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An Innovative Method to Allocate Air-Pollution-Related Taxes, Using Aermod Modeling (Case study: Besat Power Plant)

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ABSTRACT: The present study applies the model of American Meteorological Society-Environmental Protection Agency Regulatory Model (AERMOD) to investigate NO_2 emissions from Besat thermal power plant, which is fuelled by natural gas to function. Results indicate that the simulated concentration of NO_2 based on AERMOD, does not exceed NO_2 concentration limit, set by the Iranian Ambient Air Quality Standard. This shows that NO_2 emissions from Besat power plant do not have any significant impact on nearby communities. The natural-gas-based power plant is capable of reducing the air pollution level. It also can decrease the hospital treatment costs, thus protecting public health. The modeling results shows that natural-gas-based power plant as a clean technology in power generation. Also, the AERMOD model has been used to determine the pollution source matrix of Besat power plant. An innovative idea has been implemented to not only determine air-pollution-related taxes and complexities but to solve the legal problem associated with it, also. As for the complexities, their determination entails two different methods: one, based on city's boundaries along with simulated amount of air pollutant concentrations in each receptor, and the other, based on the population of each receptor (i.e., the cities of Varamin, Eslamshahr, and Nasirshahr), which plays a vital role. According to the first approach, Varamin has the lion's share in the air pollution, caused by Best power plant. However, the second approach surprisingly shows that the largest portion belongs to Eshalmshahr, indicating the significant influence of its population.

Keywords: NO_2 concentration; Air pollution; Tax; Population; Air quality standards.

INTRODUCTION

Industrial activities are responsible for continuous release of huge amounts of air pollutants, affecting both human health and environment. Released air pollutants may endanger the environmental health, disturbing the balance of the ecosystem. The air pollutants, formed in the atmosphere, are able to gradually move down and either concentrate in the breathing zone or deposit on the ground level under gravitational pool (Hao et al., 2001). All kinds of environmental receptors, such as animal and plant life, are severely affected by air

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pollutants, which might eventually result in their demise (Markandeya et al., 2016a; Kisku & Markandeya, 2015; Ghadiri et al., 2017). In order to predict the atmospheric build-up of air pollutants, many Air Quality Models have been developed over the years, which are even used to determine ground level concentrations of air pollutants, likely capable of affecting the property and life (Markandeya et al., 2016a; Ghadiri et al., 2017; Kumar et al., 2017). Thanks to a wide variety of chemical methods, the released air pollutants can be directly measured both quantitatively and qualitatively; however, recent mathematical models have proven to be more reliable and popular tools to predict ground level concentrations of air pollutants at desired locations in downwind direction. Current modern Air Quality Models are capable of providing the exposure level in any particular distance and direction from the source points at differing heights (Kisku & Markandeya, 2015). These Air Quality Models are widely used and popular, thanks to their easy operation and cost-effectiveness in comparison with actual field surveys for proper management of air pollutant emissions' impact on the environment. Also they can provide many detailed information in advance, such as the transport rate, transformation rate from one chemical form to another in an atmosphere based on prevailing climatic conditions, horizontal/vertical turbulence, diffusion/dispersal of the pollutants, and gravitational deposition of pollutants (Ali & Athar, 2010). In order to assess air pollutants' dispersion, these models generally use meteorological data, stack configurations, process technology, chemical reaction in the atmosphere, type of raw materials, terrain topology, and topography (Cuculeanu et al., 2010; Balaceanu & Stefan, 2004; Giakoumi et al., 2009). As a result of these predictions, preventive actions can be taken so that the magnitude of effects on human/animal life as well as the environment would be decreased or diluted. Also, natural sources and lands could be saved from further degradation (Markandeya et al., 2016b). Atmospheric build-up of hazardous air pollutants might lead to the formation of a fog in a particular location, especially valleys of a hilly region, which is due to weak atmospheric stability conditions, such as thermal inversion, along with extremely stable ones (Tu et al., 2012; Markandeya et al., 2016b). For the purpose of evaluating Environmental Impact Assessment, American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) has been accepted by the Department of Environment (DOE) as a standard tool to predict the transportation of air pollutants (Ma et al., 2013; Seangkiatiyuth et al., 2011; Kumar et al., 2017; Baawain et al., 2017). Also, AERMOD has been utilized to predict dispersion of such air pollutants as SO_2 and NO_2 from a power plant (Ding, 2012; Mokhtar et al., 2014), particulate matter (Kesarkar et al., 2007), and smelting of mercury from silver (Hagan et al., 2011). Also, Mokhtar et al. (2014) used Air dispersion modelling (AERMOD) to predict ground level concentration within 10 km radius of the emission source. Based on Health Risk Assessment, various health risks were identified for both short-term and long-term dispersion of the desired air pollutants. In addition, Markamdeya et al. (2016b) showed that modeling results suggested that Gas-Based Power Plants could be considered a clean substitute for coal power plants, located inside the city and polluting the environment considerably. The main objective of the current modeling study is to estimate the potentials of air emissions from Besat gas-based power plant along with maximum ground level concentration of nitrogen dioxide (NO_2), and determine its share in reduction of the air quality in three receptors (namely, the cities of Varamin, Eslamshahr, and Nasirshahr) in downwind direction.

Fig. 1. Besat power plant (the studied thermal power plant), located south of Tehran

MATERIAL AND METHODS

The studied thermal power plant is a 3 × 82.5 MW power plant, located south of Tehran (Fig. 1). It receives natural gas as fuel. Table. 1 shows the basic information of the plant, while Table. 2 gives the average emission amount of various pollutants during a winter day from this power plant.

Table. 3 presents the locations and details of the meteorological stations. The meteorological analysis employed surface wind velocities and wind directions at 10 m above the ground to evaluate the primary impact areas of NOx emissions from the thermal power plant. In order to run the AERMOD modeling system, the surface meteorological data along with cover and ceiling height were obtained from Mehrabad Station (35°41′ 21″ N, 51°18′49″E). The upper meteorological data, used for accurate wind fields' simulation, were obtained from Mehrabad station, too.

Table. 1. Information of Besat thermal plant.

Parameter	Specification
Capacity (MW)	3×82.5
Number of stack	3
Stack height (m)	28
Stack diameter (m)	2.8
Stack velocity (m/sec)	5.5
Exit gas temperature (K)	408
Flow rate of flue gas (Nm^3/h)	27

Table. 2. Emissions of air pollutants from 3 stacks of Besat thermal power plant (Kg/day).

Pollutant	Natural gas as fuel
SO_2	Insignificant
CO	Insignificant
NOx	237
PM	9.5
H.C	Insignificant

Table. 3. Detailed information of meteorological stations.

Meteorological station	Meteorological parameter	Distance from reference point (Km)	Direction from reference point
Mehrabad	Surface data: Global radiation (W/m^2), Pressure (mmHg), Relative Humidity (%), Dry bulb Temperature at 10m (°C), Wind direction (°), and Wind speed (m/sec).	17.7 Km	NW
Mehrabad	Upper air data: Dew pint temperature (°C), Height above sea level (m), Pressure (hPa), Relative Humidity (%), Dry bulb Temperature (°C), Wind direction (°), and Wind speed (m/sec).	17.7Km	NW

A steady-state Gaussian plume model (AERMOD) is an updated version of Industrial Source Complex Model Source (ISC) models. AERMOD is a refined dispersion model in complex and simple terrains for receptors, some 50 km off the modelled source. This study employed AERMOD modelling system, version 16.216r (Lakes Environmental Software, Waterloo, Ontario, Canada), which consisted of three steps: AERMET (AERMOD Meteorological Preprocessor), AERMAP (AERMOD Terrain Preprocessor), and AERMOD Gaussian Plume Model with PBL modules. Fig. 2 illustrates the sequence of the involved steps in AERMOD modelling. Based on the guideline on Air Quality Models, published by US EPA (2005), for the estimation of pollutant concentrations via an air quality model, five years of representative meteorological data are needed.

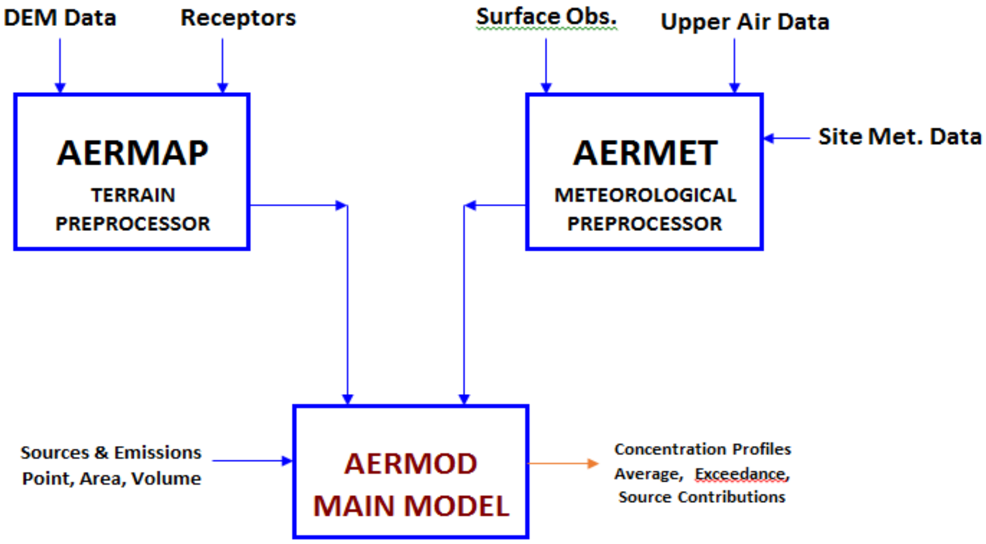


Fig. 2. AERMOD modeling system.

In this study, both surface and upper air meteorological data inputs (1st January2016 to 31st December 2016) for AERMOD were obtained from the measurements, made at the stations. Using AERMET View (Version 16.216r), the data were then pre-processed and got organized into a suitable format for AERMOD dispersion model. The required meteorological data for AERMOD are surface data (hourly values), describing conditions closer to ground level, and upper air data (daily values), describing higher conditions in the atmosphere (Table. 3). AERMOD uses boundary layer parameters, needed as input for AERMET processor. The required boundary layer parameters are albedo, Bowen ratio, and surface roughness, which were determined here in accordance with the US EPA (2005), by examining an area around the study area, with a radius of 3 km. According to land-use classification, site-specific values of albedo (0.2075), Bowen ration (1.625), and surface roughness (1) were obtained from AERMET. The topographical effects of the site were addressed by employing the elevated terrain option in the software. Prior to modelling in AERMOD, the terrain data were pre-processed with AERMAP. In order to assess the maximum ground level pollutant concentrations, the current study used a comprehensive Cartesian receptor grid, extending to 30 km from the center of the emission source in AERMOD modelling. The Cartesian receptors grid (30 km × 30 km domain) had a uniform spacing of 500 m. Three discrete receptors, namely the cities of Varamin, Eslamshahr, and

Nasirshar, were 2 km, 43 km, and 48 km from the power plant, respectively. They were set in the modelling domain and got selected in order to study the share of this power plant in air quality reduction, as a result of the released air pollutants from Besat thermal power plant. Also, two different approach were used to estimate the allocation of air pollution taxes in the mentioned receptors.

RESULTS AND DISCUSSION

Fig. 3 illustrates the prevailing wind (wind rose) over the studied period. Based on the results, the prevailing wind direction in the study area was from the west. The wind class frequency distribution indicated the prevailing wind class was 2.1-3.6 m/sec with prevail percentage of 31%.

Figs. 4- 5 show NO_2 dispersion on 1hr and annual average basis with Fig. 4 demonstrating that the maximum ground level concentration occurred near the emission source for 1-hr NO_2 dispersion, whereas the influence of west wind direction was obvious in annual dispersion, resulting in maximum ground level concentrations in receptors east of the emission source. Between the three discrete receptors, receptor Varamin city experienced the maximum NO_2 concentration in all cases because of its proximity to the emission source (Besat power plant).

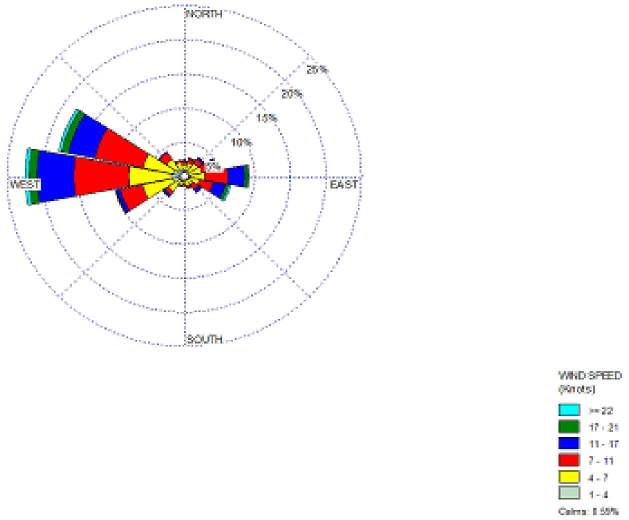


Fig. 3. Wind Rose Plot of the wind speed, blown from West to East, for the case study during studied period. The prevailing wind class is 2.1-3.6 m/sec with prevail percentage of 31%.

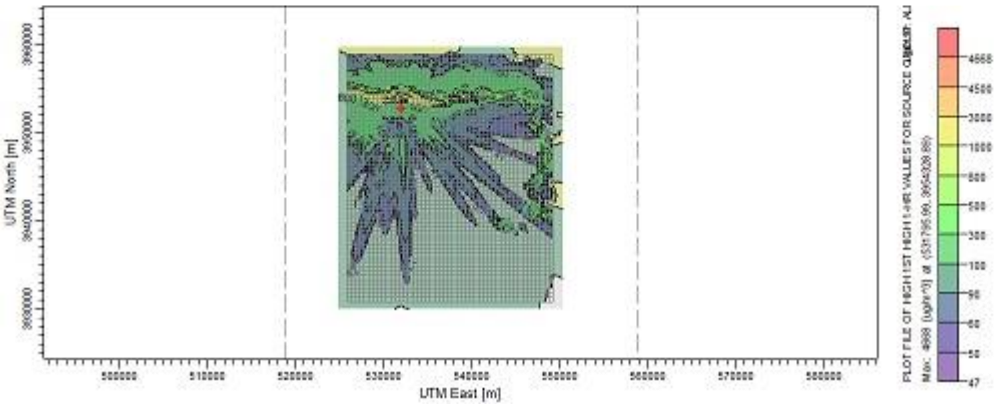


Fig. 4. Simulated NO_2 dispersion on 1hr average basis using AERMOD model.

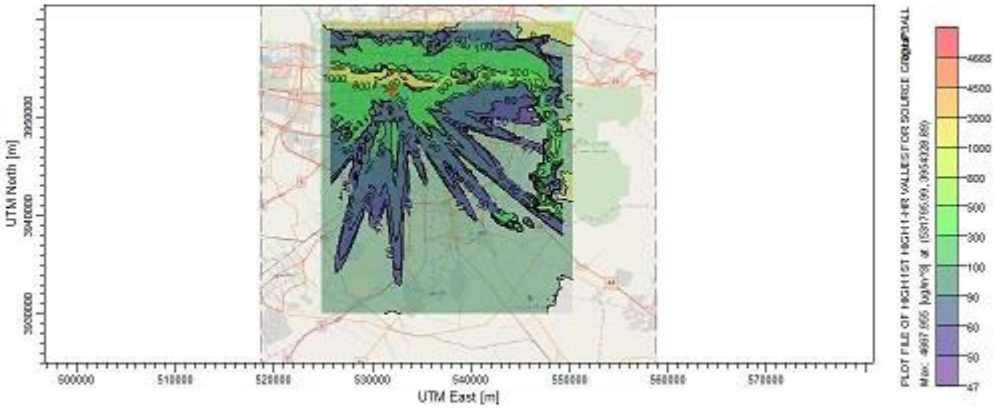


Fig. 5. Annual average of simulated NO_2 dispersion, using AERMOD model.

Table 4 shows the highest ground level concentration of the simulated pollutant for both average periods, comparing the ambient concentration of NO_2, emitted from the studied natural gas power plant (Besat power plant) with Iranian and National Ambient Air Quality Standards (EPA NAAQS) and other guidelines. The simulated concentrations turned out to fall below Iranian air ambient standard and the NAAQS standard for NO_2 (hourly standard of 188 $\mu g/m^3$ and annually one of 100 $\mu g/m^3$). Results show that the receptors, far from Besat power plant, were exposed to a very low and acceptable concentration of the pollutant. EU and WHO guidelines were used as reference, indicating that further evaluation may be necessary to determine the possibility of a true threat to human health. Other similar studies which burnt other types of fuel for power generation, (López et al., 2005, Mokhtar, et al., 2014), showed that the reported predicted annual average concentration of emitted SO_2 from the power plant were high. However, Best power plant's fuel was natural gas, composed of hydrogen and carbon only, which did not produce any Sulphur oxide, though it was responsible for production of a substantial amount of NOx. Normally, nitric oxide (NO), as the primary pollutant, is released from industrial processes to be instantly converted into NOx after undergoing chemical reactions in the atmosphere. These nitrogen oxides are responsible for secondary pollutants of liquid droplets or solid aerosols. Also, in the presence of solar energy, nitrogen oxides react with water vapor and other reactive gases to form harmful photochemical smog in the lower troposphere. Due to its higher density than air, this photochemical smog can often be detected in the urban atmosphere, accumulating in the breathing zone (Ko & Hui, 2012). It is reported that there is a relation between NO_2, on one hand, and the risk of lung cancer, on the other (Stanek et al., 2011; Krishna et al., 2004).

Table. 4. Estimated highest ground level concentration in comparison with some current ambient air quality standards

Pollutant	Average period	Estimated highest ground level concentration ($\mu g/m^3$)	EPA NAAQS[1] ($\mu g/m^3$)	Iranian standard[2] ($\mu g/m^3$)	EU[3] ($\mu g/m^3$)	WHO[4] ($\mu g/m^3$)
NO_2	1hour	4668	188	188	200	200
	Year	4667	100	100	40	40

[1] EPA National Ambient Air Quality Standards

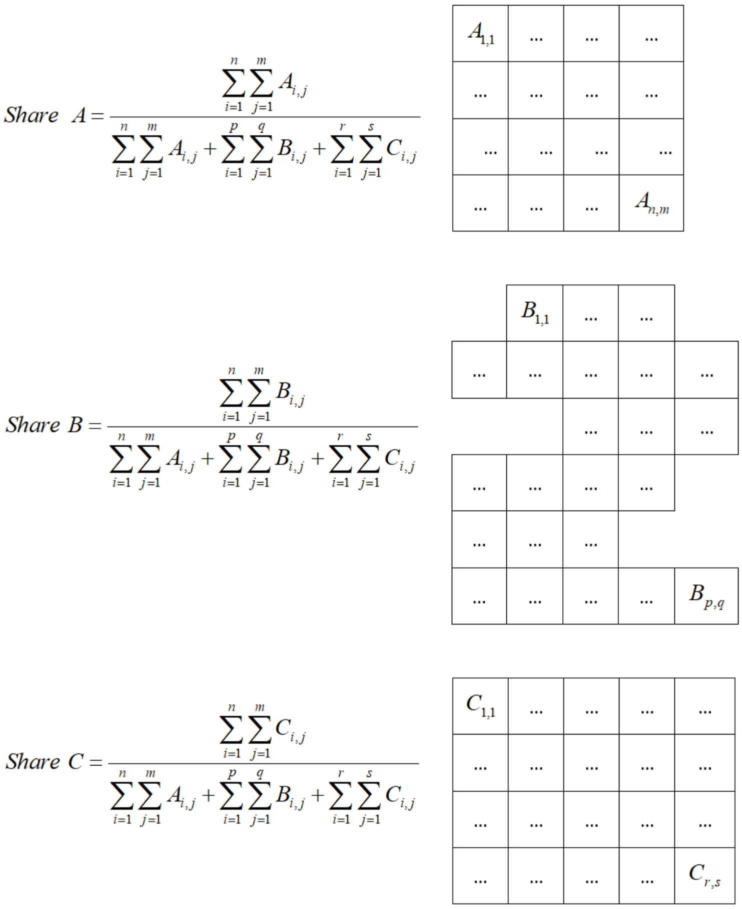
[2] Iranian air ambient standard

[3] European commission ambient air quality directive

[4] World Health Organization air quality guideline

The present study investigated the impact of Besat power plant on reduction of air quality in the three cities of Varamin, Nasirshahr, and Islamshahr, using AERMOD Model to determine the pollution source matrix of a specific source. Once the air pollutant concentration was modelled, it used an innovative idea to allocate air-pollution-related taxes. Since no scientific and cognitive method has been presented so far, this idea could be a model to determine the complications and solve the legal problems, associated with it. Two different methods were used to determine the complications: The first method was based on the city's boundaries and the simulated amount of air pollutant concentrations in each city as a receptor. It should be mentioned that estimation of air pollution taxes, based on air pollution modeling, was first developed in this study (Fig. 6, wherein A, B, and C are air pollutant concentration matrices of each city). In the second approach, the population of each receptor played a role, beside the city's boundaries and the simulated amount of air pollutant concentrations in each city as a receptor (Fig. 7). In the current study, P_A, P_B, and P_C stand for each city's population.

As aforementioned, three cities of Varamin, Eslamshahr, and Nasirshahr were selected as receptors in the current study, having a pollution of 208996, 548620, and 23802 citizens, respectively. Based on the two different used approaches, Table. 5 gives the share of each city as a receptor in air pollution tax (caused by Besat thermal power plant).



$$Share\ \ A=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}A_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}A_{i,j}+\sum_{i=1}^{p}\sum_{j=1}^{q}B_{i,j}+\sum_{i=1}^{r}\sum_{j=1}^{s}C_{i,j}}$$

$$Share\ B=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}B_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}A_{i,j}+\sum_{i=1}^{p}\sum_{j=1}^{q}B_{i,j}+\sum_{i=1}^{r}\sum_{j=1}^{s}C_{i,j}}$$

$$Share\ C=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}C_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}A_{i,j}+\sum_{i=1}^{p}\sum_{j=1}^{q}B_{i,j}+\sum_{i=1}^{r}\sum_{j=1}^{s}C_{i,j}}$$

Fig. 6. Calculation of air pollutant matrices in order to estimate air pollution taxes in the receptors (first approach).

$$Share\ \ A = \frac{P_A \sum_{i=1}^{n}\sum_{j=1}^{m} A_{i,j}}{P_A \sum_{i=1}^{n}\sum_{j=1}^{m} A_{i,j} + P_B \sum_{i=1}^{p}\sum_{j=1}^{q} B_{i,j} + P_C \sum_{i=1}^{r}\sum_{j=1}^{s} C_{i,j}}$$

$$Share\ B = \frac{P_B \sum_{i=1}^{n}\sum_{j=1}^{m} B_{i,j}}{P_A \sum_{i=1}^{n}\sum_{j=1}^{m} A_{i,j} + P_B \sum_{i=1}^{p}\sum_{j=1}^{q} B_{i,j} + P_C \sum_{i=1}^{r}\sum_{j=1}^{s} C_{i,j}}$$

$$Share\ C = \frac{P_C \sum_{i=1}^{n}\sum_{j=1}^{m} C_{i,j}}{P_A \sum_{i=1}^{n}\sum_{j=1}^{m} A_{i,j} + P_B \sum_{i=1}^{p}\sum_{j=1}^{q} B_{i,j} + P_C \sum_{i=1}^{r}\sum_{j=1}^{s} C_{i,j}}$$

Fig. 7. Calculation of air pollutant matrices to estimate air pollution taxes in receptors (second approach)

Table. 5. Estimated share of receptors in air pollution taxes, caused by Besat thermal power plant, using two different approaches.

City as a receptor	Population	Estimated share, based on the first approach	Estimated share, based on the second approach
Eslamshahr	208996	0.348	0.594
Varamin	548620	0.621	0.404
Nasirshahr	23802	0.031	0.002

Table. 5 shows each city's share of air pollution from Besat thermal power plant. Theses information can be used to determine the taxes and solve the legal problems, associated with it. According to the results from the first approach, Varamin had the largest share of air pollution, caused by Best power plant, and Nasirshahr had the least one; however, based on the second approach, the lion's share surprisingly belonged to Eshalmshahr and the least one to Nasirshahr again. Each city's population was the main reason for this disagreement, proving that beside the city's boundaries as well as the simulated amount of air pollutant concentrations in each city, pollution is of high account to determine the taxes, related to air pollution from Besat thermal power plant.

In a similar study, WRF/CALPUFE couple was used to study the dispersion and distribution of air pollutant emissions from multi-stack industrial sources in Ulsan, Korea, also evaluating the contribution of the source as categorized by different kinds of air pollution sources. It showed that point sources such as UPIAC and OSIC industrial complexes had the main contribution in air pollutant emissions (Houng- Don Lee et al., 2014). Such results can help authorities to better understand what causes air pollution in the areas. It can also enable environmental administrators to implement more effective policies for reduction of air-pollutant emissions. Generally, the income from environmental taxes should be considered a general governmental income, which should be used in order to maintain the expenditure in other areas, as well as reduce taxes or debts. Moreover, some of the related incomes could be used to make up those, most affected by environmental damages. Nonetheless, in practice they are some challenges. It is difficult to measure the impact of environmental damages to individuals from a range of pollutants. Keeping in mind that the environment is a public type of goods that can suffer from wide-spreading damages, caused by different pollutants, environmental-related taxes can be widely used to neutralize the increased costs for hospitals, thus adapting to environmental damages (Environmental taxation, 2011).

CONCLUSION

The current study investigated AERMOD modelling of NO_2 emissions from Besat thermal power plant. Based on its results, the simulated concentration of NO_2 did not exceed either Iranian or National Ambient Air Quality Standards (EPA NAAQS). Therefore, natural-gas-based power plants can be considered a clean technology in the area of power generation. Additionally, the simulated NO_2 concentrations, via AERMOD model, were used to determine the pollution source matrix of Besat power plant, employing an innovative idea to allocate air-pollution-related taxes that can be used to determine the complications and solve the legal problems, associated with it. Two different methods were used to determine the complications with three discrete receptors chosen in the modelling domain, namely, the cities of Varamin, Eslamshahr, and Nasirshar, located 2 km, 43 km, and 48 km from the power plant, respectively. In the first method the city's boundaries and the simulated amount of air pollutant concentrations were considered for each receptors' share of air pollution, caused by Besat thermal power plant, whereas the second one considered the population of each receptor, too. According to the first approach, Varamin had the largest share in air pollution, caused by the power plant, while the second one surprisingly showed the largest share to for Eshalmshahr, thus showing the significant influence of population in determining the share of air pollution, caused by Besat thermal power plant.

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