: Average of particulate matter in five sampling stations for particle sizes of PM_{10} and larger.

Results of Risk Assessment in the Civil Districts of Ahvaz

Through determination of the amount of risk for the incidence of cancer in the ambient air of Ahvaz, the amount of the daily exposure to the cancerous and noncancerous substances, hazard index, and the cancer risk in different districts of Ahvaz have been calculated, the results of which are shown in Tables 7 to 13.

Table 7: Noncancerous risk index (HI) and hazard quotient (HQ) of arsenic in the ambient air of Ahvaz

Total hazard index due to inhalation	*Inhalation hazard quotient for PM_{10} and over*	*Inhalation hazard quotient for particles sizes between $PM_{2.5}$ and PM_{10}*	*Sampling stations*
8.88×10^{-3}	5.04×10^{-3}	3.84×10^{-3}	No. 1
8.25×10^{-3}	5.05×10^{-3}	3.2×10^{-3}	No. 2
5.95×10^{-3}	4.03×10^{-3}	1.92×10^{-3}	No. 3
6.59×10^{-3}	4.03×10^{-3}	2.56×10^{-3}	No. 4
4.22×10^{-3}	2.62×10^{-3}	1.6×10^{-3}	No. 5

Table 8: Noncancerous risk index (HI) and hazard quotient (HQ) of nickel in the ambient air of Ahvaz

Total hazard index due to inhalation	*Inhalation hazard quotient for PM_{10} and over*	*Inhalation hazard quotient for particles sizes between $PM_{2.5}$ and PM_{10}*	*Sampling stations*
4.4×10^{-3}	2.68×10^{-3}	1.72×10^{-3}	No. 1
1.15×10^{-3}	7.68×10^{-4}	3.84×10^{-4}	No. 2
9.6×10^{-4}	5.76×10^{-4}	3.84×10^{-4}	No. 3
4.03×10^{-3}	2.88×10^{-3}	1.15×10^{-3}	No. 4
7.66×10^{-4}	5.18×10^{-4}	2.48×10^{-4}	No. 5

Table 9: Noncancerous risk index (HI) and hazard quotient (HQ) for aluminium in the ambient air of Ahvaz

Total hazard index due to inhalation	*Inhalation hazard quotient for PM_{10} and larger*	*Inhalation hazard quotient for particle sizes between $PM_{2.5}$ and PM_{10}*	*Sampling stations*
1.25×10^{-3}	7.8×10^{-4}	4.7×10^{-4}	No. 1
1.53×10^{-3}	8.8×10^{-4}	6.5×10^{-4}	No. 2
1.31×10^{-3}	8.01×10^{-3}	5.1×10^{-4}	No. 3
1.10×10^{-3}	6.91×10^{-4}	4.1×10^{-3}	No. 4
1.29×10^{-3}	7.93×10^{-4}	5.01×10^{-4}	No. 5

Table 10: Noncancerous risk index (HI) and hazard quotient (HQ) of magnesium in the ambient air of Ahvaz

Total hazard index due to inhalation	*Inhalation hazard quotient for PM_{10} and over*	*Inhalation hazard quotient for particles sizes between $PM_{2.5}$ and PM_{10}*	*Sampling stations*
5.94×10^{-3}	3.26×10^{-3}	2.68×10^{-3}	No. 1
2.29×10^{-3}	1.53×10^{-3}	7.6×10^{-4}	No. 2
3.07×10^{-3}	1.92×10^{-3}	1.15×10^{-3}	No. 3
1.14×10^{-3}	7.62×10^{-4}	3.8×10^{-4}	No. 4
3.44×10^{-3}	2.68×10^{-3}	0.76×10^{-4}	No. 5

Table 11: Total number of cancers during a lifetime due to the inhalation of arsenic in the air of Ahvaz

Total number of cancers	*Total risk*	*Number of cancers of PM_{10} and over*	*Inhalation risk of PM_{10} and over*	*Number of cancers of $PM_{2.5}$ to PM_{10}*	*Inhalation risk of $PM_{2.5}$ to PM_{10}*	*Sampling station*
43.48	2.44×10^{-4}	24.59	1.38×10^{-4}	18.89	1.06×10^{-4}	No. 1
25.87	2.27×10^{-4}	15.84	1.39×10^{-4}	10.03	8.83×10^{-5}	No. 2
19.37	1.64×10^{-4}	13.12	1.11×10^{-4}	6.25	5.3×10^{-5}	No. 3
14.61	1.81×10^{-4}	8.94	1.11×10^{-4}	5.67	7.06×10^{-5}	No. 4
20.77	1.16×10^{-4}	12.90	7.22×10^{-5}	7.87	4.38×10^{-5}	No. 5

Table 12: Total number of cancers during a lifetime due to the inhalation of nickel in the ambient air of Ahvaz

Total number of cancers	*Total risk*	*Number of cancers of PM_{10} and over*	*Inhalation risk of PM_{10} and over*	*Number of cancers of $PM_{2.5}$ to PM_{10}*	*Inhalation risk of $PM_{2.5}$ to PM_{10}*	*Sampling station*
4.04	2.27×10^{-5}	2.46	1.38×10^{-5}	1.58	8.85×10^{-6}	No. 1
0.66	5.92×10^{-6}	0.44	3.95×10^{-6}	0.22	1.97×10^{-6}	No. 2
0.57	4.93×10^{-6}	0.34	2.96×10^{-6}	0.23	1.97×10^{-6}	No. 3
1.65	2.06×10^{-5}	1.18	1.47×10^{-5}	0.47	5.91×10^{-6}	No. 4
0.69	3.94×10^{-6}	0.47	2.66×10^{-6}	0.22	1.28×10^{-6}	No. 5

Table 13: Total number of cancers during a lifetime due to the inhalation of lead in the air of Ahvaz

Total number of cancers	*Total risk*	*Number of cancers of PM_{10} and over*	*Inhalation risk of PM_{10} and over*	*Number of cancers of $PM_{2.5}$ to PM_{10}*	*Inhalation risk of $PM_{2.5}$ to PM_{10}*	*Sampling station*
0.15	8.37×10^{-7}	0.097	5.42×10^{-7}	0.053	2.95×10^{-7}	No. 1
0.37	3.3×10^{-6}	0.24	2.12×10^{-6}	0.13	1.18×10^{-6}	No. 2
0.08	7.88×10^{-7}	0.06	5.42×10^{-7}	0.02	2.46×10^{-7}	No. 3
0.09	1.23×10^{-6}	0.06	7.89×10^{-7}	0.03	4.43×10^{-7}	No. 4
0.34	1.96×10^{-6}	0.20	1.13×10^{-6}	0.14	8.38×10^{-7}	No. 5

Through determination of the amount of risk for the incidence of cancer in the ambient air of Ahvaz, the amount of the daily exposure to the cancerous and noncancerous substances, hazard index, and the cancer risk in different districts of Ahvaz have been calculated, the results of which are shown in Figures 6 to 14.

Conclusion

In the present study, concentrations of suspended PM in two particle sizes, $PM_{2.5}$ to PM_{10} and PM_{10} and larger, have been measured and the carcinogenic risk of inhalation of arsenic, nickel, lead, aluminium, and magnesium has been assessed. In the non-carcinogenic risk assessment due to the inhalation of PM in the ambient air of Ahvaz, the values of 3.39×10^{-2}, 1.13×10^{-2}, 1.73×10^{-2} and 1.59×10^{-2} have been found for arsenic, nickel, aluminium and magnesium, respectively, which are all less than the value of one. This shows that the presence of the aforesaid metallic particles in the air of Ahvaz exerts no adverse effect on the public health of the citizens of Ahvaz. In the carcinogenic risk assessment due to the inhalation of PM in the air of Ahvaz, the values of 9.32×10^{-4}, 5.81×10^{-5} and 1.96×10^{-6} have been observed for arsenic, nickel and lead, respectively, and the total number of cancers during a lifetime is equal to 132.74. In other words, the rate of incidence of cancer through inhalation of arsenic, nickel and lead among the citizens of Ahvaz (with an average lifetime of 70 years) is 133 individuals.

This value might at first seem insignificant; however, this measurement is only related to the concentrations of the suspended arsenic, nickel and lead particles in the ambient air. The particles which are precipitated in water or exist in soil and in the environment, and are likely to enter the human body through digestion or the skin, have not been taken into account. In this context, assuming that these cancer incidences are caused only by inhaling arsenic, nickel and lead particles, risk control is essential. To this end, it is required to measure the concentrations of the particulate matter in the air, water, soil and food at more points in the city and assess

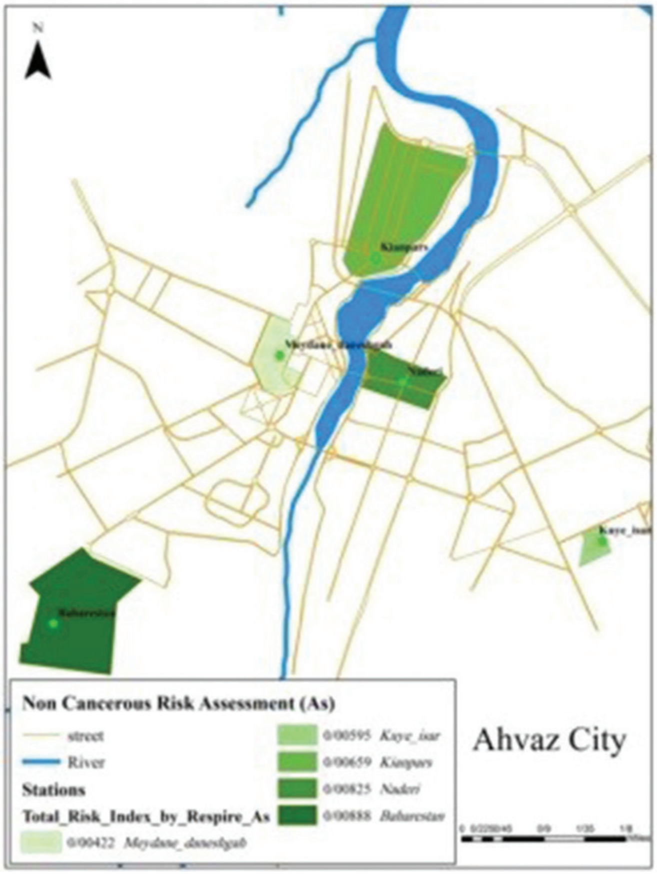

Figure 6: Noncancerous hazard index of arsenic in the ambient air of Ahvaz.

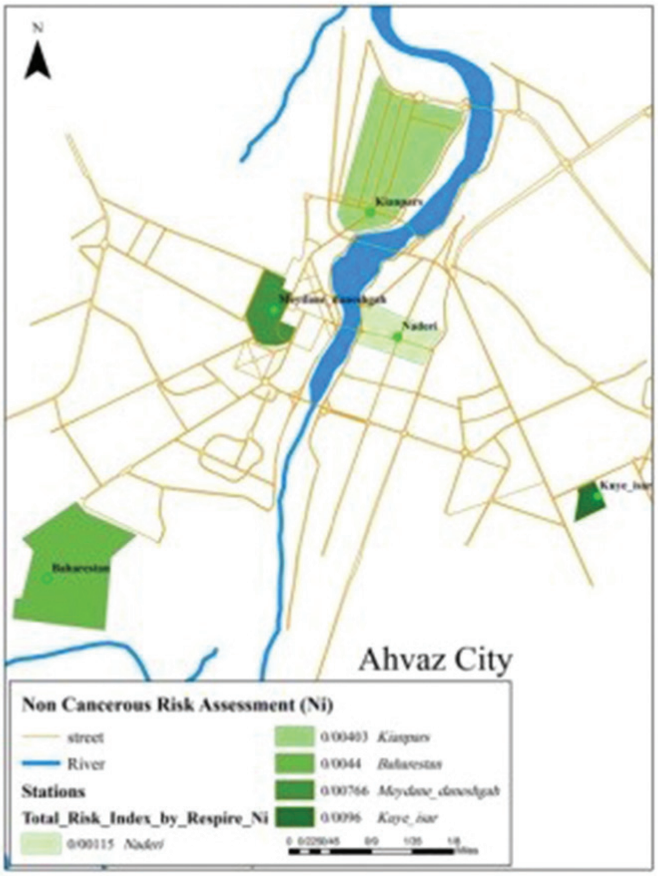

Figure 7: Noncancerous hazard index of nickel in the ambient air of Ahvaz.

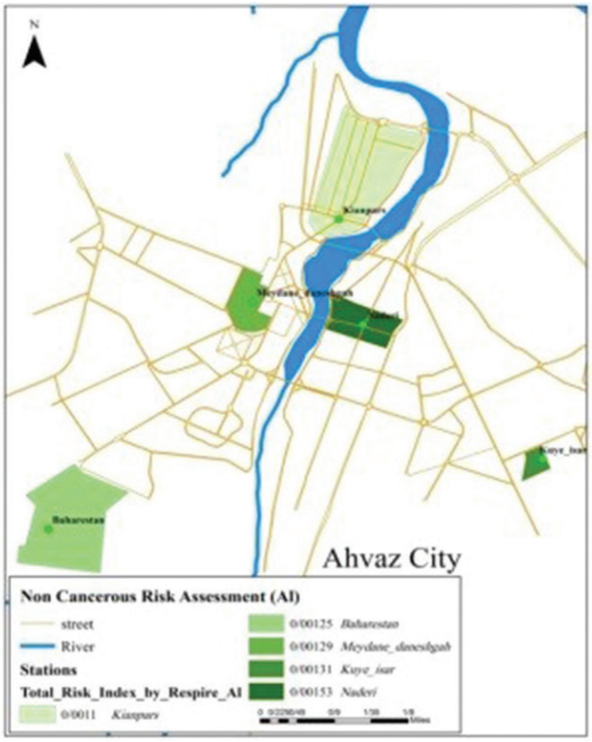

Figure 8: Noncancerous hazard index (HI) of aluminium in the ambient air of Ahvaz.

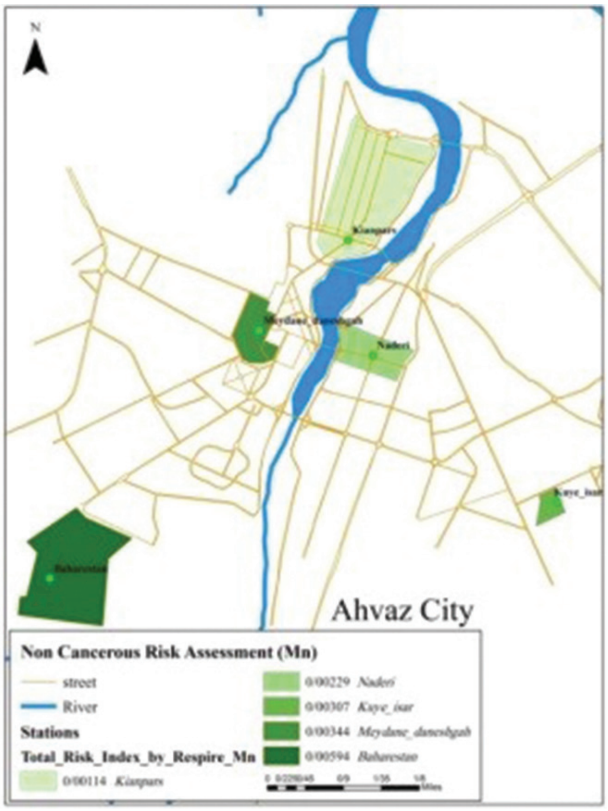

Figure 9: Noncancerous hazard index (HI) of magnesium in the ambient air of Ahvaz.

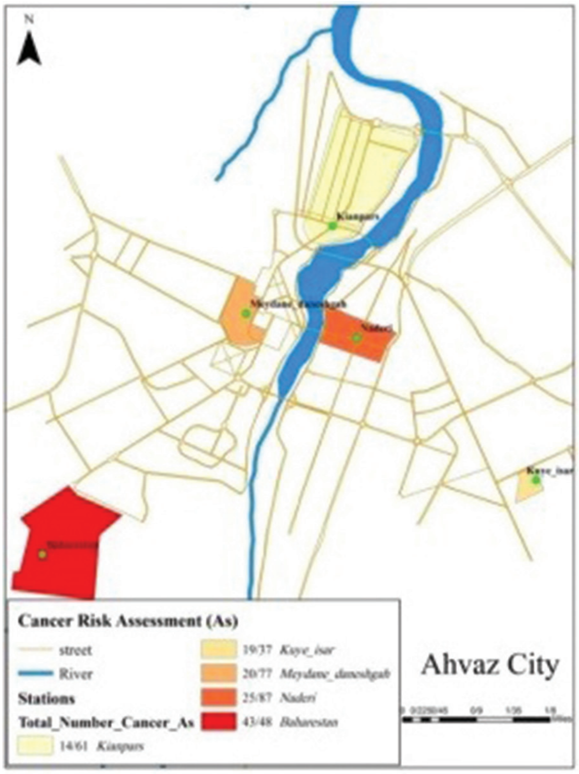

Figure 10: Total number of cancers during a lifetime due to the inhalation of arsenic in the air of Ahvaz.

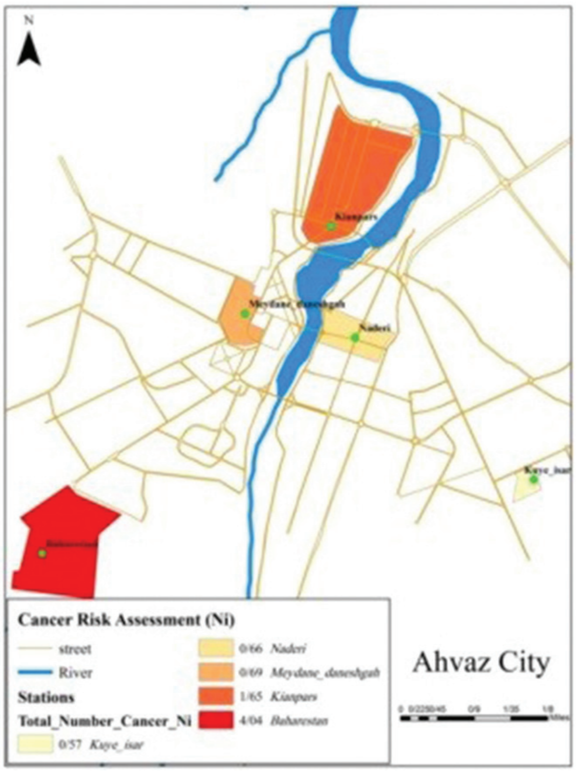

Figure 11: Total number of cancers during a lifetime due to the inhalation of nickel in the air of Ahvaz.

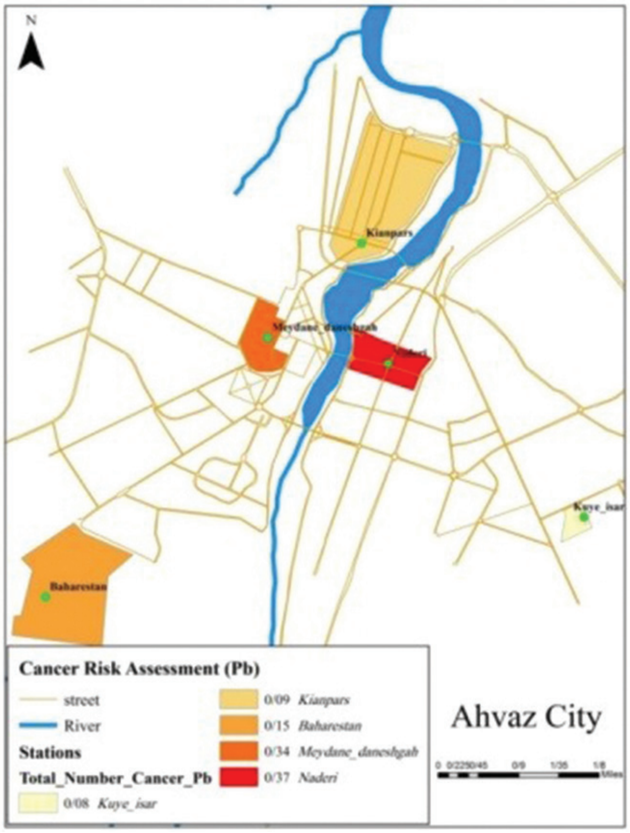

Figure 12: Total number of cancers during a lifetime due to the inhalation of lead in the air of Ahvaz.

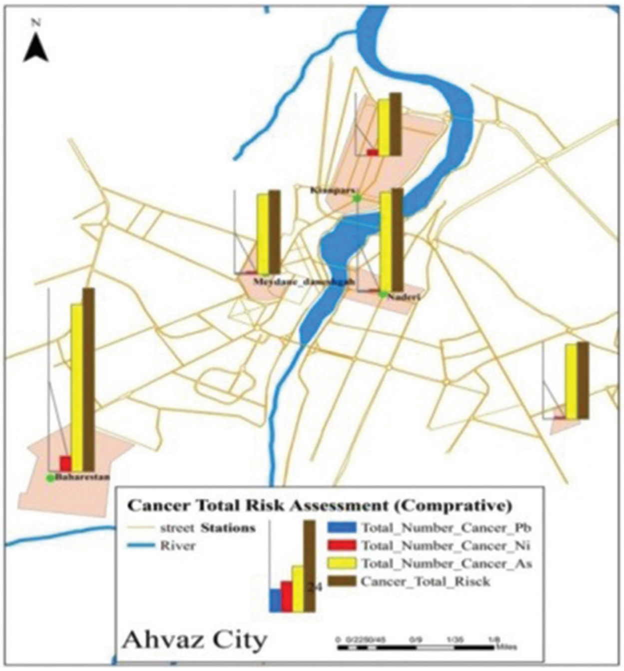

Figure 13: Total number of cancers during a lifetime due to the inhalation of arsenic, nickel and lead in the air of Ahvaz.

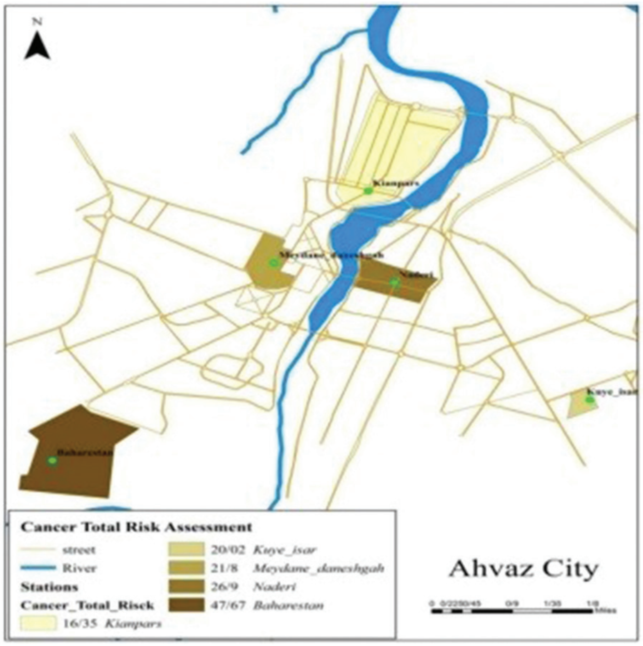

Figure 14: Total risk and total number of cancers during a lifetime due to the inhalation of arsenic, nickel and lead in the ambient air of Ahvaz.

their respiratory, digestive and dermal risks in a way that the pollution caused by the existence of aerosols in Ahvaz can best be controlled.

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