International Journal of Occupational Medicine and Environmental Health 2013;26(5):770–779
DOI 10.2478/s13382-013-0157-4

GIS-BASED ASSESSMENT OF CANCER RISK DUE TO BENZENE IN TEHRAN AMBIENT AIR

FARIDEH ATABI and SEYED ALIREZA HAJISEYED MIRZAHOSSEINI

Islamic Azad University, Tehran, Iran
Department of Environment and Energy, Science and Research Branch

Abstract
Objectives: The present study aimed to assess the risk of cancer due to benzene in the ambient air of gas stations and traffic zones in the north of Tehran. The cancer risk was estimated using the population distribution data for benzene levels and the unit risk for benzene proposed by the United States Environmental Protection Agency (US EPA). **Material and Methods:** Sixteen sampling locations were monitored, once every week, during 5 April 2010 to 25 March 2011. **Results:** The results showed that the mean annual benzene concentration was 14.51±3.17 parts per billion (ppb) for traffic zones and 29.01±1.32 ppb for outside gas stations. The risk calculated was 1026×10^{-6} for gas station 27 and 955×10^{-6} for gas station 139. **Conclusions:** According to our results, the annual benzene level in Tehran ambient air is 2 to 20 times higher than the respective value specified in International Standard (1.56 ppb). Moreover, the results showed a notable increase of cancer risks, ranging from 10% to 56%, for the vicinity population close to the gas stations in comparison to the vicinity population in the traffic zones.

Key words:
Benzene, Traffic zone, Gas station, Risk assessment, Geographic Information System (GIS)

INTRODUCTION

Benzene is commonly found in the environment. People living in cities or industrial areas are generally exposed to higher levels of benzene in air than those living in rural areas [1]. Benzene is an aromatic volatile organic compound characterized by the United States Environmental Protection Agency (US EPA) as a "known" human carcinogen for all routes of exposure based upon convincing human evidence, as well as supporting data from animal studies [2–4] and is classified by the International Association on the Risks of Cancer as a class 1 carcinogen [5,6]. Benzene plays a role in the formation of ozone [7], which causes a variety of respiratory effects [8]. The vehicles exhaust has been known as the main source of benzene in the air, followed by gasoline evaporation, emissions from the use of solvents and paintings, leakage of natural gas, and as an additive to unleaded gasoline [1,9]. Nowadays, benzene content in gasoline varies from less than 1% to 5%, depending on the fuel quality, legislations and the season. In Japan, the ambient air quality standard for benzene is set to 0.85 ppb, and its content in gasoline is regulated to be < 0.5 wt% [10].

Exposure to benzene can result in a number of critical health effects. At high concentrations, there are instant acute effects and long-term exposure to relatively low concentrations leads to chronic effects. Short exposure (5–10 min) to very high levels of benzene in air (10 000–20 000 ppm) can result in death. Lower levels (700–3000 ppm) can cause drowsiness, dizziness, tachycardia, headaches, tremors and loss of consciousness [7]. Multiple studies have shown that it is biologically plausible for benzene to cause human lymphatic tumors [11,12].

Received 2012, July 19. Accepted: 2013, September 13.
Corresponding author: S.A.H. Mirzahosseini, Department of Environment and Energy, Science and Research Branch, Islamic Azad University, P.O. Box: 1477893855, Tehran, Iran (e-mail: mirzahosseini@gmail.com).

Benzene-induced mutation and DNA damage have been demonstrated by some studies [13–15]. Meanwhile, benzene is a known carcinogen causing leukemia [6,16]. Workers involved in the transport of crude oil and gasoline and in the dispensing of gasoline at service stations, as well as taxi drivers and other people employed at workplaces with exposure to exhaust gases from motor vehicles also experience exposure to benzene [17]. The level for benzene set by Iran's Department of Environment in 2010 is 1.56 ppb [18].

The most recent data indicates that approximately 7.5 million vehicles are located in Tehran (33%) while the city has about 10% of Iran's total population, and the vehicles have been responsible for a major volatile organic compound pollution problem in Tehran [19]. Some studies have shown that traffic flow varied between 500 and 2500 vehicles/h and 54 hydrocarbons were identified in the ambient air, and the average measured concentration of benzene was 39.87 ppb [20]. Emissions of pollutants in south Tehran exceeded those in north Tehran, and the emissions during the evenings were higher than those during the mornings [21].

Despite the regulations established, cancer risk assessment has not been investigated because of the lack of data for benzene levels for the entire population living in Tehran. In this study, the possibility of the application of Geographic Information System (GIS) to monitor cancer risk was analysed, and the cancer risk was estimated using the population distribution data for benzene levels and the unit risk for benzene proposed by the US EPA. Lastly, collecting benzene concentration data, personal exposure was estimated in GIS. It is noteworthy this is the first time that such an extensive study on benzene has been carried out in Tehran.

MATERIALS AND METHODS

Case study

Tehran is divided into 22 districts, and district 1 is located in one of the northern parts of the city and surrounded by the traffic corridor. The municipality of district 1 consists of 22 zones and 26 neighborhoods. District 1 area with and without considering its vicinity is 64 km^2 and 210 km^2, respectively. Its southern borders are 'Chamran' highway, 'Modares-Babayi' highway. The 'Sadr' highway located near the southern and western border lines of district 1, has a considerable traffic volume. The 'Chamran' highway in the east is similar in that respect. High traffic volumes along with densely populated areas are the main characteristics of this area with inhabitants of around 445 000.

The present study aimed to assess the risk of cancer due to benzene in the ambient air of gas stations and traffic zones in the north of Tehran (District 1). Sixteen sampling locations were monitored, during 2.00–5.00 p.m., once every week, between 5 April, 2010 and 25 March, 2011. The sampling locations are shown in Figure 1.

The selected locations in this study were quite close to the gas stations and had a considerable traffic volume. These locations were situated 1 to 5 m away from the main roads. It should be mentioned that the 'Chamran-Velenjak' station was located 15 m away from the gas station 148, and 'Chamran' highway in the south is 5 m away from this station. 'Movahead' station located in the far north had the least traffic volume among the stations of this group, while 'Velenjak' station had the poorest conditions.

All of the traffic zones witnessed frequent traffic jams during peak hours, average vehicular speed of 15–25 km/h as well as long queues of vehicles at traffic lights. In traffic zones, vehicles had to wait at least 2 min. The traffic of heavy-duty vehicles, passenger cars and buses was quite high in this location. At the outside gas station, monitoring was carried out close to the gasoline pumps where cars halted for filling fuel. Increased traffics were observed at these locations, and they were about 10 m away from the busy roads. All of the four gasoline pumps had heavy traffic inflow. Additional hourly meteorological data on temperature, pressure, wind speed, wind direction, visibility, cloud cover and type of precipitation were collected from 'Aghdasieh' weather station in the north of Tehran.

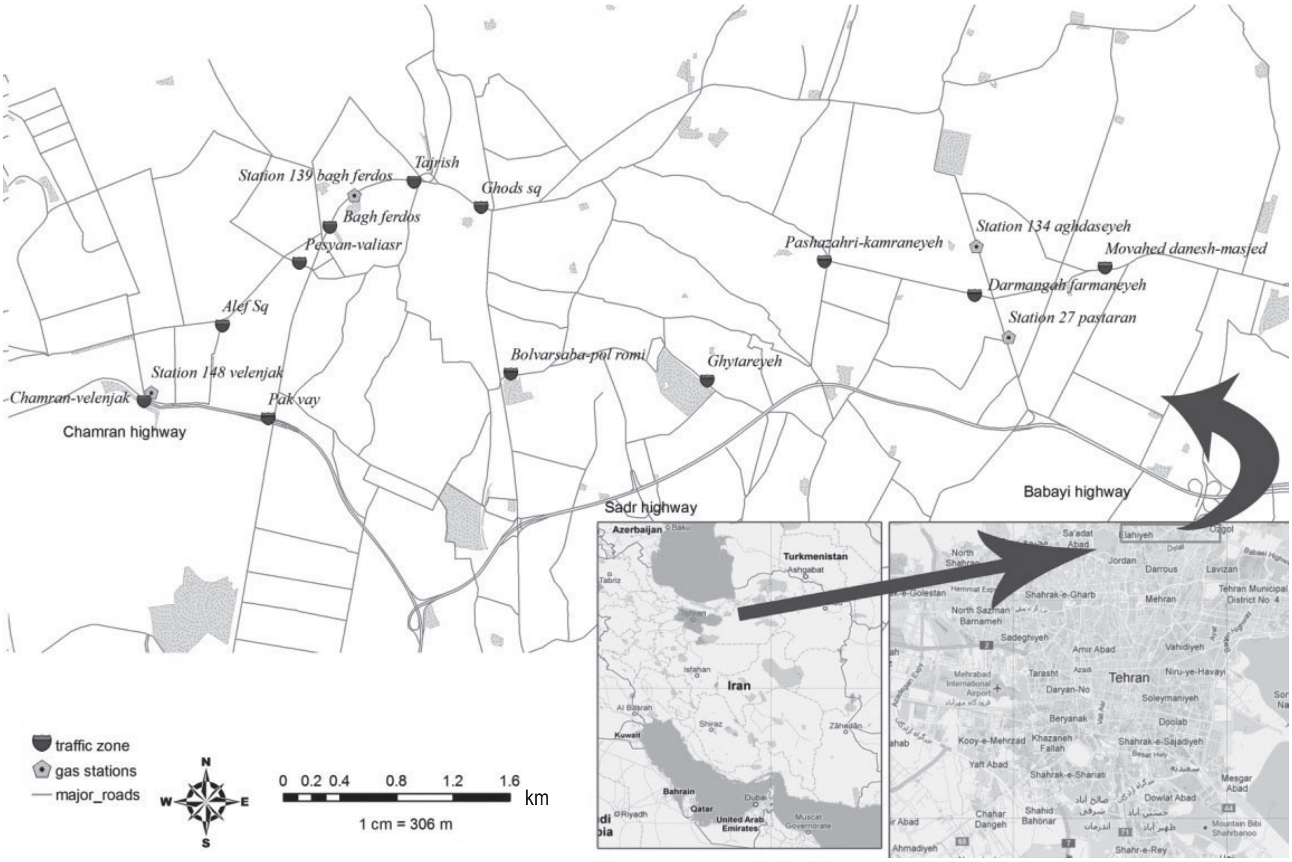

Fig. 1. Location of 16 sampling sites in Tehran

Experimental work

Benzene level was measured using a portable photo ionization detector (PID, Model PhoCheck 5000Ex, Ion Science Ltd. UK), which was calibrated using 100 ppm of iso-butene and with a dynamic detection range of 1 ppb up to 10 000 ppm. 'PhoCheck' is an intrinsically safe transportable gas-detector suitable for the detection of volatile organic compounds using a PID. The PID instrument was placed near stations, near the ring-stand that holds the sampling device, and the data were recorded for 10 min at each station. The monitoring of all stations takes a total of 5 h (for 16 sampling stations) during peak hours [22].

Geographic Information System (GIS)

Geographic Information System (GIS) has long been used to store, process and display spatial data. In addition, because GIS allows the display of concepts and relationships in map form to large audiences, it is the ideal tool for integrating environmental engineering and social science analyses [23]. To cover the benzene dispersion pattern within the area under study, Arcgis9.3 Software with the aid of an additional geo-statistical analyst module was employed. These tools, a family of interpolation methods, consist of geo-statistical methods based on statistical models that include autocorrelation (statistical relationships among the measured points). Spatial interpolation methods such as Inverse Distance Weight (IDW) helped to utilize these data to estimate levels of ambient air pollutants at unmeasured locations. IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the vicinity of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process [24,25]. The IDW formulas are given as Equations 1 and 2:

$$Z(x) = \sum wizi/\sum wi \quad (1)$$

$$wi = di\text{-}p \quad (2)$$

where

$Z(x)$ – predicted value at an interpolated point,

Z_i – predicted value at a known point,

di – distance between point i and the prediction point,

wi – weight assigned to point i.

As the distance increases, the weight decreases; p is the weighting power that decides how the weight decreases by the distance increase [26].

Health risk evaluation

The EPA publishes the toxicity of a chemical in its Integrated Risk Information System (IRIS) after extensively reviewing all the available evidence. The toxicity of the chemical is published along with an indication of the degree of certainty associated with the carcinogenic evidence. EPA's IRIS states that the lifetime risk of an individual with 70 years exposure to 0.313 ppb airborne benzene ranges from 0.68×10^{-6} to 2.4×10^{-6} ppb. This is referred to as unit risk, or the carcinogenic risk posed by exposure to one unit, or in this case, of 0.313 ppb of benzene in air [4]. Considering the above-mentioned points, of special environmental aspect is the impact of gas stations and vehicle traffic on the health of the people living in their vicinity. For this reason, cancer risk for benzene was estimated using the US EPA equation:

$$R = C\times U \quad (3)$$

where

R – risk,

C – concentration of benzene (ppb),

U – inhalation unit risk estimate (probability of cancer for a 70-year exposure to 0.313 ppb).

World Health Organization (WHO) in its update of the Air Quality Guidelines for Europe [27], used data from the updated Pliofilm cohort and models, based on relative risk and cumulative exposure, to calculate unit risks for benzene in the range of $0.68–2.4\times10^{-6}$ ppb with a geometric mean of 1.56×10^{-6} ppb. Thus, risk for the population is 1.56 people per 100 000 people [28,29].

The aggregate population cancer risk of the total population in district 1 was estimated using Equation 4, which is the sum of the yearly population risk for each station, obtained by multiplying the annual individual risk by the population for each station [30–32]:

$$R = (\sum UCiPi)/L \quad (4)$$

where

R – aggregate population excess cancer risk caused by one year exposure to benzene.

U – unit risk for benzene,

Ci – personal exposure level in station,

Pi – population in station and

L – average lifetime, set to 70 years.

RESULTS AND DISCUSSION

Estimation of benzene concentrations

The annual benzene concentration levels obtained from 16 stations were simulated for district 1 of Tehran in a GIS environment similar to the patterns quoted above. The monthly average benzene data set was used for correlation analysis, and the parameter values are listed in Table 1.

Figure 2 indicates that the highest pollution level occurs at the outside gas station area, and the concentration levels for the gas station 148 (Velenjak), gas station 139 (Baghferdos) and gas stations 134 (Aghdaseyeh) are in the range of 22 to 32 ppb. Thus, the eastern part of the map can be labeled as the most polluted area. As mentioned, no gas station can be found in the central part of the studied area, which accounts for the least annual benzene level, and the concentration level in this area

Table 1. Statistical parameters of measured data in 16 sampling stations

Station name	Situation	Benzene concentration (ppb)			
		M	SD	max	min.
Alef Sq	traffic zone	17.23	5.34	26.50	5.10
Bagh ferdos	traffic zone	13.33	5.90	23.83	5.80
Bolvarsaba-pol romi	traffic zone	18.08	7.39	30.13	5.50
Darmangah farmaneyeh	traffic zone	14.45	6.21	23.00	1.23
Ghods sq	traffic zone	16.05	4.85	23.50	5.50
Ghytareyeh	traffic zone	16.18	4.96	24.50	9.80
Movahed danesh-masjed	traffic zone	5.87	2.72	10.98	1.20
Pak vay	traffic zone	15.49	6.21	29.55	8.23
Pashazahri-kamraneyeh	traffic zone	12.89	4.76	22.45	5.13
Pesyan-valiasr	traffic zone	13.28	7.12	25.88	1.30
Station 134 aghdaseyeh	gas station	28.01	9.54	45.33	10.50
Station 139 bagh ferdos	gas station	30.63	9.80	45.60	15.80
Station 148 velenjak	gas station	29.55	7.16	42.50	17.20
Station 27 pastaran	gas station	27.85	7.32	41.50	16.69
Tajrish	traffic zone	14.65	6.96	26.10	4.23
Chamran-velenjak	traffic zone	16.63	5.99	32.90	10.25

M – mean; SD – standard deviation; max – maximum; min. – minimum.

falls in the range of 14 to 18 ppb. Equation 5 was used for the prediction of benzene levels in this study, and the related annual regression function obtained from IDW pattern for 16 stations is:

$$y = -0.194X + 21.906 \text{ and } R2 = 0.423 \quad (5)$$

The annual averages of total benzene at different stations are also presented in Table 1. The results show that the mean yearly benzene concentrations were 14.51±3.17 ppb for roads with heavy traffic and 29.01±1.32 ppb for outside gas stations. It is obvious that the benzene concentration level in outer gas stations is significantly high. This is mainly due to the lack of an appropriate system for removing and collecting the gasoline vapor in the gas stations.

Unfortunately, carrying gasoline in non-standard containers, inappropriate fueling methods, overfilling the vehicles and locations of gas stations which are usually next to roads with high-volume traffic are the main reasons for rising benzene concentration level in such areas. The gas station 139, due to its proximity to a busy and narrow road (Valie-asrAvenue), had the highest amount of benzene pollution. The annual benzene concentration level in the vicinity of gas station was about 30.63 ppb and the measured station distance from the road was 3 m.

Assessment of cancer risk resulting from exposure to benzene

Based on the results, the gas stations and road traffic are two main sources of high benzene concentrations in this case study. Unfortunately, in the site selection of gas stations, their proximity to residential areas and the heavy traffic of the areas have not been considered. To assess the risk of cancer resulting from exposure to benzene and identify the most critical points exposed to it, three main

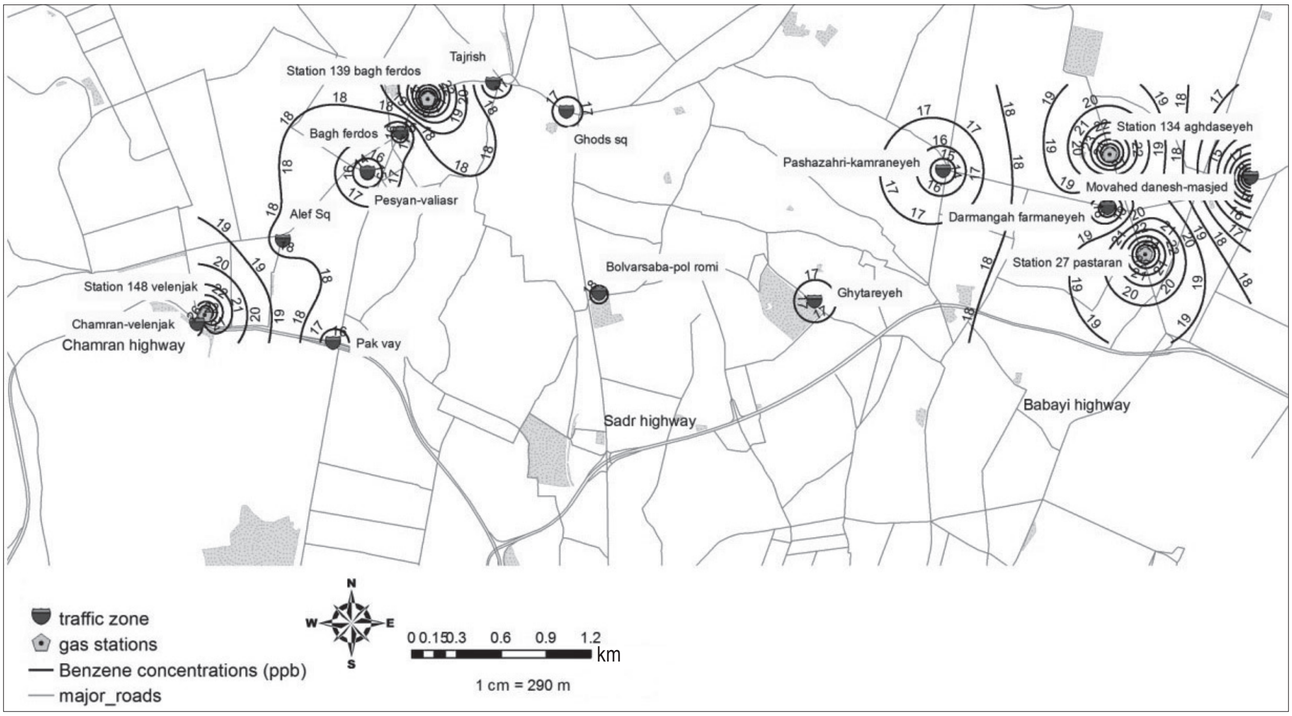

Fig. 2. Annual benzene concentration levels predicted by Geographic Information System in 16 sampling stations

Fig. 3. Estimation of population weighted average for all stations

parameters were defined in a GIS environment. These parameters were the expected and the measured values of benzene concentration at the location (Figure 3), population and inhalation unit risk factor. According to the EPA proposed model, health risk factor is a function of target population and pollutant concentration (Equation 4). The aggregate population risk of the total population in district 1 was estimated using Equation 4, and it is the sum of the annual population risks for each region, obtained by multiplying the yearly individual risk by the population for each region.

The results obtained from these parameters can provide good criteria to determine the points experiencing a critical condition. All of the three parameters were imported to the GIS environment and classified in 3 layers. To determine the population parameter, the population data of the area was collected and imported to the GIS environment as a database. To display each point's population, the whole region's population distribution was presented using an interpolation tool as a grid layer (Figure 4). Objectively, the most populated areas were illustrated by a dark polygon in Figure 4. Furthermore, the position of each measuring station as well as its suburb population were marked. It can be seen that the largest population resides close to gas station 27 (Pastaran).

It is obvious that gas station 27 (Pastaran) and gas station 139 (Baghferdos) are located in the areas with the highest risk of cancer caused by exposure to benzene. The reason is that these points possess the benzene concentration more than 25 ppb as well as high population density in terms of having more pollution. The worst point noticed in this pattern has been ascribed to gas station 139 (Baghferdos). The point is not only near to the gas station but also located in an area suffering from heavy traffic and high population density (the product of 3 parameters). According to the results, the most polluted part of the studied

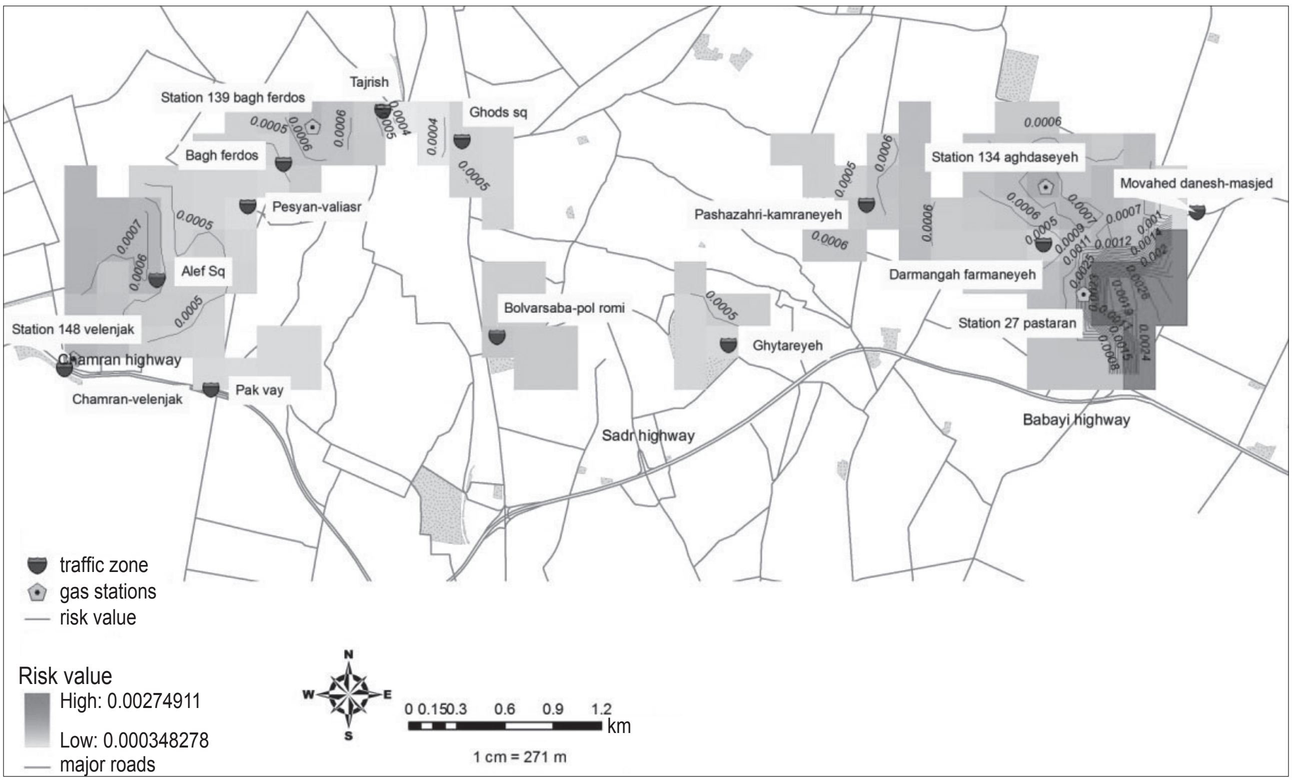

Fig. 4. Estimation of lifetime cancer risk probability for District 1, Teheran, using Geographic Information System

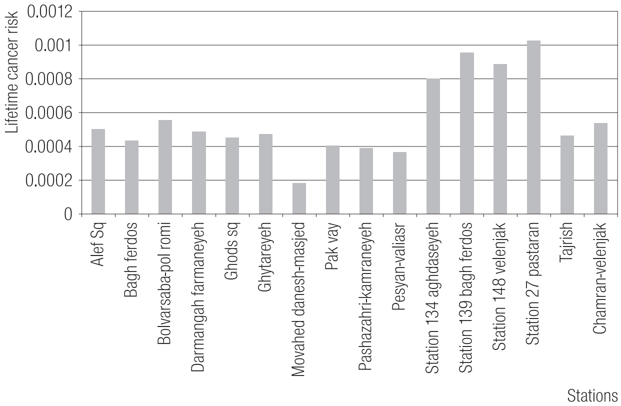

Fig. 5. Estimation of lifetime cancer risk probability for District 1, Tehran, by monitoring sites, based on the measured concentration of benzene

area is the eastern part which is now in a very crucial condition because of its high population density, encompassing the critical sites and suffering from lack of proper management in gas stations' layout planning.

Histograms of the populations exposed to each personal benzene level or benzene induced excess lifetime cancer risk are shown in Figure 5. As a result, the calculated risk for gas station 27 is 1026×10^{-6} and for gas station 139 it is 955×10^{-6}. In terms of per capita (100 000 persons), it means that 1026 persons would be in danger of cancer in station 27 and 955 persons in station 139. The mean benzene concentrations by site ranged from 14 to 30 ppb. Regulatory risk analysis resulted in cancer risk estimates ranging from 182×10^{-6} to 102.6×10^{-5}, all of which exceed the EPA acceptable risk of 1×10^{-6}.

CONCLUSIONS

The main aim of the present study was to evaluate the cancer risk due to benzene concentration in Tehran ambient air over a period of one year. Samples were collected from 16 monitoring sites in Tehran, during 5 April 2010 to 25 March 2011, and the cancer risk was estimated using the population distribution data for benzene levels and the unit risk for benzene proposed by the US EPA.

The cancer risk map of the study area has been obtained by combining two basic maps: population and predicted values of benzene concentration (in relation to Equation 4). According to the obtained results, the annual benzene concentration level in Tehran ambient air is 2 to 20 times more than the respective value specified by the International Standard (1.56 ppb) [18]. During the course of the research, the unacceptable increase of benzene from 4% to 6% in gasoline had a significant effect on benzene concentrations in Tehran ambient air. Thus, the results showed a notable increase of cancer risk, ranging from 10% to 56%, for the population close to the gas stations in comparison to the population in the traffic zones.

Carcinogenic standard concentrations were set at a risk level of one in a million (1×10^{-6}). Benzene exceeded a cancer risk level of 1×10^{-6} at all 16 monitoring sites. It is noteworthy that frequent sampling, employing GIS tool and periodic benzene dispersion modeling within the urban areas are the most important criteria for making decisions about such cities as Tehran. Employing systems that are able to collect gasoline vapor as well as improving or modifying gasoline filling patterns in gas stations will contribute to reduction of benzene concentration in ambient air. The fact that gas stations must not be built in areas with higher traffic volume and narrow routs needs also be considered by authorities.

ACKNOWLEDGEMENTS

The authors would like to thank the Graduate Faculty of Environment and Energy, Science and Research Branch, IA University for the technical support provided.

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