Journal of Air Pollution and Health (Autumn 2021); 6(4): 265-274

Original Article

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Evaluation of the volatile organic compounds (VOCs) concentration in the city of Khorramabad gas stations using AERMOD and ArcGIS

Rajab Rashidi[1,2], Mohammad Faridan[1,2], Bahram Kamarehie[2,3], Faramarz Azimi[2,3,*]

[1] Department of Occupational Health, School of Health, Lorestan University of Medical Sciences, Khorramabad, Iran
[2] Environmental Health Research Center, Lorestan Univeristy of Medical Sciences, Khorramabad, Iran
[3] Department of Environmental Health Engineering, Faculty of Health and Nutrition, Lorestan University of Medical Sciences, Khorramabad, Iran

ARTICLE INFORMATION

Article Chronology:
Received 05 September 2021
Revised 15 November 2021
Accepted 18 December 2021
Published 30 December 2021

Keywords:
AERMOD; Geographic information system (GIS); Volatile organic compounds (VOCs); Khorramabad, Gas stations

CORRESPONDING AUTHOR:

Fazimi_lums@yahoo.com
Tel: (+98 66) 33409971
Fax: (+98 66) 33409973

ABSTRACT

Introduction: In the present study, the emission of Volatile Organic Compounds (VOCs) from gas stations located in the city of Khorramabad and its impact on the environment was investigated based on the AERMOD dispersion model and the preparation of maps in Geographic Information System (GIS).

Materials and methods: 7 gas stations were randomly selected and the values of VOCs emission in two seasons of the year (winter and summer) were examined. The Phochek 5000 direct reading device was used to measure VOC concentrations. R 3.6.3 was used for the data analysis.

Results: The results showed that there was no significant difference among the gas stations in terms of VOCs emission (P>0.05). The highest mean concentration observed at gas station No. 6 with 7.7± 6.48 mg/m^3 while the lowest concentration was at gas station number 3 with a concentration of 0.52±0.18 mg/m^3. The results from the anova revealed that there was a significant difference between the seasons in terms of the VOCs emission (P<0.05). The mean concentration of the VOCs was 3.58±2.77 mg/m^3 in the summer and 2.53±2.4 mg/m^3 in the winter.

Conclusion: Based on the results, the highest estimated concentration in the summer was recorded in the vicinity of gas station No. 6, which is located below Imam Hossein square. Due to the proximity of gas station No. 5 to gas station No. 6 as well as being in the direction of the prevailing wind, the concentrations of VOC emitted by these two gas stations will increase the estimated concentration around Imam Hossein square.

Introduction

Volatile Organic Compounds (VOCs) include a variety of low-molecular-weight compounds with both human and natural origins that readily evaporate at ambient temperatures, and are therefore emitted as gases to the atmosphere [1]. These compounds act as precursors of the tropospheric ozone, so they are very important in terms of photochemical reactions. Additionally, some VOCs such as Benzene, Toluene, Ethylbenzene, Xylenes

Please cite this article as: Rashidi R, Faridan M, Kamarehie B, Azimi F. Evaluation of the volatile organic compounds (VOCs) concentration in the city of Khorramabad gas stations using AERMOD and ArcGIS. Journal of Air Pollution and Health. 2021; 6(4): 265-274.

(BTEX) are toxic and considered as major atmospheric pollutants which contribute to potential threats to human health and wellbeing [2]. In addition, volatile organic compounds contain compounds such as BTEX, which are considered carcinogenic compounds. Toxic Volatile Organic Compounds (VOC), like benzene, toluene, ethylbenzene and xylenes (BTEX), are atmospheric pollutants representing a threat to human health. They are released into the environment from mobile sources in urban settings, but newly polluted areas are gaining importance in countries where accelerated industrialization is taking place in suburban or rural settings [3].

Environmental pollution is a significant problem for humanity because of considerable changes in ecosystem behavior and the loss of biodiversity it is triggering, and because it may be at the origin of different diseases and physiological disorders in humans. Pollutants that impact air quality include Volatile Organic Compounds (VOCs), which are introduced into the atmosphere through anthropogenic or biogenic activities and add to problems in the formation of tropospheric ozone and particles lower than 2.5 μm in large cities [4].

The principal sources for the emission of VOCs (apart from the natural sources) include petroleum and petrochemical industries, evaporation from/burning of fossil fuels in industries, homes and vehicles as well as the emissions from chemical industries and industrial processes such as manufacturing of paints, lubricants, adhesives, etc. Evaporation of the toxic VOCs from fuel distribution pumps and stations is one of the main sources of their emissions that may be caused during the filling and emptying process of fuel storage tanks or the refuelling and injection system of the vehicles in the gas stations. Factors such as inappropriate sealing of the equipment used in the fuel distribution systems along with the air temperature and the number of refuelling cases can affect the release of the VOCs in gas stations [5]. Regarding the fact that the excessive release of the VOCs would contribute to adverse physiological and economic effects, these compounds must be measured, monitored and controlled effectively. The use of pollutant dispersion models is one of the appropriate methods for observing and controlling the pollutants introduced into the atmosphere [6]. AERMOD is one of the well-known atmospheric dispersion modelling system for modelling the pollutants in the atmosphere and is based on Gaussian models [7]. This model is used to estimate emission concentrations at distances of less than 50 km [8]. AERMOD is the U.S. Environmental Protection Agency (EPA) preferred and regulatory recommended air dispersion model that is developed as software for estimating the concentration of pollutants from the pollutant sources [5, 9-12].

Geographic Information Systems (GIS) and their associated software such as ArcGIS are among the leading tools for explaining events, predicting outcomes and planning control measures in the field of air quality management. These systems are able to capture, manipulate, analyse and map the geographical data that can be referencedfor makingcritical environmental decisions [13]. GIS is also able to perform the map making process particularly by integrating database operations such as query and statistical analysis through visualization and geographic analysis [14].Today, the rapid evolution of the GIS system has been widely used in many environmental studies. Some researchers have already shown the heterogeneity of the contaminant multidimensionally by using the GIS. In many studies, using multidimensional GIS functions, the atmospheric air pollutants have been modelled and presented multi dimensionally [13-15]. Considering that one of the prevailing sources of emission of VOCs in the urban atmosphere is their emission through gas stations, the present study aims to investigate the emission of VOCs from the gas stations in the city of Khorramabad and assess its associated environmental impacts by employing the AERMOD dispersion model and the map preparation of ArcGIS. The findings of this study will also be used to identify the critical areas in the city of Khorramabad that are dominantly affected by the emissions from the gas stations as well as providing the necessary warnings to the relevant authorities.

Materials and methods

Study situation

Khorramabad is the 23rd most populous city in Iran and the capital of Lorestan province. With geographical coordinates of ′22 ° 48 and ′29 ° 33,Khorramabad is located at an altitude of 1171 meters above sea level [16]. (Fig. 1) and there are totally 21 gas stations within this city.

In this study, 7 gas stations were randomly selected in order to evaluate the concentration values of the VOCs inside these gas stations. Taking into account the minimum sample size, 30 samples were obtained at each gas station in different intervals.

Moreover, due to the critical role of temperature on the concentration levels of the VOCs within the gas stations, sampling was performed in both hot and cold seasons (i.e. December and January in winter and June and July in summer), from 10 am to 4 pm.

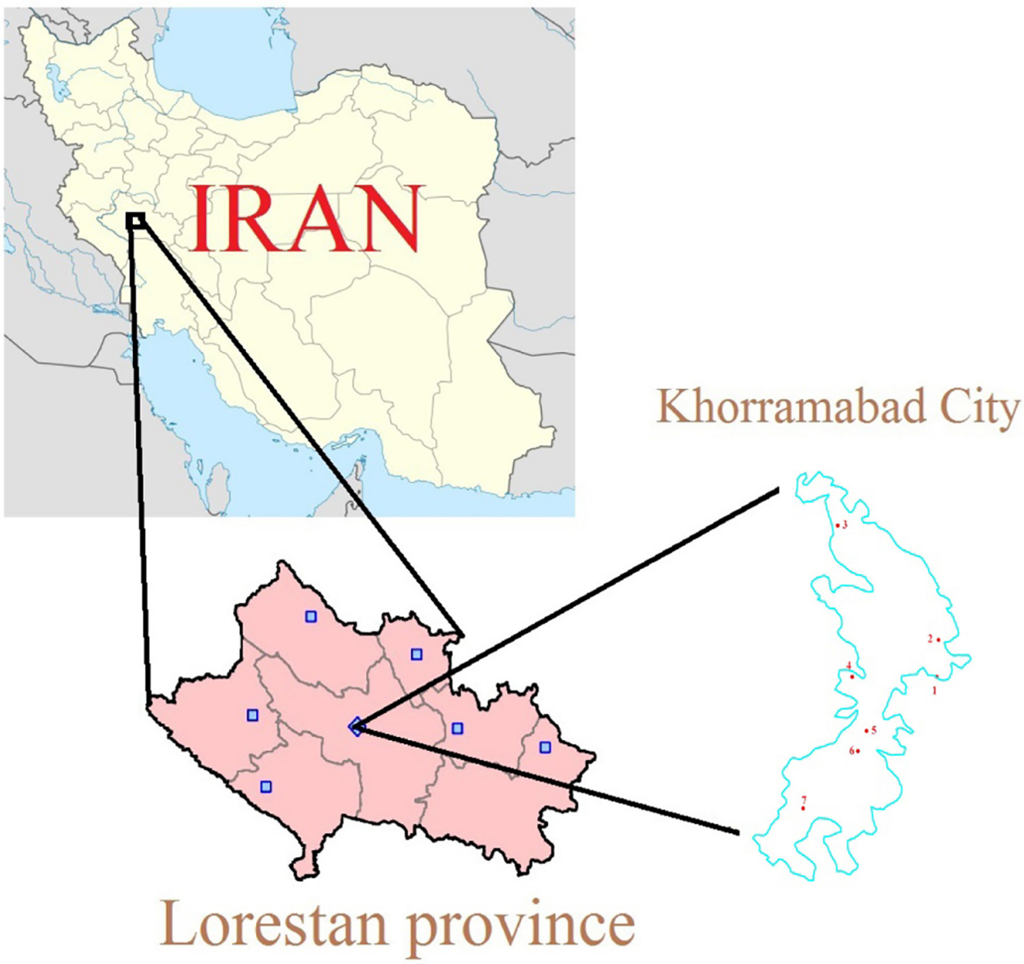

Fig. 1. Geographical location of the study and location of gas stations

Descriptions of instruments and quality assurance and quality control

Having determined the sampling stations within the area of each gas station, the procedure of instant sampling was conducted immediately using photoionization detector (PID) device, Phochek5000 (ion science company) and the obtained values were recorded at each point. Prior to the sampling process, the device was calibrated and set based on the type of the VOC that was planned to be evaluated. The device probe was then aimed at the desired sampling stations and the concentration values of the VOC shown on the device screen were recorded. Phochek 5000 is able to measure the VOCs concentrations within the range of 0.1 ppb to 10000 ppm. In order to verify the samples taken by the Phochek5000, 3 samples were taken in each station using the conventional environmental method; an air sampling pump and activated carbon adsorbent were used.

Prior to be analysed through Gas Chromatography Mass Spectrometry (GC-MS), the VOCs were extracted from the activated carbon using carbon disulphide (CS2). Regarding the analysis performed by the GC-MS, the data validity was determined to be about 65% and the relevant coefficient was applied to the initial data [7, 17].

Data analysis

After collecting the required data, 3.6.3 R version was used for data analysis. Analysis of variance was also employed to observe the difference between the seasons and the locations of the gas stations. Finally, using Air Quality Dispersion Modelling (AERMOD), the models of data distribution were performed in a radius of 2 km away from each gas station at regular intervals of 200 m. Additionally, Arc GIS 10.7 was used for the geographical zoning of the VOCs.

Results and discussion

Having observed the method of refuelling the vehicles and fuel pumps and nozzles, it was found that in all gas stations in Khorramabad, each driver performs the refuelling process in person and no Refuelling Vapour Recovery system (RVR) exists to capture the VOC emission during refuelling the vehicles. In some gas stations the refuelling pumps and nozzles either had faulty fuel shut-off sensors or were not even equipped with the sensor which routinely contributed to fuel splash back and overflow and increased the evaporation and emission rate of the VOCs released to the atmosphere.

Table 1 shows the latitude and longitude of each gas stations along with the VOC concentrations in both summer and cold winter. The amount of emission calculated in this table is shown based on the average and standard deviation of the amount measured by Phochek 5000 in 7 gas stations in Khorramabad. Referring to the fact that Phochek 5000 provides the concentration values in ppm, these values were entirely converted to mg/c^3 and then multiplied by the correction factor obtained from the activated carbon sampling method.

Analysis of variance was used to observe the difference between the gas stations and the sampling seasons. As shown in Table 2, no significant difference was seen among gas stations in terms of the release of the VOCs ($P>0.05$). The highest mean concentration occurredin gas station No. 6 with 7.7± 6.48 mg/m^3 and the lowest concentration was seen in gas station No. 3 with the concentration of 0.52±0.18 mg/m^3. The results from analysis of variance of the sampling seasons showed a significant difference between the seasons ($P<0.05$). The mean concentration of the VOCs was 3.58±2.77 mg/m^3 and 2.53±2.4 mg/m^3 in summer and in winter respectively.

Table 1.The latitude and longitude the gas stations along with the VOC concentration values in summer and winter

Gas station number	Longitude	Latitude	Hot season		Cold season	
			Average (mg/m^3)	Sd (mg/m^3)	Average (mg/m^3)	Sd (mg/m^3)
1	48.3754	33.487	3.88	2.82	0.368	0.415
2	48.376	33.498	2.91	3.23	2.62	2.71
3	48.341	33.532	1.065	1.02	4.6	3.45
4	48.346	33.487	1.72	1.11	0.52	0.18
5	48.348	33.465	3.99	2.4	2.13	3.16
6	48.351	33.471	7.7	6.48	4.66	3.77
7	48.329	33.448	3.82	2.34	2.85	3.12

Table 2. Analysis of variance for exploring the locations of gas stations and sampling seasons

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Location	6	119.4	19.91	1.058	0.3955	
Season	1	105.5	105.54	5.608	0.0204	*
Residuals	76	1430.4	18.82			

***< 0.001; ** < 0.01; * < 0.05

In order to estimate the 24 h dispersion of the VOCs released from the gas stations, the Gaussian dispersion model run by AERMOD was employed. Fig. 2 presents the results from the dispersion models in two gas stations where the lowest and highest concentrations had observed.

The highest observed concentration of VOC is depicted red colour. The highest concentration was estimated at the centre of gas station (b) with 800 μg/m^3 in summer. The estimation of the concentration values were performed within the 200 m up to a maximum of 2 km from each gas station. The lowest concentration (20 μg/m^3) was observed at a distance of 2 km.

Considering that the prevailing wind in the city of Khorramabad blows predominantly from the north to the south-west [18], the regions mostly affected by the emission from the gas stations were located in the southern parts of the city. In the lowest release rate from a gas station in the cold season, the maximum concentration occurred at the centre of the gas station (approximately 31 μg/m^3) at the same time at the furthest distance the concentration level was found to be 1 μg/m^3.

The increase in the levels of concentration in the summer as well as the expansion of the contour in the output model of the AERMOD are mainly due to the increased wind speed, average temperature and distribution factors in the warm season. According to the results from the dispersion models of AERMOD, the locations of the estimated concentrations within the radius of 2 km around each gas station were determined and recorded based on their latitudes and longitudes. Arc GIS was then used for the zone mapping of the city of Khorramabad (Fig. 3).

GIS is a powerful and effective tool for estimating and showing natural and artificial differences in various phenomena [19]. In this study, GIS was used to spatially describe the VOC concentrations prior to using AERMOD and in order to estimate such concentrations at specified distance intervals from gas stations.

Regarding the significant difference in concentration levels between the winter and summer, a zoning map was drawn for each season. To draw the zoned map by Arc GIS, the Inverse Distance Weighted (IDW) tool was used, which can easily plot the concentration data on the map and also estimate the values for the locations where no measured data is available. In this method, the concentration in each cell is determined according to the average values of its adjacent cells and the cell that is closer to the estimated cell has a greater impact on its value [14, 20]. The IDW tool has been previously used in various studies to form the zoned maps of air pollutants [3, 10, 21, 22]. As shown in Fig. 3, the highest concentrations of the VOCs were just recorded in the vicinity of the 7 studied gas stations.

The results show that compared to the cold season, the concentration of VOCs released from the gas stations covers a larger part of the city in the hot season and the maximum concentration in the summer and winter are about 600 μg/m^3 and 440 μg/m^3 (shown in Fig. 3(a) and (b) in red) respectively.

The underlying reason for the higher emissions from the gas stations in the hot season is due to the elevated air temperature as well as heavier traffic and more transportation. As shown in Fig. 3, the highest concentration of the VOCs was observed in the centre of Khorramabad and around Imam Hossein Square (adjacent to gas stations No 5 and 6) in both winter and summer, which is due to the close proximity of these two gas stations in this area. According to the predictions made by Arc GIS, the lowest concentration of the VOCs in both cold and hot seasons was observed around the Kooye Artesh neighbourhood (adjacent to the gas station No 2) and is marked in green in the Fig. 3.These low concentrations in this neighbourhood are either the consequence of the considerable distance from the gas station or not to being exposed to the prevailing wind that blows from the gas station to this area of the city.

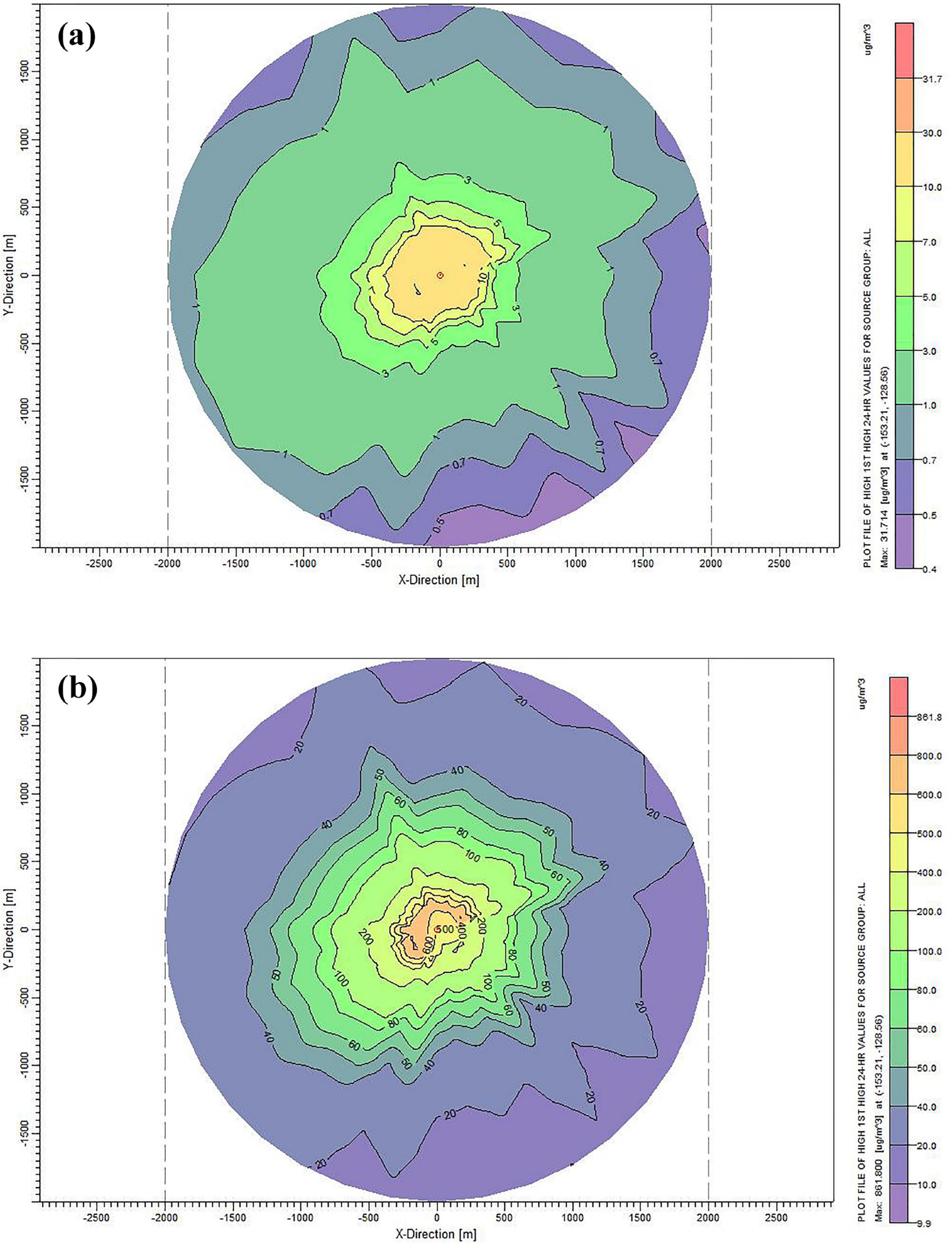

Fig. 2. Distribution of 24-h concentration values of the VOCs obtained from AERMOD in gas stations with the lowest (a) and the highest (b) diffusion rate

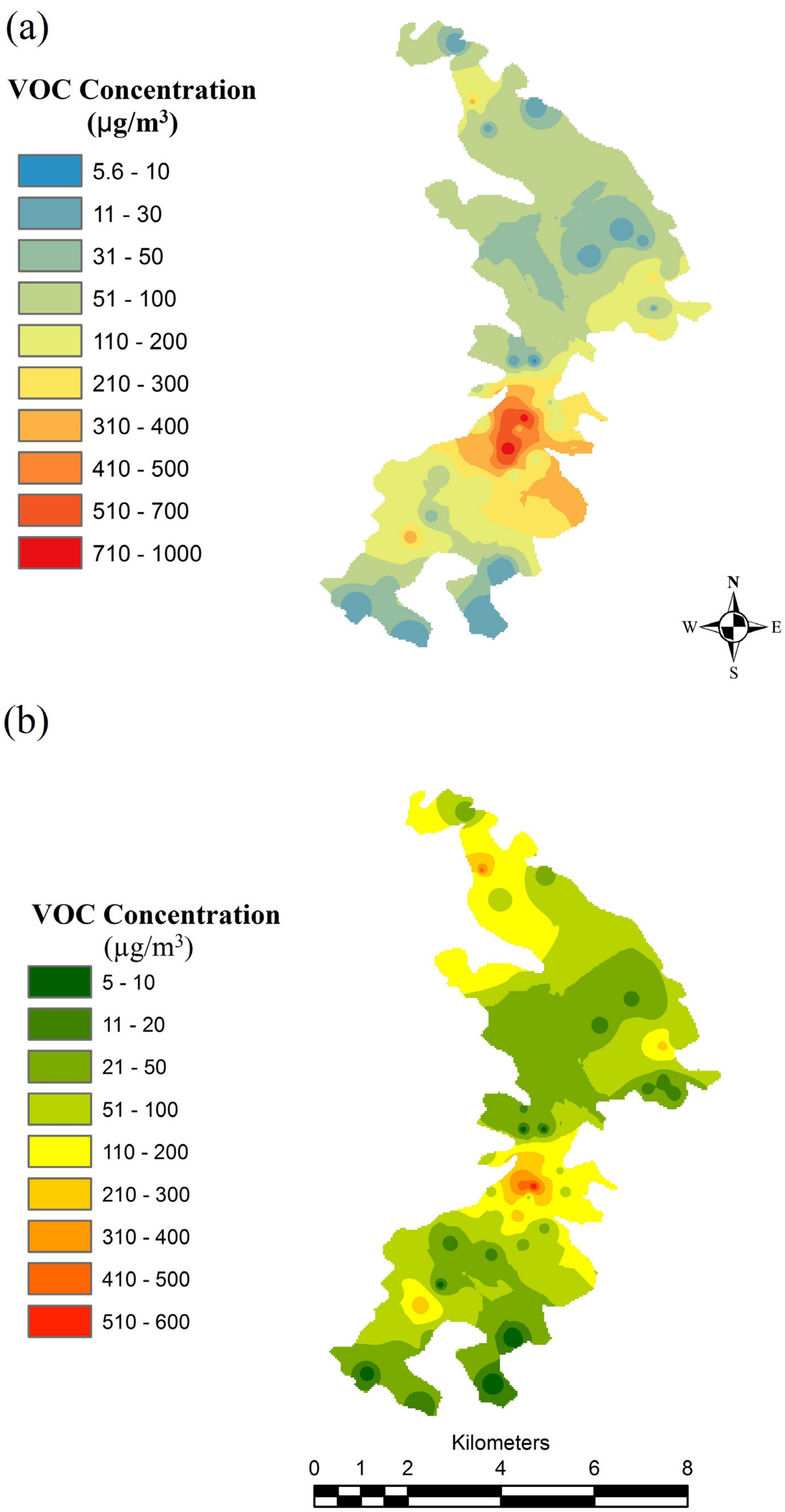

Fig. 3.The predicted values of 24-h concentration of the VOCs released from the 7 studied gas stations in the city of Khorramabad

Conclusion

The main purpose of this study was to estimate the distribution of volatile organic compounds released from the routine activities performed in selected gas stations in the city of Khorramabad during both summer and winter(hot and cold seasons) using Arc GIS along with AERMOD distribution models. In both hot and cold seasons, the measurements of the concentration values were performed at 7 gas stations. After estimating such values in different points, associated maps and therefore visualization were developed and performed using Arc GIS and AERMOD. The followings summarise the principal findings of the present study:

• The rate of releasing the VOCs from the selected gas stations in Khorramabad in the hot season was higher than the cold season; with the statistically significant difference in the average concentration values. Also, no significant difference was observed between the locations of gas stations in terms of the VOCs emission.

• The highest estimated concentration in the hot season was recorded near the gas station No. 6, which is located in the vicinity of Imam Hossein Square. Due to the proximity of gas station No. 5 to gas station No. 6 and being in the direction of the prevailing wind, the concentration of VOCs emitted by these two gas stations will increase the estimated concentration around Imam Hossein Square.

• The lowest estimated concentration was recorded in the Kooye Artesh neighbourhood, mainly due to the fact that gas station No. 2 was partly far from this neighbourhood as well as not being located in the prevailing wind direction.

Financial supports

This study was funded by Lorestan University of Medical Sciences, Khorramabad, Iran, and the grant number (IR.LUMS.REC.1399.349)

Competing interests

The authors declare they have no actual or potential competing interests.

Acknowledgements

The authors wish to extend their thanks to Lorestan University of Medical Sciences.

Ethical considerations

“Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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