ORIGINAL ARTICLE

Evaluation of a Dispersion Modeling Software Package (Case Study: Traffic Pollutants in Shiraz Iran)

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Abstract

Background: The AERMOD is one of the EPA preferred and recommended air quality dispersion models. The AERMOD is a steady state dispersion model for estimating the concentration of pollutants in urban, rural, flat and elevated, ground level and elevated receptors from different volumes, areas or point sources.

Methods: In this study, in order to evaluate the accuracy of software results, the AERMOD was used for estimating the air pollution concentrations at different locations in Emam Hossein Square and Darvazeh Kazeroun Square of Shiraz City, where there are two DOE air quality monitoring stations. The modeling was performed based on hourly annual metrological data of Shiraz airport. The variable air pollutants' emission rates were used based on different traffic loads at different hours at night and during the day.

Results: The modeling results are compared with the values measured at DOE air quality monitoring stations. The results showed that for the maximum daily concentration of pollutants, the AERMOD estimated values were about 5 and 20 percent higher than the values measured for SO_2 and CO; also, the estimated values were two times higher than the measured values for NO_x and PM_{10}. Furthermore for the average daily concentration of pollutants, the AERMOD estimated values were about 17, 41, 42 and 38 percent lower than the values measured for NO_x, CO, SO_2 and PM_{10}, respectively.

Conclusion: The quality of ambient air in Shiraz City seems to be good since, except for the PM_{10}, the concentrations of CO, NO_x and SO_2 were in the range of clean air standard. The maximum daily concentrations of PM_{10}, CO, NO_x and SO_2 were reported as 0.497 mg/m^3, 4246 mg/m^3, 0.206 mg/m^{3}and 0.037 mg/m^3, respectively.

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Received: 30 July 2017
Revised: 16 August 2017
Accepted: 11 September 2017

Please cite this article as: Asrari E, Faraji M. Evaluation of a Dispersion Modeling Software Package (Case Study: Traffic Pollutants in Shiraz Iran). J Health Sci Surveillance Sys. 2017;5(4):164-168.

Keywords: Traffic pollution, Air pollutants, Quality, Ambient air

Introduction

Air pollution is the presence of one or more substances in the air at a concentration or for duration above their natural levels, with the potential to produce an adverse effect.[1] The main air pollutants are suspended particulate matter (SPM), carbon monoxide, nitrogen oxides and sulfur oxides. The Particulate Matter (PM) refers to solid particles and liquid droplets in the air. Carbon Monoxide (CO) is a toxic gas which is mostly produced by incomplete combustion of fossil fuels. Nitrogen Oxides (NO_x) are toxic gases which are produced by high temperature combustion of fuels and contribute to the formation of smog and acid rain. Sulfur Oxides (SO_x) are toxic gases which are produced by burning of fossil fuels contaminated with sulfur compounds. The

Iranian Clean air Quality standard was developed by Department of Environment (DOE) to limit the PM, CO, NO_x, SO_x to 0.15 mg/m^3, 10 mg/m^3, 0.2 mg/m^3 and 0.39 mg/m^3, respectively, in the urban and rural ambient air.

In the cities, the main emission sources of air pollutants (PM, CO, NO_x, SO_x) are motor vehicles in the streets. Previous studies have shown that long-term exposure to traffic-generated pollutants is the main factor of various adverse health problems.[2] Mostly, the air quality monitoring stations were located beside square/streets with a high traffic rate. It is expected that the measured concentration of air pollutants should be the maximum concentration in an air quality monitoring stations. Therefore, in order to find the city zones with high air pollutants' concentration or select a zone for installation of a new air quality monitoring station, there is a need to know air pollutant concentrations at different locations in the city streets. The ambient air sampling is costly and time wasting and the dispersion modeling has some uncertainties in results. Dispersion models are now widely used for assessing roadside air quality by providing predictions of the present and future air pollution levels as well as temporal and spatial variations.[3] They can be very useful in giving insights into the physical and chemical processes that govern the dispersion and transformation of atmospheric pollutants.[4] The results of a dispersion study of CO along a street path in Tehran showed that the maximum concentration of pollutants was in the dense level and at early hours of the day.[4] The simulation of different wind speed and direction on the pollutant dispersion showed that the wind speed and direction had a great impact on the air flow and pollutant dispersion in streets.[6] The pollutant concentrations for vertical and inclined wind at the leeward side is much higher than the windward side,[7] but before using the results of a dispersion model the uncertainties of the results should be evaluated.

The EPA Regulatory Model (AERMOD) is one of EPA preferred and recommended air quality dispersion models. The effectiveness of AERMOD was studied by Bin Zou, suggesting that SO_2 concentrations simulated by AERMOD at the 8 h, daily, monthly, and annual intervals match their respective observed concentrations much better compared with the simulated 1 and 3 h SO_2 concentrations.[8] This study aimed to evaluate the uncertainties of AERMOD predicted values for PM_{10}, CO, NO_x, SO_x by modeling of street cars traffic emission in Shiraz city in Iran.

Methods

In this study, EPA AERMOD software was used to estimate the concentration of air pollutants in two different locations in the Eman Hossein Square and Darvazeh Kazeroun Square in Shiraz City where there were two air pollution monitoring stations, as shown in Figures 1 and 2.

Figure 1: Eman Hossein Square of Shiraz City

Figure 2: Darvazeh Kazeroun Square of Shiraz City

The AERMOD dispersion model developed for modeling short-range (up to 50 km) dispersion from the point, area, and volume polluting sources. The configurations include urban or rural dispersion coefficients for simple and complex topographies.[8] The model has the capacity to employ hourly sequential preprocessed meteorological data to estimate concentrations of the pollutants at receptor locations and different time scales ranging from 1 h to 12 months.[9]

The seasonal change affects the pollutants' dispersion, especially changes in atmospheric parameters such as wind velocity and direction, ambient air temperature, and relative humidity. Therefore, the modeling was carried out based on 2012 hourly weather data as recorded by weather station located in Shahid Dastghaib airport in Shiraz. Figure 3 shows the resulted wind rose of 2012 for Shiraz City. Also, the surface roughness, Bowen ratio and Albedo should be specified monthly, seasonally, or annually. The features used are presented in Table 1.

The maximum traffic load was estimated for all street lines full of cars with 15 meters intervals. The maximum emission rate of air pollutants was estimated based on 30 km/h speed for vehicles, considering the emission factor of each pollutant. The emission factor used for CO and NO_x was respectively 0.86 g/km and 13 g/km. The emission factor used for SO_2 and PM_{10} was 1.3 g/l and 2.2 g/l based on fuel consumption of 0.16 l/km (Table 2).[10]

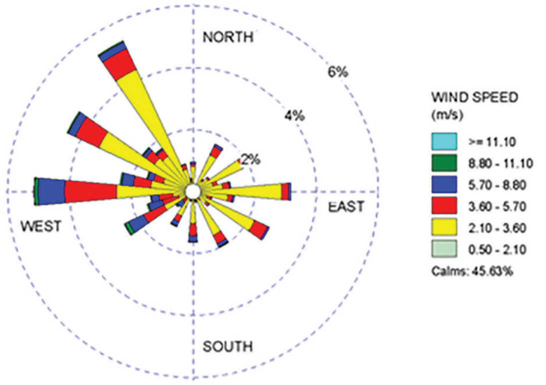

Figure 3: Windrose of Shiraz City Based on 2012 Meteorological Data

Table 1: Parameters for different seasons

Seasons	Albedo	Bowen ratio	Surface (m) roughness
Spring	0.18	4	1
Summer	0.16	4	1
Autumn	0.14	2	1
Winter	0.35	2	1

Table 2: Emissions flux of traffic pollutants

Pollutant	Emission rate	Pollutant flux
NO_x	0.86 g/km	0.44 g/m^2.h
CO	13 g/km	11.47 g/m^2.h
SO_2	0.21 g/km	0.11 g/m^2.h
PM_{10}	0.35 g/km	0.18 g/m^2.h

The Emissions Flux of traffic pollutants in a street varies with the number of vehicles at different times in a day. In order to estimate the amount of emission at different hours in a day, we applied the hourly traffic ratio to maximum pollutant fluxes for 24 hours period, as reported in Table 3. The coefficients were estimated based on the counting of cars in the street at different time intervals.

The AERMOD model requires an input file containing the information of pollutant emission sources and the positions of the receptors. The streets crossing the square were defined as line area emission sources and the location of pollution monitoring station was defined as receptor. The monitoring station close to Eman Hossein square was receptor 1 and the other one was receptor 2 which was close to Darvazeh Kazeroun square.

Results

Traffic emissions were modeled for the adjacent streets of monitoring stations 1 and 2based on the hourly traffic data and meteorological data by AERMOD software. The maximum, average and minimum daily concentrations of air pollutants were compared with the values recorded by monitoring stations. The results are presented in Table 4.

For the daily concentration of pollutants, the maximum daily concentrations were estimated by AERMOD about 5% and 20% higher than the maximum recorded concentration at monitoring stations for SO_2 and CO, respectively. The estimated maximum daily concentration of NO_x and PM_{10} was about twice higher than the maximum values recorded. The AERMOD estimated average daily concentrations were less than the average of daily recorded values for all pollutants. The AERMOD estimated daily average concentrations were 17, 41, 42 and 38 percent lower than the average of daily recorded values for NOx, CO, SO_2 and PM_{10}, respectively. The minimum daily concentrations estimated by AERMOD were much less than the minimum of daily recorded values at monitoring stations for all pollutants.

For the monthly average concentration of pollutants, the estimated values by AERMOD software were compared with the monthly average of the recorded daily concentrations at online monitoring stations. The results are shown in Figures 4 to 7 for NO_x, CO, SO_2 and PM_{10}.

As stated in Figure 4, the calculated average monthly CO concentration by the AERMOD software was significantly lower than the average of the recorded values. Since the difference of the estimated monthly

Table 3: Traffic coefficients

Time in night/day	00-04	04-05	05-06	06-07	07-09	09-11
Peak Fraction	0.05	0.1	0.5	0.8	1	0.8
Time in night/day	11-14	14-16	16-20	20-22	22-23	23-24
Peak Fraction	1	0.8	1	0.5	0.3	0.1

Table 4: Daily Min./Max/Avg. Concentrations

Pollutant	Recorded by Monitoring Station			Modeling results by AERMOD		
	Max. (mg/m^3)	Avg. (mg/m^3)	Min. (mg/m^3)	Max. (mg/m^3)	Avg. (mg/m^3)	Min. (mg/m^3)
NO_x	0.206	0.082	0.053	0.605	0.068	0.002
CO	4.246	1.821	1.187	5.126	1.071	0.031
SO_2	0.037	0.019	0.005	0.039	0.011	0.001
PM_{10}	0.497	0.068	0.011	1.428	0.042	0.001

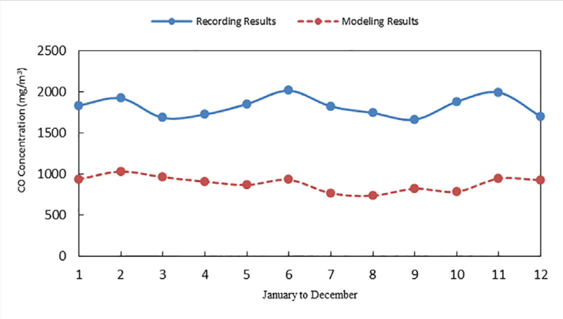

Figure 4: The estimated monthly average concentration of CO by AERMOD versus monitoring station (1)

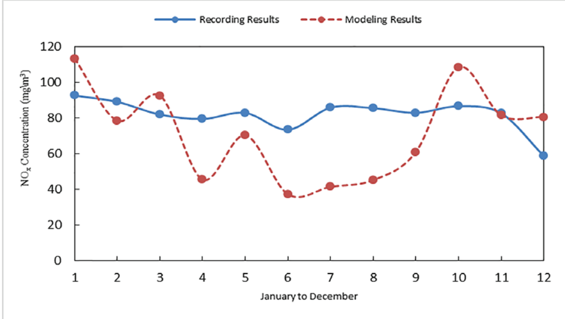

Figure 5: The estimated monthly average concentration of NO_x by AERMOD versus monitoring station (2)

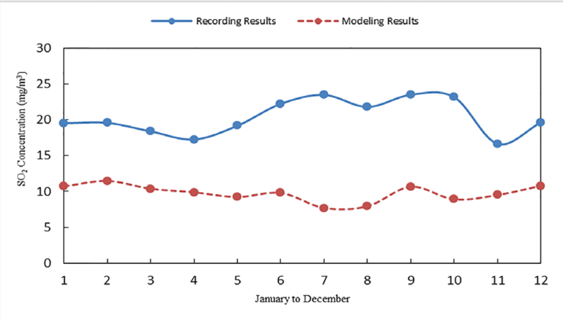

Figure 6: The estimated monthly average concentration of SO_2 by AERMOD versus monitoring station (1)

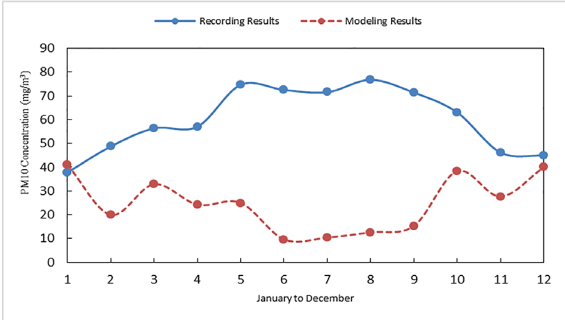

Figure 7: The estimated monthly average concentration of PM10 by AERMOD versus monitoring station (2)

average concentration with the monthly average of the recorded values in all months was almost constant, it seems that this may be due to uncertainty in the CO emission factor for vehicles and/or traffic load. The results of the calculations iare acceptable with an increase in the emission factor about 1.4 times.

As shown in Figure 5, the calculated average monthly NO_x concentration by the AERMOD software was less than the values measured during 5 months of the year. This difference was significant for the spring and summer, considering the fact that this was partly due to the increase of NO_x emissions in the autumn and winter due to the operation of household heating devices.

As shown in Figure 6, the calculated average monthly SO_2 concentration by the AERMOD software was significantly lower than the average of the recorded values. Since the difference of the estimated monthly average concentration with the monthly average of the recorded values during all months was almost constant, it seems that this may be due to uncertainty in the SO_2 emission factor for vehicles and/or traffic load. The results of the calculations are acceptable with an increase in the emission factor about 2 times.

As shown in Figure 7, the calculated monthly average concentration of PM_{10} by the AERMOD software was significantly less than the recorded values during the months of the summer and autumn. This difference was significant due to dust transfer from the deserts to cities by wind.

Discussion

For the daily concentration of all pollutants, the predicted maximum daily concentrations by AERMOD were greater than the recorded values. Therefore, the AERMOD estimation for maximum daily concentrations was conservative and the uncertainty of AERMOD results would be acceptable in estimation of maximum daily concentration of pollutants resulting from vehicles emission. However, for the AERMOD estimated daily average concentration and also for the daily minimum concentration, the AERMOD estimated values were lower than the recorded values. Consequently, the uncertainty of AERMOD would not be acceptable in estimation of average and minimum daily concentration of traffic pollutants.

For the monthly average concentration of pollutants, the AERMOD modeling results showed that the calculated values for all traffic pollutants were lower than those recorded in different months. Since the average monthly pollution rates are not dependent only on traffic pollution and there are many other fixed emission sources of air pollutants such as small industries and heating sources at homes which were not considered in this study, the uncertainty of modeling results may be due to the lack of input data or model. Thus, further studies are required to be conducted to evaluate the AERMOD uncertainties in estimation of the monthly average concentration of the pollutants.

Conclusion

As to the clean air standard and the pollutant concentrations recorded in 2012, with the exception of PM_{10}, the daily concentrations of CO, NO_x and SO_2 were within acceptable limits on most days of the year in Shiraz city. The results revealed differences between the estimated maximum, average and minimum daily concentrations of air pollutants by AREMOD modeling versus records of monitoring stations.

The constant differences between the estimated concentrations versus the records of air pollutants indicate some uncertainties in the model input data like emission factors and/or traffic load. The results confirm the research conducted by Bin Zou, showing that AERMOD model has better estimation for monthly average concentrations versus 1 hour, 8 hours or daily averages.

The AERMOD estimation for maximum daily concentrations was conservative. The results showed that in order to predict the concentration of pollutants in an urban atmosphere by AREMOD, we should take the uncertainties of the input data like emission factors, the traffic load and other stationary emission sources into account.

Conflict of Interest: None declared.

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