original article

Outdoor investigation of air quality around Bandar Abbas — Iran oil refinery

Mehdi Zare, Ali Toolabi[1], Mohammad Reza Zare[2], Maryam Sarkhosh[3], Amir Hossein Mahvi[3,4,5], Ayat Rahmani[3], Ali Fatehizadeh[2]

Department of Occupational Health, School of Health, Hormozgan University of Medical Sciences, Bandar Abbas, Iran, [1]Department of Environmental Health Engineering, School of Health, Kerman University of Medical Sciences, Kerman, Iran, [2]Environment Research Center Isfahan University of Medical Sciences, Isfahan, Iran, [3]Department of Environmental Health Engineering, School of Health, Tehran University of Medical Sciences, Tehran, Iran, [4]National Institute of Health Research, Tehran University of Medical Sciences, Tehran, Iran, [5]Center for Solid Waste Research, Institute for Environmental Research , Tehran University of Medical Sciences, Tehran, Iran

Address for correspondence:
Dr. Amir Hossein Mahvi,
National Institute of Health Research, Tehran University of Medical Sciences, Tehran, Iran.
E-mail: ahmahvi@yahoo.com

ABSTRACT

Aims: This study has been conducted to assess air pollution, with respect to particulate matter less than 10 μm in diameter (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), and the Air Quality Index (AQI), in a location at close proximity to the Bandar Abbas-Iran oil refinery.

Materials and Methods: In this study, a location with close proximity to Bandar Abbas oil refinery was selected as the sampling station. The Air Sampling period was from June to September 2010. In order to assess PM_{10} concentrations, the samples were collected using a high volume sampler with fiberglass filters. To measure the concentrations of other air pollutants, including, SO_2, CO, H_2S, and NO_2, real-time instruments were used. With regard to air pollutant concentrations, the AQI values were calculated and for the wind rose, the effect of the oil refinery on Bandar Abbas was evaluated.

Results: According to the results from the present study, PM_{10}, SO_2, nd NO_2 concentrations were higher than the recommended values of the national ambient air standards. The maximum PM_{10} and SO_2 concentrations and their resultant AQI values were observed in August and September, respectively. Other air pollutants had their highest concentrations in July and September, but in no case did they exceed the standard values.

Conclusion: The three most significant outdoor problems with the air quality around Bandar Abbas oil refinery were the NO_2, SO_2, and PM_{10} levels.

Key words: Air quality index, exceeding the standards, refinery

INTRODUCTION

Nowadays, air pollution resulting from fossil fuel combustion, refineries, and many other industries is one of the most important health and environmental problems in developing countries.[1,2] Air pollution effects on human health have been considered by researchers and the public for a long time. As a result, in many developed countries, air pollution control plans have been implemented from the first decade of the twentieth century, for saving human health and the environment.[3]

The most popular and important air pollutants are Ozone (O_3), Sulfur dioxide (SO_2), total suspended particulates (TSP), nitrogen dioxide (NO_2), and carbon monoxide (CO).[4,5] Particulate matters are the most significant pollutants in the world's megacities.[6] Qin and Oduyemi[7] reported construction, excavation, and burning of oil products as the main sources of releasing particulate matters to the atmosphere of Dundee, England. The World Health Organization (WHO) has estimated that 500,000 people die before maturation age as a result of particulate matter in the

Access this article online	
Quick Response Code:	Website: www.ijehe.org
	DOI: *****

air. According to the WHO investigations, every 10 μg/m^3 increase in particulate matters increases the mortality from one to three percent.[8,9] Accordingly, the study of particulate matter characteristics, their sources, and their pattern of release in different cities, is one of the priorities in air pollution control plans. Carbon monoxide, after CO_2, is the most abundant atmospheric pollutant gas in most cities. This gas can bond with hemoglobin and reduce the capability of hemoglobin for oxygen transportation.[3,4] Sulfur dioxide and NO_2 are also important compounds that produce acid rains. These compounds are released into the atmosphere by fossil fuels, vehicles, and gas and oil refineries. The effects of these oxidants on human health include coughing, shortness of breath, impairment of lungs, dry edema, and irritation of eyes, nose, and throat.[5,10]

The air quality index (AQI) is an index for the description of the air pollution status, which was developed in 1993, to describe the air pollution status in a manner that was comprehensible to the public.[11]

Bandar Abbas is one of the most important cities in Iran with regard to its economic, industrial, and historical status, and it has developed greatly in the recent decades. On the one side, the development of industries, increment of vehicles, and high rate of immigration to Bandar Abbas, and on the other, the special geographical location (close to Persian Gulf and Oman sea) and meteorological conditions (high temperature and humidity), increase the potential impact of air pollution in Bandar Abbas.[12,13]

This study was conducted to evaluate AQI and the air pollutant concentrations including PM_{10}, SO_2, CO, H_2S, and NO_2, with regard to the national ambient air standards. In addition, in this study the relationship between air pollution and meteorological parameters, including temperature and humidity, was considered.

MATERIALS AND METHODS

The location of the sampling station was in close proximity to the Bandar Abbas oil refinery. As the most important effects of the pollutant emissions from the refinery were toward the Bandar Abbas city, the location of sampling was chosen between the refinery and the city. The geographical locations of Bandar Abbas and the oil refinery are shown in Figure 1. For 24-hour air sampling, a high volume sampler (Grasseby-Andersen) was used and the samples were collected on fiberglass filters at a flow rate of 1.2 m^3/minute. Air sampling was performed every other day and at least thrice a week, for the period from June to September 2010. To restrict the effect of humidity on the measurements, filters were placed in desiccators and weighed 24 hours before and after sampling. The concentrations of the particulate matter, with a diameter of less than 10 microns, were calculated in μg/m^3 using Equation 1:

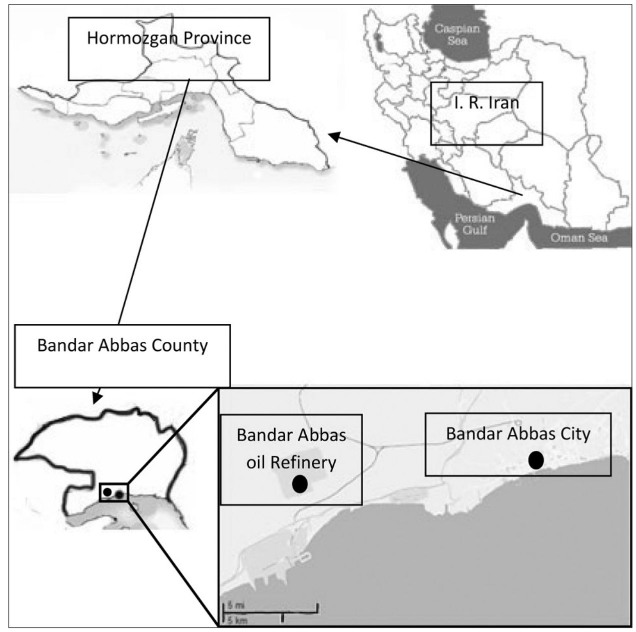

Figure 1: Geographical location of Bandar Abbas and the oil refinery

$$C = \frac{W_2 - W_1}{V} \times 10^6 \quad (1)$$

Where:
C was the concentration of particulate matter (μg/m^3), W_1 and W_2 were the filter weights before and after sampling (g), and V was the volume of air that passed through the filter (m^3).

For measurement of SO_2, CO, H_2S, and NO_2 concentrations, portable real-time instruments (BABUC/A LSI Italy) were used. It was noteworthy that parallel to air sampling, the meteorological parameters, including air temperature, relative humidity, and wind speed were measured. In this study, the data were analyzed using SPSS ver. 16 and the relationship between the monthly mean concentrations of contaminants and meteorological parameters were tested using the Pierson correlation coefficient. The AQI was calculated using the Center for Science and Environment (CSE) according to Equation 2 and Table 1:

$$IP = [(I_{HI} - I_{LO})/(BP_{HI} - BP_{LO})] \times (CP - BP_{LO}) + ILO \quad (2)$$

Where:
IP represents the air pollution index for pollutant P
CP represents the rounded concentration of pollutant P
BP_{HI} represents the breakpoint that is greater than or equal to CP
BP_{LO} represents the breakpoint that is less than or equal to CP
I_{HI} represents the AQI value corresponding to BPHI
I_{LO} represents the AQI value corresponding to BPLO

In order to determine the relationship between the pollutant concentrations and other atmospheric parameters, the

Pearson correlation coefficient was calculated by the SPSS ver.16.0 software.

RESULTS

The results of measuring the air pollutant concentrations, temperatures, and humidity are presented in Tables 2 to 7. According to the results, the concentrations of particulate matters, SO_2, and NO_2 are higher than the maximum allowable concentration of the ambient air standard on some days. The maximum concentrations of particulate matter (430 μg/m^3), NO_2 (0.135 ppm), and SO_2 (0.620 ppm) have been observed in August, July, and September, respectively [Tables 2, 4, and 5]. The highest concentrations of CO and H_2S were observed in July and September, respectively, but in no case were the concentrations higher than the national ambient air standards.

The results of air temperatures showed that the maximum and minimum air temperatures during the investigation period were 38.41°C and 8°C, respectively. In addition, the maximum and minimum wind speeds were recorded to be 4.3 m/s and 0.1 m/s, respectively. Low fluctuations of wind speeds indicated a stable atmosphere in Bandar Abbas. Contrary to wind speeds, the results showed high variations in the level of relative humidity (4 – 87.06%). Analysis of the relationship between air pollutant concentrations and meteorological parameters showed a direct and weak relationship between air temperatures and particulate matter concentrations (R^2=0.0935). In addition there was a direct and weak relationship between relative humidity and SO_2 concentrations (R^2=0.493). Investigation of the relationship between relative

Table 1: AQI categories and break points[14]

Index value (AQI)	Description	PM_{10} (μg/m^3)	NO_2 (ppm)	CO (ppm)	SO_2 (ppm)
0 – 50	Good	0 – 54	*	0 – 4.4	0 – 0.034
50 – 100	Marginal (moderate)	55 – 154	*	4.5 – 9.4	0.035 – 0.144
100 – 200	Unhealthy (poor)	155 – 354	*	9.5 – 15.4	0.145 – 0.304
200 – 300	Very unhealthy (very poor)	355 – 424	0.65 – 1.24	15.5 – 30.4	0.305 – 0.604
>300	Critical	>425	>1. 25	>30.5	>0.605

*NO_2 has no short-term National ambient air quality standards (NAAQS) and can generate an AQI only above a value of 200

Table 2: Maximum, minimum, and mean values of PM_{10} (mean of 24 hours) during the entire study period

Month	Mean concentration (μg/m^3)	Minimum concentration (μg/m^3)	Maximum concentration (μg/m^3)	AQI for maximum concentration
June	100	40	195	123
July	60	20	205	128
August	100	30	430	>300
September	30	20	65	61

Table 3: Values of CO (mean of eight hours) during the entire study period

Month	Mean concentration (ppm)	Minimum concentration (ppm)	Maximum concentration (ppm)	AQI for maximum concentration
June	0.25	0.06	0.41	10
July	0.27	0.02	0.73	12
August	0.15	0.02	0.41	10
September	<0.01	<0.01	<0.01	<2

Table 4: Values of NO_2 (mean of 24 hours) during the entire study period

Month	Mean concentration (ppm)	Minimum concentration (ppm)	Maximum concentration (ppm)	AQI for maximum concentration
June	0.013	0.005	0.027	<200*
July	0.071	0.007	0.135	<200*
August	0.010	0.004	0.027	<200*
September	<0.005	<0.005	<0.005	<200*

*NO_2 has no short-term National ambient air quality standards (NAAQS) and can generate an AQI only above a value of 200

Table 5: Values of SO_2 (mean of 24 hours) during the entire study period

Month	Mean concentration (ppm)	Minimum concentration (ppm)	Maximum concentration (ppm)	AQI for maximum concentration
June	>0.001	>0.001	>0.001	0
July	>0.001	>0.001	>0.001	0
August	>0.001	>0.001	>0.001	0
September	0.342	0.065	0.620	>300

humidity and particulate matter concentrations showed a high and significant correlation (R^2=0.9).

Calculated AQI values for pollutants including PM_{10}, CO, NO_2, and SO_2 are presented in Tables 2–5. According to the results, the AQI values for PM_{10} were higher than the standard levels (100) in June, July, and August and the AQI value for SO_2 was higher than the standard level in September.

The wind direction and speed roses indicated that the prevailing wind direction was eastward during the study period [Figure 2], but the highest wind speeds were related to the south east and south west [Figure 3].

DISCUSSION

The results of the present study suggest that concentrations of CO during the study period comply with the national ambient air standards. Although there were some fluctuations in the atmospheric concentrations of CO at midnight and early morning, they did not lead to an increase from the national ambient air standards. The fluctuations could have been due to vehicle traffic in the refinery. The source of H_2S was believed to be mainly from the refinery processes. Considering the results, it was revealed that the H_2S concentrations were lower than the national ambient air standards. According to the wind rose graph, the extension of H_2S release was north-eastward and toward the eastern regions during the study period. Regarding the eight-hour ambient air standard level for SO_2 (0.14 ppm), the concentrations of SO_2, except for September, were less than the ambient air standard levels. For NO_2, it was revealed that in July, the NO_2 concentrations exceeded the ambient air standard levels. These exceedances from the national ambient air standards had occurred in five days and their cause was mainly repairing of the caustic unit of the refinery. With regard to the investigation of particulate matter, it was revealed that there was a direct and significant relationship between particulate matter concentrations and relative humidity (R^2=0.9). This could be due to the increasing adhesion capability of the submicron particles, because of higher humidity, which created larger particles that could be trapped by a fiberglass filter. The results indicated that the maximum concentration of particulate matter was 430 $\mu g/m^3$. As, according to ambient air standard, the maximum 24-hour allowable concentration of PM_{10} was 200 $\mu g/m^3$, it could be implied that in this case the concentration of particulate matter was more than twice that of the ambient air standard level. The calculated AQI (>300) for this concentration revealed that this situation should be considered as a critical situation [Table 1]. Although this level of PM_{10} concentration was much higher than that of ambient air standard. A similar study was conducted by Gurjar *et al.* (2007) in several megacities that maximum concentration of PM_{10} was reported to be 700 $\mu g/m^3$ in Karachi.[4] Although the mean PM_{10} concentration in our study was lower than that in Karachi city, it was higher than the concentrations of PM_{10} in many other cities that were reported by Gurjar.[4] The reason for such high concentrations could be attributed to high relative humidity and low wind speeds in the Bandar

Table 6: Values of H_2S (mean of eight hours) measured during the entire study period

Month	Mean concentration (ppm)	Minimum concentration (ppm)	Maximum concentration (ppm)
June	0.003	0.0001	0.0055
July	0.0025	0.001	0.007
August	0.0023	0.0015	0.004
September	0.0033	0.001	0.0145

Table 7: Maximum and minimum temperatures and humidity during the entire study period

Month	Minimum temperature (°c)	Maximum temperature (°c)	Minimum humidity (%)	Maximum humidity (%)
June	12	37	4	62
July	25	38.5	14	78
August	17	37	28	78
September	8	35	20	82

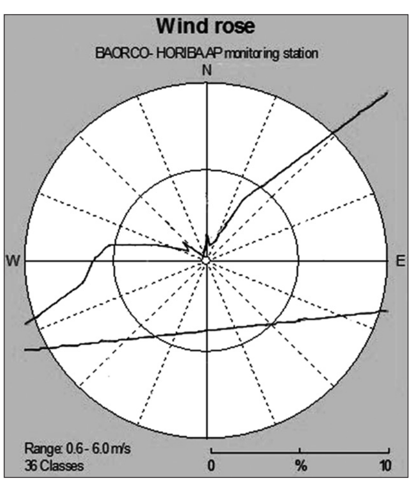

Figure 2: Wind direction rose during the study period

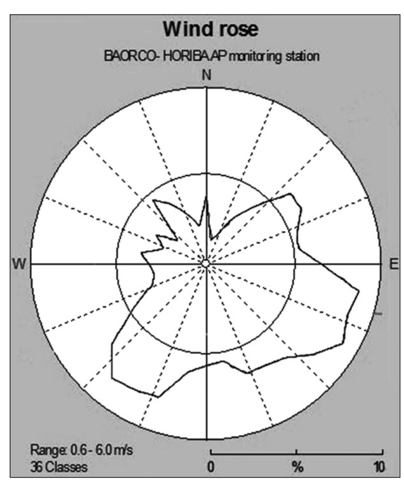

Figure 3: Wind speed rose during the study period

Abbas County. Considering the results of this study, it could be implied that although air pollution was anticipated to be a problem in winter, as a result of inversion and atmospheric stability, it could be a problem even in summer in Bandar Abbas.

Unlike this study, the results of Lee *et al.*'s study showed that the SO_2 levels at 14 public places in Hong Kong were much lower than the standards.[15] The main reason for this difference was the place of sampling. In fact in this study, the place of sampling was near the oil refinery where sulfur fuels were one of the important raw materials.

In the time period study, the wind direction was eastward from the refinery to Bandar Abbas [Figure 2]. Regarding this condition and taking into account the fact that the speed of the wind was not high, the AQI was anticipated to increase during some periods of time, especially in September (according to Table 7, AQI in the sampling station was more than 300 in September).

Although this study has highlighted some potential air quality problems at places near the refinery, it needs to investigate more pollutants, at longer time periods, at such places.

Generally the three most important outdoor air quality problems around the Bandar Abbas oil refinery are the NO_2, SO_2, and PM_{10} levels. Although this study shows that the concentration of particulate matters, SO_2, and NO_2 are high only for short periods of time, the risk of air pollution hazards seems to be considerable. The main reason for this statement is that the meteorological conditions of Bandar Abbas observe fluctuations in the concentration of contaminants, probable atmospheric stability, and a probable synergistic effect of particulate matters and sulfur compounds. Therefore, this study highlights the need for conducting more studies to find the main sources of air pollution and strategies for their control, in the Bandar Abbas.

REFERENCES

1. Wark K, Warner CF, Davis WT. Air pollution its origin and control. Berkley, California: Addison Wesley Longman Inc.,1998.
2. Neidell MJ. Air pollution, health, and socio-economic status: The effect of outdoor air quality on childhood asthma. J Health Econ 2004;23:1209-36.
3. Bai N, Khazaei M, van Eeden SF, Laher I. The pharmacology of particulate matter air pollution-induced cardiovascular dysfunction. Pharmacol Ther 2007;113:16-29.
4. Gurjar BR, Butler TM, Lawrence MG, Lelieveld J. Evaluation of emissions and air quality in megacities. Atmos Environ 2008;42:1593-606.
5. Dab W, Medina S, Quenel P, Le Moullec Y, Le Tertre A, Thelot B. Short term respiratory health effects of ambient air pollution: Results of the APHEA project in Paris. J Epidemiol Community Health 1996;50: S42-6.
6. Gamble JF, Lewis RJ. Health and Respirable Particulate (PM_{10}) Air Pollution: A Causal or Statistical Association?. Environ Health Perspect 1996;104;838-50.
7. Qin Y, Oduyemi K. Atmospheric aerosol source identification and estimates of source contributions to air pollution in Dundee. Atmos Environ 2003;37:1799-809.
8. Jerretta M, Buzzellib M, Burnettc RT, DeLuca PF. Particulate air pollution, social confounders, and mortality in small areas of an industrial city. Soc Sci Med 2005;60:2845-63.
9. Spengler JD, McCarthy JF, Samet JM. Indoor Air Quality Handbook. New York: MC Graw-Hill; 2000.
10. Atkinson RW, Anderson HR, Strachan DP, Bland JM, Bremmer SA, Ponce de Leon A. Short-term associations between outdoor air pollution andvisits to accident and emergency departments in London for respiratory complaints. Eur Respir J 1999;13:257-65.
11. Hamekoski K. The use of a simple air quality index in the Helsinki Area, Finland. Environ Manage 1998;22:517-20.
12. Breed CA, Arocena JM, Sutherland D. Possible sources of PM_{10} in Prince George (Canada) as revealed by morphology and *in situ* chemical composition of particulate. Atmos Environ 2002;36:1721-31.
13. Moolgavkar SH. Air pollution and daily mortality in three U.S. Counties. Environ Health Perspect 2008;108:777-84.
14. Goyal P. Flexibility in estimating air quality index: A case study of Delhi. Global Journal of Flexible System Management. 2001;2:39-44.
15. Lee SC, Chan LY, Chiu MY. Indoor and outdoor air quality investigation at 14 public palaces in Hong Kong. Environ Intern 1999;25:443-50.

How to cite this article: ???

Source of Support: Nil, **Conflict of Interest:** None declared.