Available online www.ijpras.com

International Journal of Pharmaceutical Research & Allied Sciences, 2016, 5(4):262-270

Research Article

ISSN : 2277-3657
CODEN(USA) : IJPRPM

Evaluation of AERMOD for Distribution Modeling of Particulate Matters (Case Study: Ardestan Cement Factory)

Afsaneh Fadavi, Maryam Foroughi Abari*, Mozhgan Ahmadi Nadoushan

Department of Environmental Sciences, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

ABSTRACT

*Air pollution is a major consequence of modern life, and industrial pollution is one of the primary sources of environmental pollution. In fact, the cement industry is one of the biggest sources of environmental pollution and it has a huge impact on air quality. In this respect, modelling of the air quality is a suitable tool for forecasting the air quality in the future. This method helps determine the strategies of emission control because, otherwise, monitoring and measuring air pollutants is a time-consuming and costly task. The main objective of this study is using the AERMOD model as a tool to analyse the distribution of Total Suspended Particles (TSP) derived from the stacks of Ardestan Cement Company. The distribution of pollutants is studied using the AERMOD in a 30*30 Km^2 area in every direction of X and Y for average time periods of 1 hour, 24 hours, and a year. Moreover, the output of this model is compared with the results of a field survey, based on Environmental Protection Agency (EPA) factors in four-point surroundings of the factory. The results showed that the concentration of particulate matter (PM) was below the defined standards of the EPA and clean air in Iran. Also, the analysis showed that modelling with AERMOD generated acceptable results.*

Keywords: *Dispersion, Cement Industry, AERMOD, Total Suspended Particles (TSP), Modelling, EPA Factors*

INTRODUCTION

Air pollution is one of the biggest results of civilization. Considering the increase in the use of energy along with population growth and rapid development and industrialization, the trend of air pollution across the world is an inevitable one. Air pollution can be defined as an undesirable change in the physical, chemical, and biological properties of the air [1]. Today, the effects of air pollution have resulted in the fact that supervision and control of air quality are discussed in all societies and are at the top of national issues [2]. The spread of this pollution severely jeopardizes human life. In fact, the World Health Organization (WHO) has reported the deaths of 800,000 people per year because of lung cancer, respiratory diseases, and cardiovascular diseases caused by air pollution. Therefore, air quality management strategies are essential to minimize the acute effects of air pollutants. Identifying the type of pollutants from various sources and investigating their effects are important for proper management of air quality. Industrialization is one of the major air polluting factors, and there is a significant relationship between the number of asthma patients and level of urban air pollution in response to industrialization [3]. Furthermore, the cement industry is one of the biggest sources of air pollution in today’s world. It plays a vital role in disrupting the balance of natural life and the development of environmental anomalies [4]. This industry leads to the entrance of particulate matter (PM) into the atmosphere and the accumulation of debris around the factory, resulting in environmental pollution. Further, the rise of PM in the atmosphere is of special importance, affecting the health, ecosystem, and biosphere [5]. Considering the constant growth of industries, the need of instruments and methods for controlling and managing pollutants is now being felt more than ever. Air pollution modelling is an instrument that helps researchers understand the main characteristics of air pollution and predict the concentration and distribution of pollutants [6]. It is one of the effective and reliable methods for simulation and prediction of air quality [7]. The American meteorological/ environmental protection Agency Regulatory Model (AERMOD) is a new generation distribution model, which was introduced by the Environmental Protection Agency (EPA) in 2004. This was introduced after 14 years of investigation as the body's favourite model, which can be used to determine the concentration of different pollutants of surface sources. The studies that have been performed on AERMOD confirm great similarities between the results of the model and those in the real world [4]. This system of modelling consists of three primary components: AERMET, the processer of meteorological data; AERMAP, the earth digitized processer; and AERMOD, the model of pollution distribution in the air [8]. To determine the accuracy of the model, proper validation is essential. The EPA applies various stages for validation and for recognizing whether changes have been developed arbitrarily in the model or not [9].

2. MATERIALS AND METHODS

2.1. Study area

The Ardestan cement factory has been constructed on a 90-hectare plot of land situated at a longitude of 598802.00 and latitude of 366347.00. The land is 65km away from the northeast of Isfahan province in a region with poor water resources. This factory was established in July 2003 and construction work started officially in 2005. Within three years, the entire construction was over and the factory was officially inaugurated.

Fig.1. A view of the factory

The current production capacity of the factory is 3,550 tonnes/ day and it produces a wide variety of grey cements. The high-quality Ardestan cement has domestic uses in both Isfahan province and its adjacent provinces. It is also exported to Iran's neighbouring countries including Iraq, Uzbekistan and Turkmenistan, and Persian Gulf countries through railway. But the cement production process in the factory results in the presence of particulate matter components around the Ardestan cement complex. Therefore, determining the factory's contribution to the level of pollution in the region is significant in controlling and monitoring it. The Ardestan cement factory has 25 stacks, around which TSPs are present. In fact, TSPs are among the major pollutants, thereby causing air pollution in the factory's enclosure and its surroundings. The main objective of this study is to evaluate the AERMOD model to predict the distribution of PM and to suggest solutions to control and decrease emission of these pollutants.

2.2. Data and procedure

2.2.1. Collecting required information about particulate matter emission fromstacks

Firstly, the level of emission of PM from the stacks of the factory was estimated across all four seasons in 2014. This was based on the monitoring of reports of the concentration of PM, which had been done by a trusted laboratory of the environmental agency in a periodic fashion. Furthermore, the concentration of TSP in the air around the factory was measured for validation and evaluation of the results of the model's output in four stations around the factory. The MET ONE device, which had exchangeable laser sensors and had been made in USA, was used as the tool of measurement. This device transfers the parameters to the system based on vaulted change and then demonstrates in terms of standard unit.

2.2.2. AERMOD model

AERMOD is a Gaussian plume model (distribution of permanent state) for steady state and close-to-site cases. This model is able to simulate multiple sources of pollution from different types of pointed, superficial, and volumetric in urban and rural regions. It also demonstrates air distribution based on boundary turbulence structure and at stack scale with acceptable states [10]. Moreover, it consists of two pre-processors called AERMET and AERMAP. When the information derived from these two pre-processors is completed and run, the main processing takes place in AERMOD, which presents the final simulated output [11].

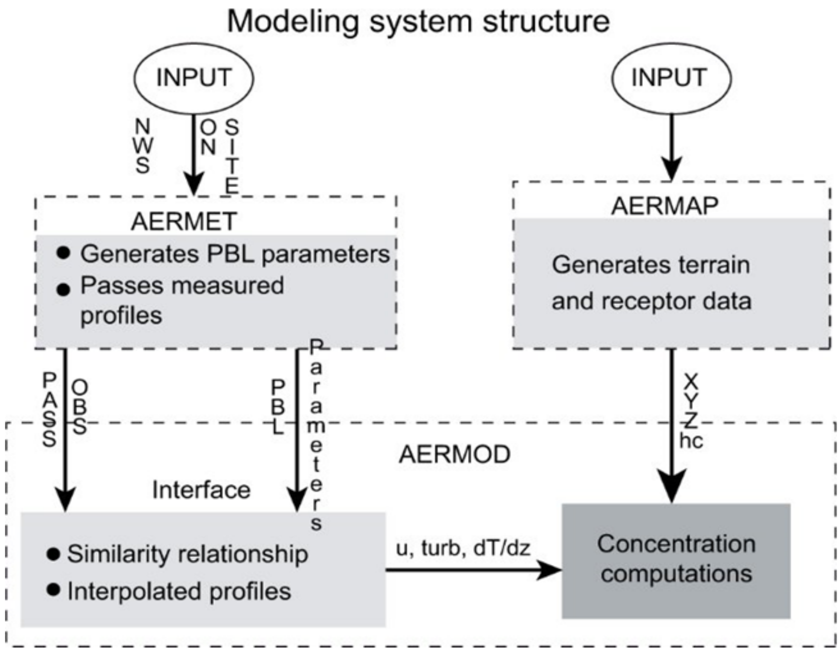

Fig. 2. The structure of AERMOD model [12]

2.2.3. Running AERMET pre-processor

AERMET calculates the boundary conditions required for AERMOD, based on meteorological information and the properties of the environment. Meteorological data was prepared from all meteorological stations in Ardestan city, with a longitude of 52 and latitude of 33, and altitude of 1200. These data were in Excel form. To detect these files in the AERMET pre-processor, they were converted to SAMSON format. In this project, temperature, humidity percentage, cloud coverage, wind speed, dew point, and the station pressure were considered as profile parameters. The AERMET pre-processor needs three superficial characteristics of the studied region, which are Bowen ratio, Albedo coefficient, and the length of the surface roughness. To determine these values, the studied region was divided into suitable segments considering the type of use and vegetation of the surrounding areas. Based on the abovementioned points, one segment was taken into consideration, and the values of the three characteristics were specified annually, as shown in Table 1.

Table 1. The surface characteristics of the study area on an annual basis

The length of the surface roughness	Bowen ratio	Albedo coefficient
0.2625	4.75	0.3275

In Fig. 3, the wind rose plot of the region has been presented based on meteorological data. As can be observed in the figure, the direction of the dominant wind is from Northeast to Southwest.

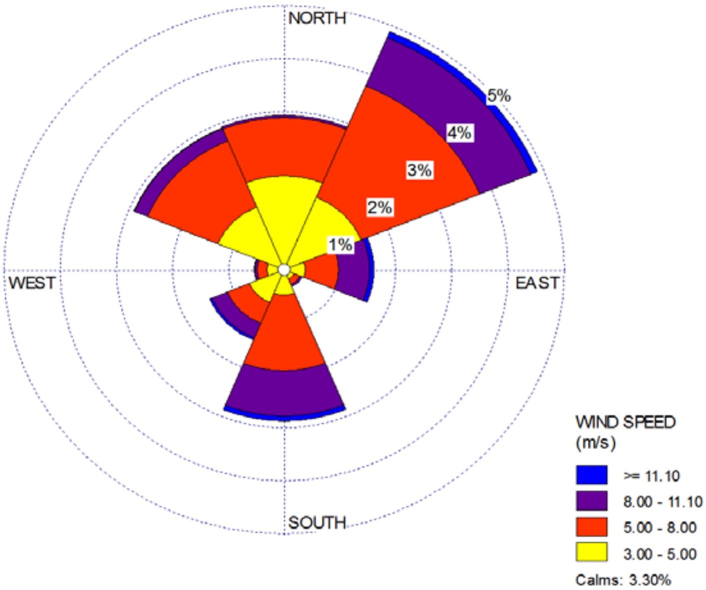

Fig. 3. The wind rose plot prepared by the meteorological data of the study area

After running the AERMET pre-processor and preparing the meteorological files required by the AERMOD model, the information of the project was introduced using the input file that is to be processed by the model.

2.2.4. Running AERMAP pre-processor

AERMAP is the second pre-processor of AERMOD. To analyse the topography of the region, the AERMAP pre-processor was used. This pre-processor determines the altitude of the ground beneath all the receivers, sources, and the height scale of every receiver that has the greatest effect in the distribution of the pollutants in that receiver [8]. This pre-processor called Terrain can be found in the main AERMOD software. In this project, digitized elevation model (DEM) was adopted from the US geology site (USGS) with a format of GEO TIFF.

In this study, the main stack of the factory was chosen as the origin of the coordinates. Further, the homogeneous network receiver dimensions which had 441 cells was defined, where each cell lay within a range of 81*81 km^2 (regional scale) with a network distance of 1248m at a longitude of 59479.20 and latitude of 2973.96. The scales were selected in a way that the range would reach Ardestan city. The modelling of the manner of distribution of the PM pollutants was performed for mean times of one hour, 24 hours, and one year.

2.3. Model validation

In this study, four receivers were determined, belonging to the four main directions of the factory. This was done to evaluate the results obtained from the modelling by AERMOD model with the field-measured values. The evaluation was done by statistical parameters proposed by the United States Environmental Protection Agency.

Table 2. The criteria specified for the factors by EPA [13]

Parameter	Proper value
Model Bias $= (\overline{C_p - C_0})$	N/A
Fractional Bias (FB) $= 2(\frac{\bar{C}_0 - \bar{C}_p}{\bar{C}_0 + \bar{C}_p})$	-0.5<FB<0.5
Fractional Variance (FS) $= 2(\frac{\sigma_{C_0} - \sigma_{C_p}}{\sigma_{C_0} + \sigma_{C_p}})$	N/A
Normolized Mean Square Error (NMSE) $= \frac{\overline{(C_p - C_0)^2}}{\overline{C_0}\,\overline{C_p}}$	NMSE<0.5
Geometric Mean Bias (MG) $= \exp[\overline{(\ln C_0)} - \overline{(\ln C_p)}]$	0.75<MG<1.25
Geometric Mean Variace (VG) $= \exp\left[\overline{(\ln C_0 - \ln C_p)^2}\right]$	0.75<VG<1.25
Factor of Two (Fa2) = Fraction of Data which $0.5 \leq \frac{C_p}{C_0} \leq 2.0$	Fa2>0.8

3. RESULTS

In this research, the manner of distribution of the pollutants was investigated using the AERMOD distribution model in a region with an area of 30*30 km^2 at a longitude of 598802 and latitude of 3663470. The study was done within a one-year statistical period (2014) for mean times of one hour, 24 hours, and one year. The results were individually compared with the standards of Iran's clean air, EPA's, and WHO's. Based on Fig. 4, which demonstrates the maps of distribution of the pollutants with regard to one-hour map, the greatest concentration of PM within this period lay within 4.7mcg/m^2 and 471.9mcg/m^2. The highest concentration was observed in the range of the factory's main centre (close to the source). When measured at a distance from the centre, the concentration of TSP started to decline. According to Fig. 5, which is the distribution map extracted from the model for the 24-hour mean time, the range of the distribution of concentrations was estimated to be somewhere between 0.4mcg/m^3 and 35.9mcg/m^3. As can be observed in Fig. 6, the range of concentrations simulated within the annual time period lay between 0.02mcg/m^3 and 2.31mcg/m^3.

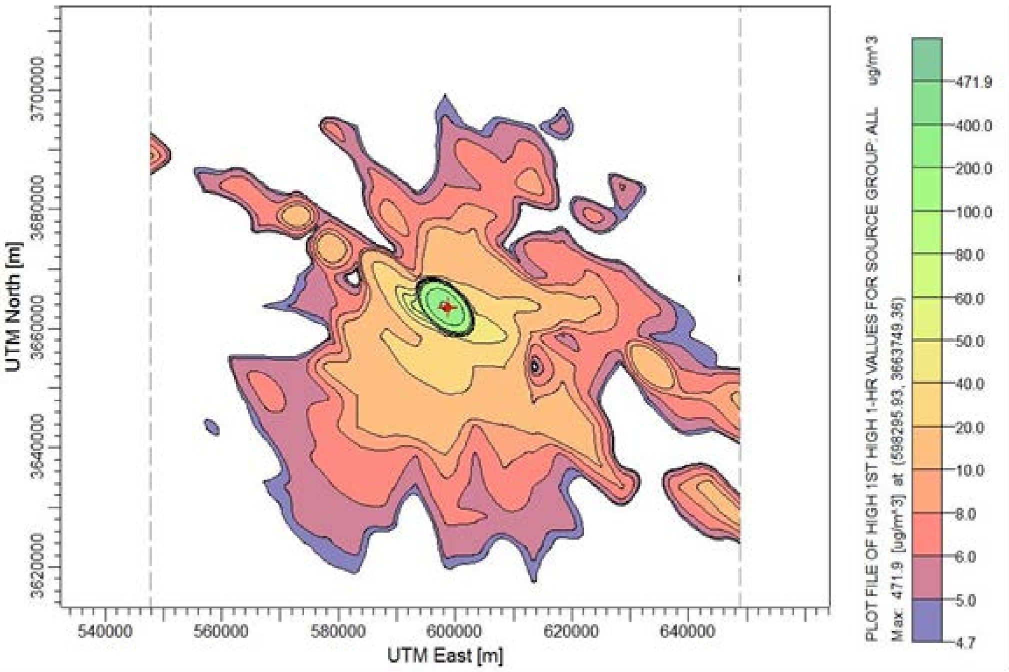

Fig. 4. The distribution of total suspended particulates (TSP) for the mean time of one hour

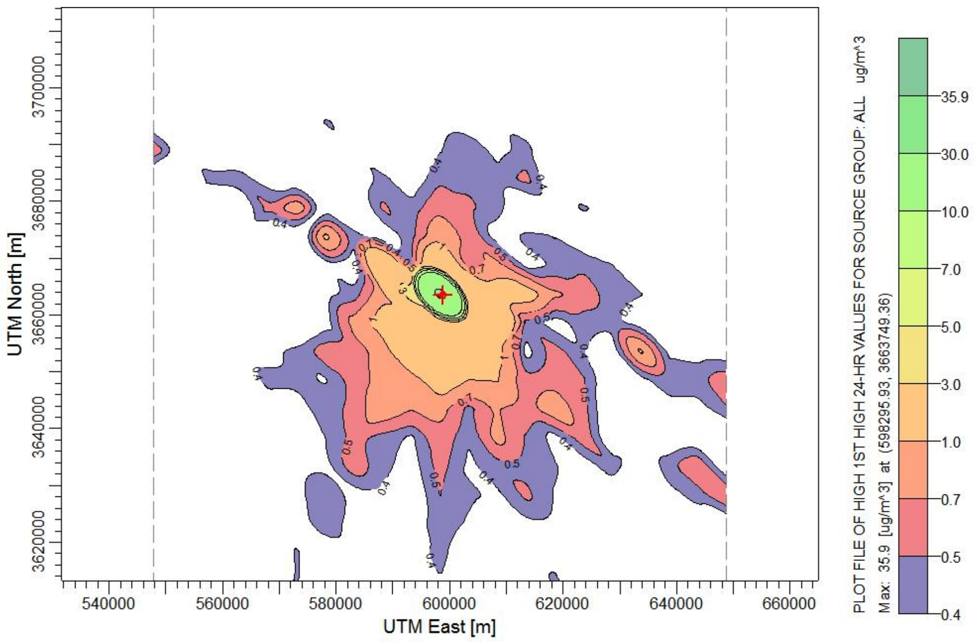

Fig. 5. The distribution of total suspended particulates (TSP) for the mean time of 24 hours

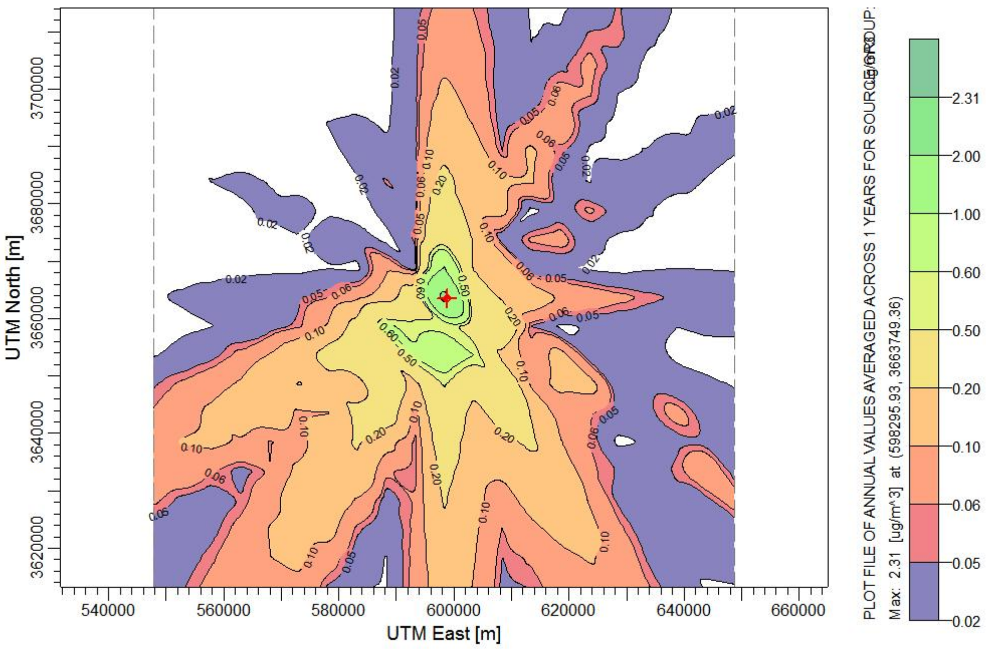

Fig. 6. The dispersion of total suspended particulates (TSP) for annual statistical period

In table 3, the maximum concentrations are presented in each of the one-hour, 24-hour, and annual temporal means along with geographical longitudes and latitudes.

Table 3. The maximum concentrations simulated by AERMOD model for all of the PM emittedfrom stacks

Longitude	latitude	Concentration mg/m^3	The mean time
598295.93	3663749.36	471.85142	**One hour**
598295.93	3663749.36	35.92774	**24 hours**
598295.93	3663749.36	2.30961	**One year**

3.1. Comparing the maximum concentrations with the standard of Iran's clean air, and that suggested by EPA and WHO

So far, modelling the emission of the pollutants has been carried out, and the manner and direction of their distribution, and estimation of the maximum concentrations, have been shown. But in order to understand the status of the studied region in relation to this pollutant, the maximum concentrations were compared with the standards of clean air in Iran, and that suggested by EPA and WHO.

Table 4. Air quality standard

150	24hours	standardEPA
-	Annual	
50	24hours	the Iran's clean air standard
20	Annual	
150	24hours	standardWHO

As all the three tables of Iran's clean air, and that suggested by EPA and WHO standards, are available for the mean times of 24 hours and one year, comparison of the concentrations was performed with only these two mean time periods.

3.1.1. Comparison with the standards determined for the 24-hour and annual mean times

The maximum environmental concentration of the TSPs for 24 hours based on the AERMOD model has been estimated to be 35.92774. According to the tables related to the standards of Iran's clean air, and that suggested by EPA and WHO, the permitted limit for PM_{10} has been respectively determined to be 50, 50, and 150mcg/m^3. Comparing the predicted values with the standards, it was found that the concentration of PM_{10} for all of the three standards is at an acceptable level.

The output of the AERMOD model estimated the maximum environmental concentration of the TSPs for the annual period as 2.30961mcg/m^3. In comparison with the standards of Iran's clean air and WHO's, which are both equal to 20 mcg/m^3, the concentration of PM_{10} is acceptable. In EPA standard, no permitted limit has been determined for the annual statistical period.

3.1.2. Evaluation of the model

To validate the results, environmental monitoring was performed at the four main directions of the factory within a one-hour time period (at 12 o'clock) in a day.

Table 5. The locations of designated points for model validation

concentration PM (mg/m^3)	Air temperature (°C)	humidity	longitude	latitude	Sampling site
26	30	12%	05204426	3306275	Station 1
11	31	12%	05202323	3304872	Station 2
14	31	11%	05204100	3307820	Station 3
19	31	11%	05202993	3307156	Station 4

The longitude and latitude of the monitored points were introduced into the model as pointed receptors to determine the concentrations predicted on the same day. Validation of the data was done using EPA's acceptable factors.

Table 6. Validation result for particulate matter, according to EPA factors

Factor 2	The variance of geometrical	The bias of geometri	Normalized mean	Relative bias	Modelling concentra	Monitoring concentrat	sample
1.092	0.838	0.915	0.008	-0.088	28.4	26	1
1.122	0.795	0.891	0.013	-0.115	12.34	11	2
0.949	1.110	1.053	0.003	0.052	13.29	14	3
1.456	0.472	0.687	0.143	-0.371	27.66	19	4

Table 5 indicates the monitored and modelled concentrations. Based on Table 2, the acceptable criterion for the relative bias lies between -0.5 and 0.5. The acceptable criterion for the normalized mean squared error is lower than 0.5. Further, that for the geometrical mean bias is between 0.75 and 1.25. The same for the geometrical mean variance also ranges between 0.75 and 1.25. Finally, the acceptable criterion for Factor 2 is above 0.8. Statistical evaluations indicate that the predictions of the model have been in line with the results of measurement in areas around the factory, suggesting the success of the modelling.

4. CONCLUSION

Monitoring air quality and investigating the extent of transgression of air pollution standards around an industrial region can be useful for controlling, and developing limitations for, pollutant sources. In this study, the AERMOD distribution model, which is one of the favourite and advanced models of EPA, was employed. The distribution of TSP from the stacks of the Ardestan cement factory for mean time periods of one hour, 24 hours, and one year was simulated. Next, the maximum concentrations obtained were compared with the clean air standards set by EPA, Iran, and WHO. It was found that the concentrations were acceptable in relation with all the three standards. To evaluate the results obtained from the modelling by the AERMOD model, validation of the results was performed by statistical parameters proposed by EPA. The distribution of TSP from the stacks of Ardestan cement factory was simulated for mean time periods of one hour, 24 hours, and one year.Statistical evaluation also indicated that the predictions of the model were in line with the results of measurement in stations around the cement factory. Further, when the overall performance of the model was investigated, all results calculated for the statistical parameters suggested the success of the modelling process. Moreover, the investigation of air quality in the region showed that the AERMOD emission model is a suitable model for determining hour and annual concentration of TSP from pointed emission sources. Overall, it can be said that the AERMOD model can be used as an acceptable tool for analysing the controlling and policymaking strategies for mitigating and preventing air pollution.

REFERENCES

1. Vallero D A. 2008. Fundamental of Air Pollution.4th edn, Burlington: Academic Press,067p.
2. Yuri C, Tarik B, Astrid B. 2015. Tool for Assessing Health and Euty Impacts of Interventions Modifing Air Quality in Urban Environment. Evaluation and Program Planning. 53 (2015) 1-9.
3. Ozcan N, Cubukca K. Evaluation of Air Pollution Effects on Ashna Disease: The Case of Izmir. Ppocedia-Social and Behavioral Sciences. 202 (2015) 448-455.
4. Nabil H, Abbas A. 2015. Combined influence of stack height and exit velocity on dispersion of pollutants caused by Helwan cement factory (study using AERMOD model). 121(9): 19-24.
5. Rood A. 2014. Performance evaluation of AERMOD, CALPUFF, and legacy air Dispersion models using the Winter Validation Tracer Study dataset.Atmospheric Environment 89: 707-720.
6. Leelossy A,Molnar F,Izsak F,Havasi A,Lagzi F,Meszaros R.2014.Dispersion modeling of air pollutants in the atmosphere.DOI:10.2478/s13533-012-0188-6.
7. Ma J, Yi H, Tang X,Zhang Y,Xiang Y, Pu L.2013. Application of AERMOD on near future air quality simulation under the latest national emission control policy of China: A case study on an industrial city. Journal of Environmental Sciences ISSN 1001-0742 CN 11-2629/X.

8. Sadiq Aliyan A, Ramili A, Saleh m. 2015. Assessment of potential human health and environmental impacts of a nuclear power plant (NPP) based on atmospheric dispersion modeling. Atmósfera 28(1): 13-26.
9. Jayadipraja E,Daud A, Assegaf A. 2016. The application of the AERMOD model in the environmental health to identify the dispersion area of total suspended particulate from cement industry stack.DOI:10.18203/2320-6012.
10. Cimorelli, Perry SG, Venkatram A, Weil J, Paine R, Wilson RB, Lee RF, Peters ED, Brode RW.2005. AERMOD: a dispersion model for industrial source applications, parI:general model formulation and boundary. Journal of Applied Meteorology, 44:682-693.
11. Zou B, Zhan B, Wilson G, Zeng Y. 2010. Performance of AERMOD at different time scales. 18 (5):612-623.
12. U.S. Environmental Protection Agency. 2004. User guid for the AERMOD METEOROLOGICAL PREPROCESSOR (AERMET). Research Triangle Park, North Carolina: Office of Air Quality Planning and Standards, Emissions Monitoring and Analysis Division EPA-454/B-03-002,252 p.
13. Ashrafi K,Shafie pour motlagh M, Tavakolli H. Analysis of dispersion of particulate matter (PM) emitted from a steel complex affecting its surrounding urban area."U.S.-Iran Symposium on Air Pollution in Megacities"September 3-5, 2013.