Application of AERMOD to local scale diffusion and dispersion modeling of air pollutants from cement factory stacks (Case study: Abyek Cement Factory)

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Abstract: Today, the cement industry is one of the major air polluting industries in the world. Hence, in this study, owing to the importance and role of contaminants from the plant, an appraisal of the emission contributions in addition to other factors have been discussed. There are several reasons behind the importance of modeling air pollutants. First, the assessment of standards for air pollution, and the fact that the measurement points are limited. Furthermore, in all industrial areas, measurement and installation of assessment and monitoring stations are not feasible. The AERMOD model is a dispersion steady state model which is utilized to determine the concentration of various pollutants in different areas from urban and rural, flat and rough, shallow diffusion in height, from standpoint and different shallow sources. In this model, it is assumed that the dispersion of concentration in Stable Boundary Layer (SBL) in two horizontal and vertical directions are similar to that of horizontal within Gaussian convectional boundary layer (CBL). With regard to assessment of the parameters and pollutants of stack outlet, the amount of particulate matter was measured as the most important pollutant in the region. Then, via dispersion and diffusion modeling of pollution (AERMOD) along with environmental measurements, the nature of dispersion of this pollutant in the analysis of the surrounding areas was verified. According to the presented results, the highest level of concentration for particulate matters in all areas affected by cement factory amounts to 43.68 ($\mu g/m^3$) which occurred at a distance of 1500 m in the east direction and 2100 m in the north direction.

Keywords: air pollution, cement industry, diffusion and dispersion modeling, particulate matter.

INTRODUCTION

Today, the industrial complex which has big size of combustion chamber produce air pollutants, and have to be considered. Abyek cement industry in Iran has the biggest combustion chamber in the middle-east with a capacity of 8000 ton clinker per day. The local air quality has been an issue of social concern because of rising industrial and vehicular pollution in most cities and urban areas (Garg, 2011). Outdoor air pollution has become a major concern for public health world-wide. Short-term exposure to outdoor air pollution has been linked to increased mortality, increased rates of hospital admissions and emergency department visits, exacerbation of chronic respiratory conditions (e.g., asthma), and decreased lung function (Kampa and Castanas, 2008).

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Most of these studies were conducted in developed countries, and only a small number of studies have been conducted in Asia's developing countries (Health Effects Institute, 2004; Chen et al., 2010). One of the major pollutants in the borderlands is particulate matter (PM), which is categorized into particles with aerodynamic diameter less than 10 mm (PM10) and those less than 2.5 mm (PM2.5 or fine PM). It is the US EPA's regulatory PM10 standard that is frequently violated in the border towns, with reported violations of the PM2.5 standard being far fewer (Choi et al., 2006). Hence, in this study, owing to the importance and role of contaminants from the plant, appraisal of the emissions contribution in addition to other factors have been discussed. For this purpose, in the first place, the flow parameters and the particulate matter from stack outlet were measured using appropriate equipment. Then, by applying the AERMOD software, diffusion and dispersion of particulate matter in the surrounding area was modeled.

Air quality largely influences the ecology, environment and public health in a region. In recent years, several research efforts have been made to developair quality prediction models. Atmospheric dispersion models are used to predict the ground level concentration of the air pollutants around the sources (Cimorelli et al., 2005; EPA, 2005; Kesarkar et al., 2007; Bhaskar et al., 2008; Singh et al., 2012). Air pollution is of particular concern in urban and industrial areas where significant emissions coupled with unfavorable meteorology may lead to pollutant accumulation and long-term exposure. In such contexts, an integrated approach of Air Quality Management (AQM) is needed. Long- term monitoring campaigns are associated with high costs and often lack sufficient spatial density to adequately characterize ambient air quality (Prabha and Singh, 2006), particularly in

areas where air quality exhibits large spatial and temporal variations due to complex meteorology and terrain, variable land use, and shoreline fumigation (Ghannam and El-Fadel, 2013).

There are several reasons behind the importance of modeling air pollutants. First, the assessment of standards for air pollution and the measurement points are limited. Furthermore, in all industrial areas, measurement and installation of assessment and monitoring stations are not feasible. It would also be possible, by means of measurement, to assess the modeling results and reduce its error and uncertainty (Zou et al., 2011). Dispersion modelling uses mathematical equations, describing the atmosphere, dispersion of chemical and physical processes within the plume, to calculate concentrations at various locations.

The American Meteorological Society and EPA developed the AERMOD modeling system (Cimorelli et al., 2004). Treatment of both surface and elevated point sources, area sources, and volume sources in a simple or complex terrain model domain are addressed in the model. It was intended as a replacement of the Industrial Source Complex Version 3 (ISC3) model. Currently, AERMOD is the EPA's preferred model for regulatory compliance and demonstration for criteria pollutants in the near field (<50 km) (Rood, 2014).

The Gaussian model analytically resolves the dominant equation, using simplifying premises. The modeling of air pollution is performed utilizing the data of the extent of emission from different sources including, the finding of concentration in sampling stations, meteorological results, and the data of topography and the type of soil application. In fact, in modeling there is a dynamic relationship between the emission sources and concentration, which ultimately presents the diffusion and dispersion of air pollutants.

Air dispersion modeling calculates the movement of pollutants that are in the air using mathematical models that consider emission quantities, meteorology, topographical factors, and chemical and physical processes within the atmosphere over time and space, in order to calculate concentrations of air pollutants at different 'receptors' (researcher-defined locations for concentration calculations). If sufficient data exist and are accessible for pollution sources and environmental conditions, air dispersion modeling has the potential to provide a more accurate assessment of possible exposure without the need for extensive monitoring networks (Dent et al., 1998; Hodgson et al., 2007; Jerrett et al., 2005; Maroko, 2012).

Air pollution modelling is performed by finding out the amount of dispersion from sources, concentration in sampling station, meteorology and topography data, the kind of ground usage. In modeling, there is a dynamic relationship between sources of dispersion and concentration which ultimately leads to dispersion of pollutants in places with no assessment station.

Because of the entering of suspended particles from the West of the country to the study area, in order to determine and evaluate the factory's share of total available particles, the amount of particles in the atmosphere is measured at four points around the plant using the SKC pump. By subtracting the measured amount of particles resulting from modeling, from measured ones using the SKC pump, Abyek cement factory's share percent, compared to other sources of pollution in the region, can be estimated.

MATERIALS AND METHODS

Of course, the detail and quality of the input requirements depend on the sophistication of the model used. Older dispersion models, i.e. simple Gaussian plume models, are based on the use of the Pasquill-Gifford-Turner stability classes for the characterization of the vertical and lateral dispersion (EPA, 1995). Instead, the new generation of short-range dispersion models, including more complex Gaussian plume models such as ISC3, AERMOD and ADMS, uses the Monin-Obukhov similarity to describe the mean and turbulence structure in the surface boundary layer. The ground-level concentration is generally expressed in terms of specific variables, such as the surface friction velocity and the Monin-Obukhov length, which contain information on the turbulence and the mean wind that govern dispersion (Vankatram, 2004; Capelli et al., 2013).

The AERMOD model was utilized to determine the concentration of various pollutants from different areas such as urban and rural, flat and rough, shallow diffusion in height, from the standpoint and different shallow sources. In this model, it is assumed that the dispersion of concentration in the Stable Boundary Layer (SBL) in two horizontal and vertical directions is similar to that of horizontal within the Gaussian convectional boundary layer (CBL). However, the CBL dispersion of concentration is defined in the vertical direction with a Gaussian dispersion of density. In rough grounds, the AERMOD model employed the concept of stream division lines. It determined the final dispersion by adding the weights of concentrations produced by two states of plume; horizontal and ground terrain dependent which are similar in flat grounds. Under very stable conditions, to face a barrier, plumes tend to remain horizontal. In unstable conditions, it moves on the surface of the barrier. That is why the resultant weight of these two states were used to determine the final condition. Each of the above-mentioned states was weighted based on the concepts of critical stream line and the altitudinal scale of each recipient. This weight depends on the extent of transmission mass in each state.

This division of mass is implemented based on the connection between the height of critical stream line and the vertical dispersion of concentration in each recipient.

AERMOD predict the most stable condition and the lowest mixing height, being the emission above the mixing height. For the rest of the simulated period, a lower concentration far away from the source at the ground level was observed. This is because the instability of the atmosphere was increasing and the vertical spread is higher, distributing the contaminant along the whole PBL at a higher height (Caputo et al., 2003).

In this research, in order to model the diffusion and dispersion of pollutants, the AERMOD model was employed. The AERMOD model is a stack in a stable condition which explains the dispersion of air based on the structure of boundary layer and turbulence in an acceptable scale. AERMOD is a permanent dispensational state which is used to determine the concentration of various pollutants in urban and rural areas, shallow diffusion and in the height of standpoint and shallow sources. It is mainly proposed to assimilate dispersion of pollutants in limit of 50 Km.

Abyek cement factory is located in the east of Alborz Province in Iran. It is in latitude 36 degrees 1 minute and longitude 50 degrees 35 minutes. The plant's elevation is 1440 m above sea level. Four cities namely Hiv, Hashtgerd, Nazarabad, Abyek are around this cement factory and the mean distance of each of them from Abyek cement factory respectively is equal to 5,9, 6, and 5 Km. The total human population of this area is more than 250,000. Figure 1 shows the location of the factory in Iran, Alborz Province.

Fig. 1. Location of the Abyek cement factory in Iran, Alborz Province

To achieve the research objectives, primarily the output suspended particulates from the cement factory's stacks should be measured by sampling. Thus, output gas speed, temperature and pressure were measured by applying the device KIMO and suspended particulate matter were assessed by using WESTECH. Table 1

shows the location of stacks in the Universal Transverse Mercator (UTM) coordinate system, Local coordinate system and also the line 1 electro filter of the cement factory were considered at the origin and the property of other recipients relative to it were determined.

Table 1. Location of stacks in Universal Transverse Mercator (UTM) coordinate system and Local coordinate system

N.O	Source	Eastern (meter)	Northern (meter)	X-diameters (meter)	Y-diameters (meter)
1	Electro Filter in Line 1	463334	3986148	0	0
2	Grid cooler in line 1	463319	3986053	-15	-95
3	Mill	463204	3986098	-130	-50
4	Electro Filter in Line 2	463384	3986178	50	30
5	Grid cooler in line 2	463478	3986078	140	-70

Measurements from fixed monitoring stations (FMS) have been commonly used as surrogates for personal exposure levels to represent community exposure to pollutants. Exposure estimates obtained from FMSs have been the basis of air quality guidelines and policy (Kaur et al., 2005).

AERMOD uses a meteorological preprocessor called AERMET to characterise the atmospheric conditions in the Planetary Boundary Layer, and a terrain preprocessor called AERMAP to characterize terrain elevation and prepare source/receptor heights for pollutant dispersion (Misra et al., 2013). This model, in addition to the main AERMOD processor is made of a topographical preprocessor called AERMAP. The AERMAP preprocessor analyzes the regional topographical information. Ultimately, the model perform its final sources using results of this preprocessor and the complementary information regarding the diffusion sources and the recipient net.

The ground level data included are: topography, mean sea level pressure, local pressure, temperature, friction velocity,

sensible heat flux, latent heat flux, specific humidity, vegetation type, total accumulated precipitation, soil moisture, momentum flux, general pollutant deposition velocity. The upper- level data corresponds to a terrain-following coordinate system for 20 levels, and are: U-wind component, V-wind component, vertical velocity, water–vapor mixing ratio, temperature, pressure, turbulent kinetic energy and potential temperature. This set of meteorological data does not include the mixing layer depth and the Monin–Obukov length (Caputo et al., 2003). In the stable boundary layer, the dispersion is assumed to be Gaussian in both the vertical and the horizontal directions. In the convective boundary layer, the horizontal distribution is assumed to be Gaussian whereas the vertical distribution is described by a bi-Gaussian probability density function (Tartakovsky et al., 2013).

In principle, meteorological data can be obtained from one single meteorological station. An important aspect to be considered when choosing the meteorological station is its distance from

the emission source: in cases of complex terrain, the meteorological station shall be located in the same valley or in a position as to be representative of the wind conditions of the considered emission. This is particularly true for the wind speed and wind direction data. The data registration frequency and the extension of the simulation time domain may depend on the simulation purposes (Capelli et al., 2013). All necessary ground-level data were obtained from the nearest National Weather Service (NWS) station located in Hashtgerd City, code 99396, located 15 km from the original study site. Due to the lack of available data on Abyek, Hashtgerd Station data was used as well. On the basis of meteorological data, two statistical periods have been performed for the first and third quarters of 2013 (O'Shaughnessy and Altmaier, 2011).

For any atmospheric condition, AERMET can calculate the mixing height or use the value given by input. For stable atmospheric condition, if the user introduces the mentioned value, it is assigned to the mechanical mixing height, otherwise it is internally calculated. Under unstable condition, the code chooses the maximum between the value given by input and the mechanical mixing height calculated internally (Capelli et al., 2013). The AERMET processor is designed in such a way which makes it feasible to define all the existing meteorological information within the onsite and use them for processing. Therefore, in this project precipitation amount, sky cover, station pressure, sea level pressure as surface parameters, also dew-point temperature, wind direction, and relative humidity were considered as profile parameters.

The settings and parameters for AERMOD were determined and processed with those (e.g. albedo, bowen ratio, and surface roughness) described in our earlierwork (Zou et al., 2010). After these preparations, the AERMOD model was run

at daily and annual temporal scales, for simulating the PM concentrations at each receptor from different emission sources (Zou et al., 2010). As it has been mentioned, in order to perform its calculations (AERMET) needs three surface parameters from the studied region, namely Bowen ratio, Albedo coefficient and the roughness length of surface. The Albedo coefficient is sunlight radiation which is reflected to space without absorption by surface. Its amounts varies from 0.1% for woods with dense trees to 0.9% for soft snow. Bowen ratio is an index to determine the moisture ratio of sensible heat flux to latent heat flux. During the day, its amount varies from 1% for water surface to 10 for desert surface. The length of surface roughness is related to the wind stream and the height of surface barriers. In fact, it is a height in which, the average of the horizontal velocity of wind reach to zero. The amount of these parameters range from the limit of less than 0.001 m for stagnant surface water to more than 1 m for wood surfaces and urban regions.

PBL height depends on the strength of both convective mixing of air masses generated by the solar heating of the Earth's surface and by mechanical mixing due to the interaction between wind and surface roughness (Oke, 1987; Stull, 1988). In sunny days and when mechanical mixing is not relevant (i.e., low wind speed conditions), PBL exhibits a typical diel (24 h) cycle characterized by low nocturnal levels and elevated daytime heights. During the night, when mechanical turbulence is present, PBL heights can rise significantly over the typical nighttime levels (Morselli et al., 2012).

To specify these amounts, it is necessary to divide the studied region in terms of the usage type of surrounding grounds and its plant covers in a clockwise direction, can be divided into suitable sections.

422

RESULTS

Air quality model can be an adequate tool for future air quality prediction, also for atmospheric observations supporting emission control and strategy responders. The model of AERMOD is used as a tool for the analysis of particulate matter emissions from an industrial complex, as a part of environmental impact assessment. Both variability and uncertainty affect Gaussian modeling results. Variability in the Gaussian model, results primarily through meteorology and emission rates, because weather conditions and processing rates vary over time. We believe uncertainty in Gaussian models can be categorized into three components: input uncertainty, parameter uncertainty, and conceptual uncertainty. The AERMOD model was applied as a tool for the analysis of particulate matter (PM) emissions from a cement complex, as a part of the environmental impact assessment. The dispersion of PM from four cement plants within the selected cement complex was investigated both by measurement and AERMOD simulation in dry and wet seasons. Simulated values of NO_2 emissions were compared with those obtained during a 7-day continuous measurement campaign at 4 receptors.

The AERMOD model requires special information for each kind of pollutant and sources. For used sources of this research which are considered as standpoint sources, the same information is required such as the rate of pollutant dispersion, the height of pollutant released from the ground surface, temperature and velocity of outlet gas from the sources, also the internal diameter of stack and exit place which were determined for each of the sources. In addition, it is necessary to specify the position of sources in relation to each other. To do this, it is possible to determine the position of stacks in the Universal Transverse Mercator (UTM), relative to an arbitrary origin.

In this research, the line 1 electro filter is considered as the origin and property of other sources relative to it is determined and introduced and also the recipients in Cartesian position within limit of 35*35 Km², which web distance on 100 meters (351 web line) in each, the two directions of X,Y are defined. Arrangement of recipients relative to a selective origin, namely line 1 electro filter. It is necessary to mention that in this case study, assimilation is performed for the recipients situated on the ground surface.

Table 2 shows the maximum concentration for mean time at 1hour, 3hours, 8hours, 24hours, 1month and 1 year.

Figure 2 shows the dispersion of TSP pollutant for all the plant sources in satellite view. Also, Figure 3 shows the seasonal (on the basis of meteorological data of the second quarter of 2013) dispersion of TSP pollutant.

Figure 4 show the dispersion of TSP pollutant for all of the plant sources in satellite view, also, Figure 5 shows the seasonal (on the basis of meteorological data of third quarter of 2013) dispersion of TSP pollutant.

Table 2. Maximum concentration of TSP for Separate mean times

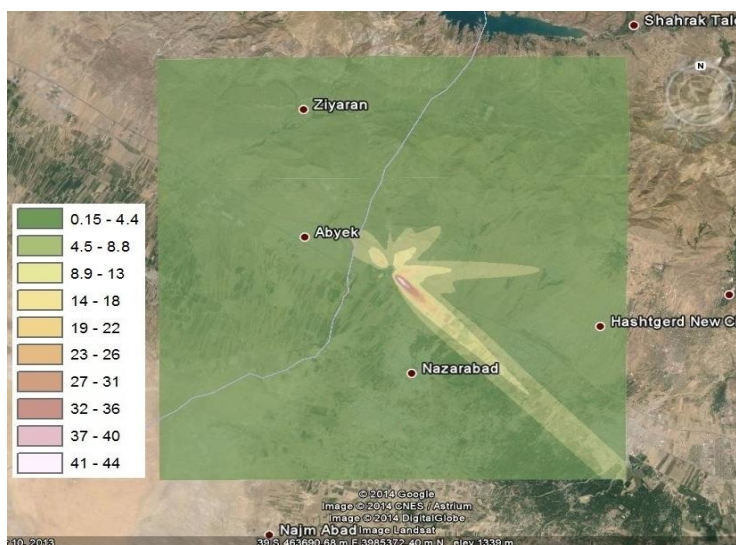| Mean time	Concentration (µgr/m3)	Hour	Day	Month	X-diameters (meter)	Y-diameters (meter)
1hour	173.04	7	28	7	260	-420
3hours	154.34	9	28	7	260	-420
8hours	90.75	8	13	8	420	-580
24hours	60.50	-	13	8	-480	320
1 month	53.41	-	-	9	-640	480
1 year	43.68	-	-	-	-2100	-1500

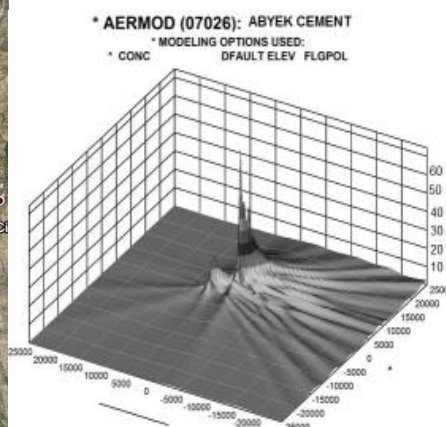**Fig. 2.** Dispersion of TSP pollutants for all the plant sources **Fig. 3.** Seasonal dispersion of TSP Pollutants
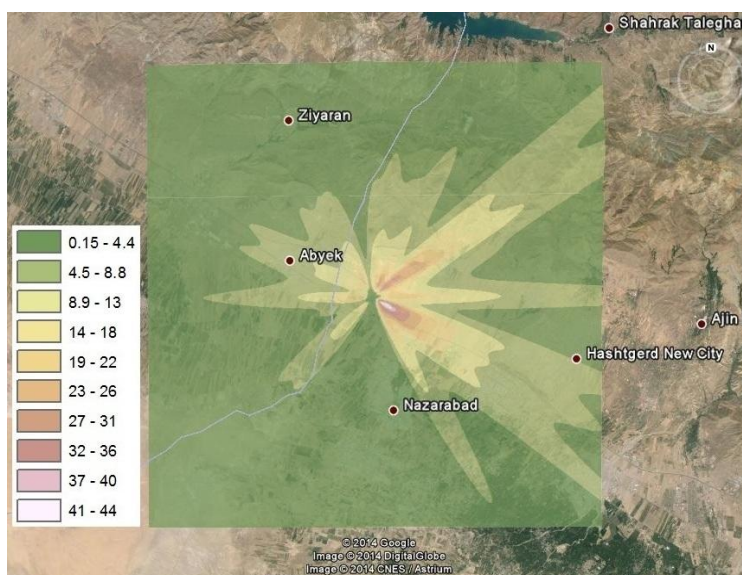

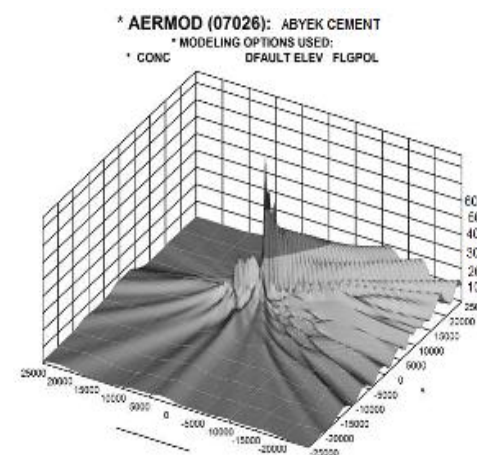**Fig. 4.** Dispersion of TSP pollutants for all of the plant sources **Fig. 5.** Seasonal dispersion of TSP Pollutants

The Figures show that the urban areas of Nazarabad and Abyek are less affected by the sources of the particulate matter exited from the cement factory source. The Hiv and Hashtgerd areas due to dominant wind and the movement of pollutant in the direction from South-west to North- east, are more affected by pollution sources.

The previous concentration in various temporal local conditions as it has been mentioned earlier, in this research, the nature of pollutant dispersion for particulate matter dispensed by Abyek cement factory in limit of 35*35 Km² was carried out. The average time period of 1, 3, 8, 24 h and the statistical one-month and one-year period as well as the altitude of ground surface were considered.

This modeling objective compared the predicted and observed maximum one-hour and three-hour average concentrations measured at a sampler during the three-hour test period at either the 3-km or 11-km distance from the release point. The predicted maximum concentrationwas not paired in space, and also unpaired in time

for the maximum-hourly average concentration (Rood, 2014). Sampling was carried out in order to analyze and verify the modeling for the dispersion of particulate matter in the surrounding area. Table 3 shows the concentration of TSP pollutant in the surroundings of Abyek cement factory.

Table 3. The concentration of TSP pollutant in surroundings of Abyek cement factory

Sampling Point	Distance(meter)	Concentration(µgr/m3)
Point 1 (Abyek)	6200	282.2
Point 2 (Hiv)	4600	354.8
Point 3 (Nazarabad)	5300	235.7
Point 4 (Hashtgerd)	9800	268.8

CONCLUSION
The model was defined and performed with respect to all data centered around the Abyek cement industry. The results of these modeling were transferred to Google Earth software via the Arc GIS software and final results were observed. In this research, the model was assessed for three states. The first state concern assessment of the amount of pollution steamed from the factory's first line, and second line, respectively. The third state was carried out for all the factory stack outlets, in order to separately assess facts separately.

The maximum concentration in unstable conditions in the boundary layer of the atmosphere, in larger extent of concentration occurred in stable condition, and the maximum amounts of concentration occurred in farther distance from the similar but stable conditions in the boundary layer of the atmosphere. The findings indicate that there is a reverse relationship between concentration and wind velocity in Gaussian model. Moreover, the concentration depends on the emission factors, the effective height of plume rise, atmospheric conditions, wind velocity and the meteorological parameters have an important role in emission of air pollutants.

Comparison of results in a functional state (enabled simultaneously for all sources) is presented in Table 2, by proposed limit values for particulate emissions, shows that even though all the plant sources are active, the maximum concentration for mean time at 24 h and 1 year are much lower than the clean air standards.

As the satellite image (Fig. 2) shows some areas such as Nazarabd and Abyek, which are less affected by output of particulate emissions from cement plants. Although in comparison with other areas, Ivan district is more affected by pollution from these sources, it does not meet the limit proposed by the Environmental Protection Agency.

According to the presented results, the maximum concentration of particulates originating from Abyek cement plant in all points is equal to 43.68 microgram per cubic meter and occurred at a distance of 2100 m and 1500 m in the south-east direction. Furthermore, the model was implemented according to the NIOSH0500 standard and for the day, outdoor sampling at 2-hour state and then its results are presented. The differences between these results and the measured values indicate another significant source of particulate emissions in the region, besides the Abyek cement plants.

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