Environmental Engineering and Management Journal January 2021, Vol. 20, No. 1, 151-157
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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ATMOSPHERIC DISPERSION PREDICTING MODEL OF PM_{10} IN A GYPSUM PLANT

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Abstract

Industries are the major sources of air pollution, especially suspended particulate matter. These sources can cause adverse health effects particularly when they are located close to populated areas. The present paper addresses the prediction of the PM_{10} dispersion from Zarch Gypsum plant. A Gaussian dispersion model (AERMOD) was used for particulate matter dispersion modeling. Emission rates of PM_{10} were evaluated by emission factors and modeling tools. The AERMOD model was implemented with upper and surface meteorological data and the results were verified by the measurement data around the Gypsum plant. The predicted concentrations were considered to be in good agreement with the measured data. The values of coefficient of determination were about R^2=0.88 and RMSE=10.55 µg/m^3. Results of this study have confirmed that the AERMOD could be applied to study the predictions of PM_{10} concentration with reasonable accuracy. Furthermore, the results represent that in some areas PM_{10} concentration is higher than the standard concentration (which is 150 µg/m^3).

Keywords: AERMOD, air pollution modeling, Gaussian model, gypsum industry, PM_{10}

Received: April, 2020; Revised final: May, 2020; Accepted: June, 2020; Published in final edited form: January, 2021

1. Introduction

The World Health Organization reports show that 2.4 million people die each year from causes directly attributable to air pollution. Epidemiological studies also suggest that more than 600,000 people die each year from cardiopulmonary disease linked to breathing in fine particle air pollution (Galindo et al., 2018). Industries are one of the biggest contributors to poor air quality, especially in urban areas. The Gypsum plant contributes significantly to the imbalances of the environment; in particular air quality. The key environmental emission in these industries is PM_{10}, inhalable particles with a diameter of 10 micrometers or less, due to miscellaneous processes. The principal aim in pollution control in the Gypsum industry is to minimize emission by reducing the mass load emitted from the point and area sources (Li et al., 2015).

Gaussian dispersion models have been widely used for concentration prediction, sampling network design, EIA and environmental management scenarios (Hunt, 2008; Tertakovsky et al., 2013). These models are typically used to predict transport of air pollutants from industrial sources to comply with environmental standards, regulatory requirements, as well as to air pollution management requirements (Holmes and Morawska, 2006; Ma et al., 2013). The robust predictions, relative simplicity of use, quick setup, acceptable accuracy and applicability for the great

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proportion of cases in different atmospheric conditions are the most significant advantages of these models (Hunt, 2008; Yang et al., 2005). Gaussian based dispersion models like Airviro, AERMOD or ADMS quantify emission sources and predict air pollutant concentrations. Outputs of the dispersion model in the form of contour maps highlight spatial variability of air pollutant concentrations in the cities and provide a continuous maps that can be used to further fine-tune the air quality monitoring network (Munir et al., 2020).

The AERMOD system, a Gaussian based model, was certified by many researchers as a dispersion modelling by predicting the impact of different sources of air pollutants in different terrain and meteorological condition (Gulia et al., 2015; Huertas et al., 2012; Silverman et al., 2007). This model can be applied in various case studies such as heavy metals modeling in incinerators in urban areas. AERMOD is a next generation steady-state plume model suggested for short-range dispersion from stationary sources. The AERMOD consists of one main module and two pre-processors (Rood, 2014; Zou et al., 2010). The major purpose of meteorological pre-processors, AERMET, is to convert raw meteorological data to planetary boundary layer (PBL) parameters. The AERMAP pre-processor calculates terrain heights and receptor grids for AERMOD. Both AERMET and AERMAP are designed to parameterize the structure and growth of the PBL using observational data (Dash et al., 2017; EPA, 2004b). AERMOD uses terrain, boundary layer and source data to model pollutant transport and dispersion for calculating temporally averaged air pollution concentrations in ambient air. The minimum meteorological data required for running AERMOD are the following parameters (EPA, 2004a):

- Year, Month, Day, Hour
- Cloud Cover (tenths)
- Dry Bulb Temperature
- Wind Speed
- Wind Direction

2. Material and methods

The area of study is Zarch Gypsum plant and the geographical location in UTM system is in zone 40 S, 240148.79 m Easting, 3543795.85 m Northing and altitude is 1236 m. It is the largest and the only Gypsum plant in Yazd whose total production is 220 $^{ton}/_{day}$. The aerial view of the site plan is displayed in Fig. 1.

There are a sizeable amount of non-buoyant and buoyant sources in the Gypsum plant including point, line and area sources. The point sources like stacks, line sources like roads and conveyors, area sources like storage piles and wind erosion can be found in the surrounding areas. PM_{10} is the main pollutant in all processes of the factory which is modeled in this paper. The emission of piles and wind erosion from area sources is evaluated by Fluent CFD model in conjunction with AP-42 (EPA, 1980). The sources and emission rates are mentioned in Table 1.

Fig. 1. Aerial view of Zarch Gypsum plant (Reproduced from Makermi et al. (2019), under the terms of Creative Commons Attribution 4.0 International License)

Table 1. PM_{10} emission rate of Zarch Gypsum plant*

Process	*Method of emission calculation*	*Contri-bution*	*Emission rate (g/s)[1]*
Stack	measurement	7%	0.0144
Drying	measurement and emission factor[2]	10%	0.02
Grinding	measurement and emission factor	34%	0.07
Conveyors	emission factor	0%	0.00026
Stockpile and roads wind erosion and miscellaneous	emission factor and CFD-Fluent[3]	49%	0.1
Total			**0.20466**

*[1] The emissions from all sources have been converted to g/s.[2]The AP-42 emission factors.[3]The modified Fluent software has been usedș; *(Reproduced from Makermi et al. (2019), under the terms of Creative Commons Attribution 4.0 International License)*

The modeling area is the radius of 8 km from the center of the factory with both flat and elevated topography. According to a reference (Gimson et al., 2007) the site area category for modeling is urban. The AERMOD air modeling software is implemented for the time period of one year from 2018 to 2019. The meteorological data is required for this model during the time period that is prepared by the AERMET model.

The AERMET preprocessor generates two meteorological output files of surface and upper air data for input to AERMOD; a file of hourly boundary layer parameter estimates and a file of multiple-level observations of wind speed and direction, temperature, and standard deviation of the fluctuating components of the wind. The AERMET surface data is obtained from a local meteorology station located in Yazd City.

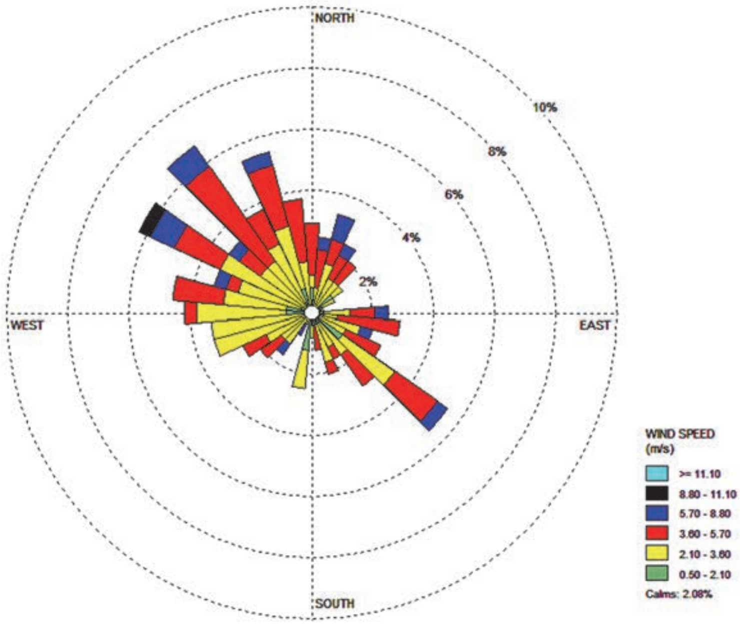

Fig. 2. Zarch Gypsum plant wind rose from year 2018 to 2019
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Yazd Synoptic Meteorological Station is located 13 kilometers south of Zarch city and 24-hr meteorology data is recorded including temperature, humidity, air pressure, horizontal visibility, wind direction and speed, cloudiness, precipitation and sunlight duration.

Wind velocity and direction are considered as determinate meteorological parameters. The wind rose of the Zarch area is presented in Fig. 2. The wind rose above indicates that the main wind directions and highest wind speeds are from North West to the South East. According to the wind rose, the maximum wind speed was 10 m/s at a height of 10 m. AERMET can extract upper air sounding data from Forecast Systems Laboratory (FSL) format where global upper air data in FSL format is available from the NOAA Earth System Research Laboratory (ESRL) Radiosonde Database.

A problem emerges when trying to estimate the convective mixing height because upper air meteorological data are required. Fig. 3 represents the Radiosonde FSL file sample at the nearest Station to Zarch Gypsum Factory. In Fig. 3, the first four lines are information lines and all additional lines are data lines. An entry of 99999 indicates that the information is either missing, has not been reported or not applicable. In some stations, upper air soundings are not available with the required frequency or due to incomplete data. Under these conditions the AERMET UPPERAIR defaults are considered. Each upper air sounding is composed of two parts; the first four lines are an identifying header record consisting of the year, month, day, hour, and the number of sounding levels and second a sounding record composed of pressure, height above ground level, temperature, dew-point temperature, wind speed, and wind direction, which is repeated for each height level.

In the AERMOD model another main required input data is emission information of sources at the Gypsum industry. The input data of emission sources and meteorology data provide a comprehensive set of information in order to run the AERMOD model and simulate the concentrations of PM_{10} from all sources of the Gypsum industry.

254	0	19	SEP	2017		
1	99999	40800	32.62N	51.67E	1590	2359
2	8490	2070	1010	129	99999	0
3		OIFM			99999	ms
9	8490	1590	184	4	0	0
4	10000	169	99999	99999	99999	99999
4	9250	851	99999	99999	99999	99999
4	8500	1579	99999	99999	99999	99999
5	8470	1610	174	-6	99999	99999
5	8320	1762	202	-28	99999	99999
5	8300	1783	202	-28	99999	99999
6	8090	1993	99999	99999	125	51
6	7740	2355	99999	99999	115	51
4	7000	3180	100	-50	290	31
5	6970	3215	96	-54	99999	99999
6	6560	3697	99999	99999	305	51
6	6390	3906	99999	99999	325	72
5	5600	4971	-65	-98	99999	99999
6	5590	4985	99999	99999	320	98
5	5490	5126	-69	-209	99999	99999
6	5410	5240	99999	99999	330	129
5	5390	5268	-77	-257	99999	99999
5	5020	5816	-111	-231	340	118
4	5000	5860	-113	-233	340	118
5	4840	6108	-123	-323	99999	99999
5	4510	6642	-163	-293	99999	99999
5	4380	6861	-169	-389	99999	99999

Fig. 3. NOAA ESRL Radiosonde database sample

3. Results and discussion

The 2D contours of the annual PM_{10} concentration as the highest 1-hr concentration of PM_{10} in a radius of 8 km around the factory is shown in Fig. 4, while the annual 24-hr PM_{10} concentration is presented in Fig. 5. Furthermore, the background concentration of PM_{10} is added to the modeling results.

In Fig. 4, the PM_{10} highest 1-hr concentration dispersion contour represents that in 1.5 kilometers radius to the center of the factory, PM_{10} concentration is about 100 μg/m^3. Generally, 5 kilometers away from the factory, the highest concentrations of factory PM_{10} emissions exist and with an increased distance from the center, concentration reduces to 50 μg/m^{3,} in this area. In particular, PM_{10} dispersion direction is from West to the North area, and also from East to the South area, which means North West and South East zones are more affected by Gypsum factory emissions according to the distance from the center. In the zones mentioned above, PM_{10} concentration reduces to 11 μg/m^3, in an 8 kilometer distance from the factory center.

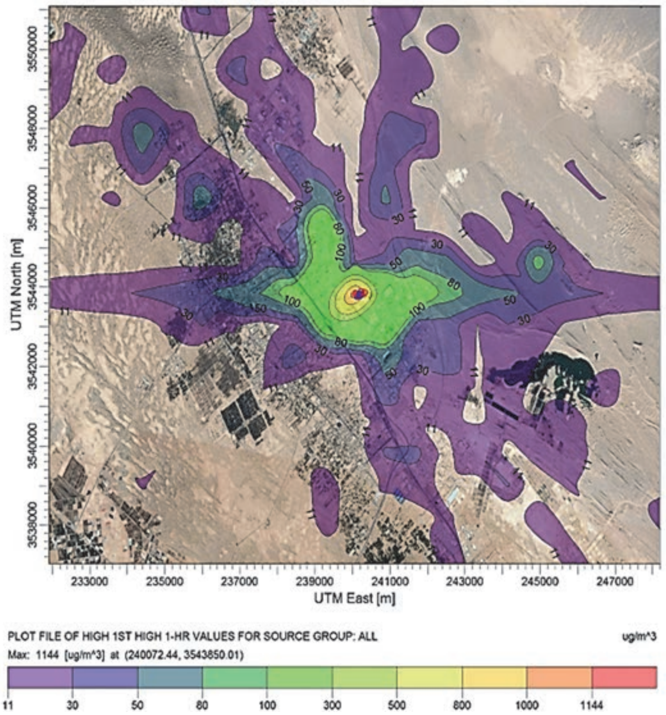

Fig. 4. Highest 1-hr PM_{10} concentration dispersion of Gypsum plant
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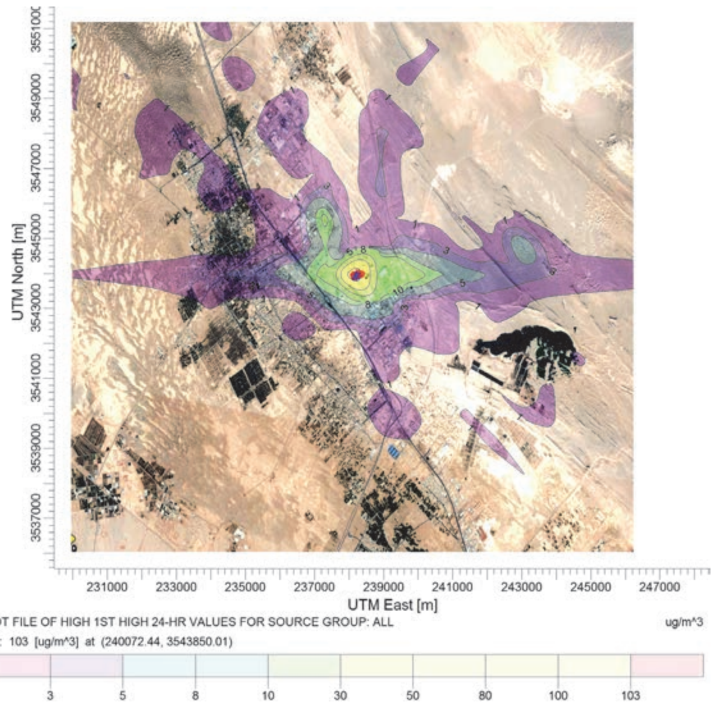

Fig. 5. Annual 24-hr PM_{10} concentration dispersion of Gypsum plant
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In Fig. 5, the PM_{10} highest 24-hr concentration dispersion contour indicates that 5 kilometers away from the factory, the highest concentration of PM_{10} exists and in the distance from the center, concentration reduces to 5 μg/m^3. In 8 kilometers from the center, dispersion is from West to the North direction, also from the East to the South direction, and the concentration decreases to 1 μg/m^3. In addition, in the South West and North East zones, there are lower dispersions and the least concentrations.

Variation of concentration in the distances from the factory is displayed in Fig. 6. The variation is presented from 8 kilometers in East direction to the center of the factory, up to 8 kilometers to West direction. Fig. 6 represents the PM_{10} annual 24-hr concentrations in different distance points from the center of factory by 500 meters intervals. As shown above, a *descending* trend with distances from the factory occurred which is expected according to Gaussian model formulation. Because of the several area sources in the factory, the maximum concentration occurs inside the factory near area sources and the concentration decreases by distance.

In order to verify this modeling method, a sampling network is created to measure PM_{10} average 24-hr concentrations. Sampling network consists of 40 radius stations located on 8 sides and every 1 kilometer to the center of the gypsum factory. For example the A-1 station is located at 1 kilometer to the East of the factory, while C-3 is located at 3 kilometers to the South. The PM_{10} concentration measurement is devaluated from both inside and outside stations of the factory area according to EPA CFR40 method with OMNITM FT Ambient Air Sampler. Measurement points' layer over the satellite map of Zarch Gypsum plant is displayed in Fig. 7. As shown in Fig. 7, the sampling network is in various radius circles around the factory in different directions to cover all the areas which are impressed by different wind directions according to wind rose shown in Fig. 2. The results of sampling and AERMOD prediction are presented in Table 2. Also, correlation between PM_{10} measurement and modeling prediction is shown in Fig. 8.

Table 2 represents that the PM_{10} concentration in both measurement and modeling has a small amount of difference between the estimates in each measuring station. Fig. 8 suggests an coefficient of determination R^2=0.88 and RMSE=10.55 μg/m^3. The results of Zarch Gypsum plant declare that AERMOD modeling output concentrations were found to be compatible to the sampling measurement data.

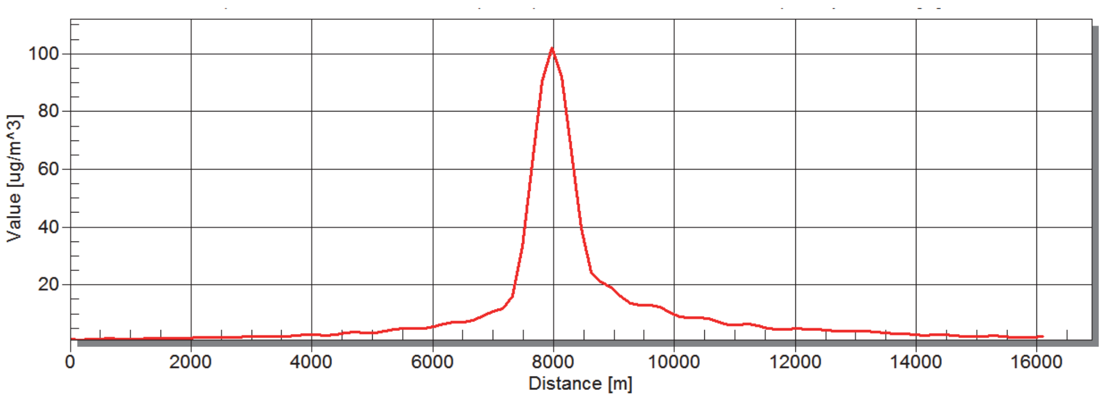

Fig. 6. The annual 24-hr PM_{10} concentration variation by distance

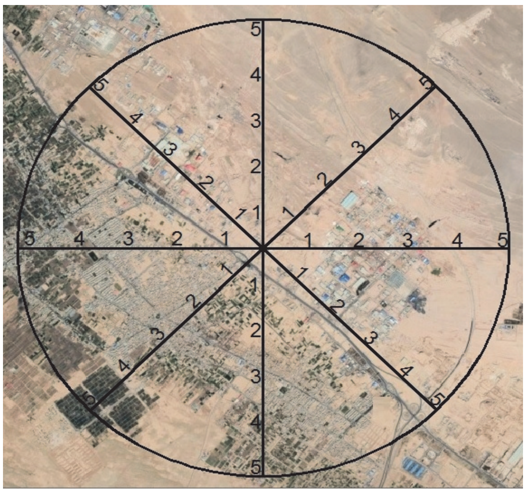

Fig. 7. Measurement points around Gypsum plant

Table 2. PM_{10} modeling and measurement concentrations of Gypsum plant (µg/m³)

Station Location and Concentration (µg/m³)		***A East***	***B SE***	***C South***	***D SW***	***E West***	***F NW***	***G North***	***H NE***
1	Modeling	80.3	75	76.4	90.4	74.9	82.3	77.7	88.9
	Measurement	74.1	59.3	67.5	75.5	67.6	78.7	59.9	74.1
2	Modeling	30.2	35.4	45.3	55.7	43.8	49.5	43.4	45.4
	Measurement	43.1	45.5	34.5	55.8	45.9	55.4	55.3	44.9
3	Modeling	10.4	14.5	10.6	8.8	14.9	23	9.3	9.9
	Measurement	12.3	15.5	15.7	19.1	34.5	34.9	34.8	33.7
4	Modeling	5.8	7.7	3.4	2.5	7.3	7.2	1.6	1.7
	Measurement	7.2	10.6	7	5.6	15.1	19.2	19.3	13.1
5	Modeling	1.1	2.3	1.5	0.6	1.5	1.4	0.7	0.8
	Measurement	5.2	7.1	4.4	5.7	4.7	5.6	33	1.5

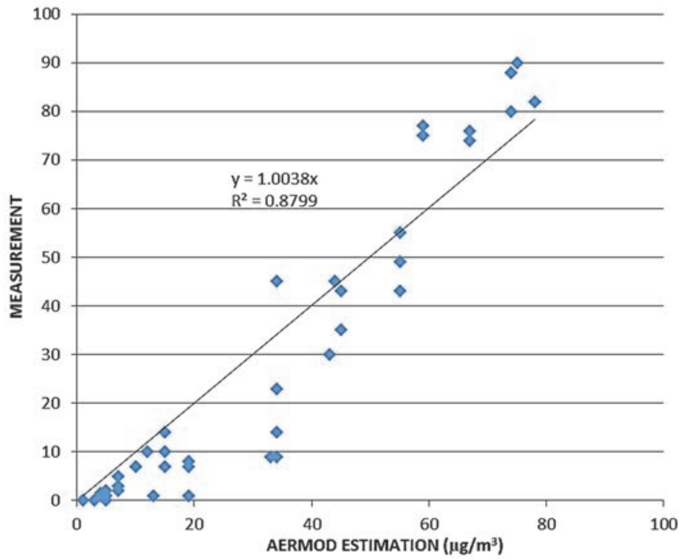

Fig. 8. Correlation between PM_{10} measurement and modeling estimation

4. Conclusions

In the present case study, a Gaussian air pollution model of AERMOD is implemented for a Gypsum plant. The annual 24-hr and maximum 1-hr concentration of PM_{10} is estimated and the results are compared to the measurements. The comparison of prediction with measurement confirms that emission rates have been evaluated correctly. The dispersion of PM_{10} is in accordance with privilege wind direction patterns.

The annual 24-hr PM_{10} concentration inside the factory exceeds the standard limit. The output results are verified by wide measurement data around the factory. The predicted concentrations were found to be relatively similar to the measured data. The results of the current study confirm that the AERMOD could be applied to study PM_{10} concentration predictions in Gypsum industries with reasonable accuracy.

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