Establishing the Local Emission Standard Level: the Case of Assaluyeh

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Abstract

Environmental consequences of air pollution have necessitated quantitative analyses of adverse effects of human activities via environmental risk assessment methods. Energy production chain is one the most polluting industries as high concentration of activities in sensitive regions has been associated with serious environmental issues. This paper aims to address this issue by establishing local emission standards for large energy systems via back calculation of common pollution dispersion modeling. In a case study, it is shown that the current national regulations on emission rates are not guarantor of local ambient air standards and precise local emission limits are needed. The back calculation of standard situations to assess the total emission level studied in our case shows a need for emission reduction of 65\% to ensure tolerable health criteria in the worst probable situations. Also, environmental gains of some system modifications were examined. Findings of the process of local emission standard estimation could then provide appropriate information for identifying the permissible level of pollution from each emission source in further studies.

Keywords:
Air pollution, Local Standard, Emission, PM\textsubscript{10}, Energy conversion.

1. Introduction

Pollution of the environment has been recognized as an obstacle to sustainable development in the last four decades [1]. Human activity and its impact on air quality has led to an adverse social and economic situation [2]. Consequences of the environmental impact of air pollution have necessitated quantitative analysis of the adverse effects of human activities via air dispersion modeling.

Air dispersion models differ from each other based on several parameters: calculation methods, subjected matter, emission source type, data requirements, environmental conditions and their
There have been several studies which have compared models based on their compatibilities, closeness to empirical data and simplicity [4-6]. One of the most important factors in choosing a model is the ability to take into account the topographic characteristics of the region. The case study of the region of Assaluyeh has this distinction.

Assaluyeh is an energy rich region located in the south of Iran, and it is a core industrial zone for natural gas production and conversion in the Middle East. The South Pars Special Economic Energy Zone (SPEEZ) is located in Assaluyeh. It is envisaged that this region would eventually contain 28 natural gas upstream production units and 17 petrochemical complexes. However, only 12 natural gas upstream production units and 11 of petrochemical complexes are in operation at the present time; producing 300 MMSCM of refined natural gas, 400 Mbbl of gas condensates and 17 Mton of petrochemical products daily totaling 60% of Iran's gas production and one third of the country's petrochemical production.

The high concentration of industrial activity in the region has been associated with serious environmental issues which have been the subject of many studies in recent years. A group of these studies have looked at the energy efficiency and environmental impact of individual industrial complexes [7-9] while others have focused on the environmental consequences of air pollution, waste water disposal [10, 11] and waste management systems [12] in certain industrial units [13]. The conclusions of recent studies indicate that emission and disposal of pollutants are compatible with national and international standards but the pollution level of the region as a whole is beyond the acceptable level. Of the aforementioned studies only a handful has investigated the environmental status of the region as a whole. Instead they have viewed the emission of pollutants from only certain industrial units as isolated entities, whereas the combined effect of activities from various industrial units requires an integrated approach to the problem. Hence, a review of recent studies has led to the formulation and initiation of the present research work.

Since the 1970s the cardiopulmonary health effects from high concentration of particulate matters has been identified and addressed in many observations [14, 15]. Research on particulate matter with an aerodynamic diameter less than 10 micrometer (PM$_{10}$) has shown consistent and strong associations between adverse health effects and exposures to high concentrations of particulates [16, 17]. Moreover, the particulate matters also have a large effect on other environmental assets such as vegetation systems [18]. Thus, many social and environmental external cost assessments of particulate matter emissions include these additional damage costs for PM$_{10}$ in comparison to other criteria pollutants [19, 20]. Added to these factors the availability of more precise emission factors data in comparison to other criteria pollutants$^1$, more developed control actions, and local environmental controversies of PM$_{10}$ concentration gives this pollutant a higher priority for policy makers to assess standard emission limits in Assaluyeh. Thus PM$_{10}$ was considered as the subject of the case study in this research.

Local site air quality reports have indicated that Iranian national emission regulations do not guarantee an adequate basis for preserving the Assaluyeh environment, and observation of national emission restrictions does not necessarily limit the health hazards in the region. Therefore, better local emission regulations need to be developed in order to be able to introduce better management of the environment in Assaluyeh. Thus, the present work aims at applying an

$^1$ Emission factors for Nitrogen Oxides (NOx) are highly uncertain and the emission of Sulfur Oxides (SOx) is highly dependent to the concentration of Sulfur compounds in the fuel.
integrated approach in order to model the environmental status of the region and to develop reliable local emission limits to guarantee ambient air quality standards. An attempt shall be made to indicate that Assaluyeh is a special case in which the local environment cannot be successfully managed with the current national guidelines on emission of pollutants. Rather, it is necessary to formulate specific emission limits to preserve the quality of its environment. Therefore, a back calculation of environmental air quality is implemented in the present study to assess the proposed amount of emission. Such a back calculation would enable concluding the acceptable level of emission and this level of admissible emission can then be distributed to the industrial units. The results of this process of estimation could also then provide appropriate information for identifying the permissible level of emission from each emission source. Hence, a brief description of the emission standard estimation method and available dispersion models shall be outlined in the next section of the present paper. Next, local specifications and their current emission levels will be described. Then, the results of application of a dispersion model for the current situation and emission limit assessment shall be validated and discussed. Finally, the gap between the current emission level and the admissible level of emission shall be presented.

2. Methodology

According to the International Association for Impact Assessment (IAIA), the environmental impact of any human activity (plan, policy, program, or project) must be assessed [21]. This assessment is done using environmental predictive models (Environmental Risk Assessment tools (ERA)). Then based on the ambient air quality standards, a maximum emission limit for the pollutants must be addressed, considering the best available techniques (BAT) and cost-benefit analysis of control actions. This method is being used in many national environmental regulatory guidelines [22]. These regulations may address the polluting unit for certain modifications or provide rule outcome-based targets to give enough flexibility to the unit in their choice of appropriate action. In the case of nonsatisfaction of BAT for a special meteorological or geographical condition, the regulator may ask for further restrictive actions or closure of the polluting unit, even if the act is not economically cost-effective [22, 23].

2.1. Modeling

Pollution dispersion models are a type of environmental risk assessment tools used to assess or simulate the environmental impacts of human activity. Based on the conceptual algorithm for simulation of air quality, models may be categorized into five main groups: Box models, Gaussian models, Lagrangian/Eulerian models, CFD models and aerosol dynamic models which all are satisfactorily introduced in Holmes review of dispersion models [3]. The Gaussian dispersion models, which are widely applied [3, 26], are based on the assumption that the plume of a buoyant pollutant is continuously emitted and its vertical dispersion follows a Gaussian distribution pattern. The plume rise is dependent on the air stability and the travel time of the pollutant which is related to the wind speed and distance from the emission source. Most of the Gaussian dispersion models affect the turbulent surface reflection of the pollutant as well as chemical and physical processes.

Among the dispersion models the Complex Terrain Dispersion Model (CTDM), Industrial Source Complex (ISC3), Atmospheric Dispersion Modeling System (ADMS) and AMS/EPA Regulatory Model (AERMOD) are widely used in industrial applications [27]. These models require a large variety of meteorological and topography data. The Atmospheric Dispersion
Model System (ADMS) developed by the Cambridge Environmental Research Consultant (CERC) is a verified model used for national environmental regulations [29]. The ability to interpolate hourly meteorological data for several predefined pollutants, emission sources and geographical characteristics and a user-friendly interface and linkage to output visualizers are some of the competitive strengths of this model. The model is known as a new generation dispersion model as it combines general skewed Gaussian concentration distribution techniques with boundary layer height and Monin-Obukhov length to calculate dispersion under convective conditions [29].

3. Case Study

Almost all current operating facilities in Assaluyeh (are concentrated in the Pars 1 region while future production developments in new plants will be approximately located in the Pars 2 region southeast of the city of Kangan (Fig. 1).

The Pars 1 territory is surrounded in the southwest by the Persian Gulf and from the northeast by the tail of the Zagros mountain range. The terrain starts from a distance of 3.3 Kilometers from the coastline and rises with a slope of 0.7 up to 4000 meters. As shown above, the Pars 1 industrial facilities are located in the vicinity of four urban areas - Assaluyeh city, Nakhl Taghi, Bidekhoon and Shirinoo- and other rural villages. According to the terrain distribution in the region, the wind direction is mostly northwest and southeast, parallel to the terrains. Gathered meteorological details may be presented upon request. All the meteorological data were gathered based on reports from the Pars Special Zone/Persian Gulf International Airport (OIBP) synoptic weather station 15 Km Eastern of the city of Assaluyeh. Also, all the geographic data were gathered for a square of 52° to 53° Eastern longitude and 27° to 28° Northern latitude as depicted in Fig. 1.

![Fig 1. Map of modeled region showing industrial area and the surrounding residential areas from Google™ Earth](image)

3.1. Region Specifications and Model Inputs

The required input data for a precise modeling of pollutant dispersion may be categorized into three areas: meteorological data, emission source data, and geographical data.

Based on the availability of data, 9 indicators were used for each hourly meteorological input line to the model: Temperature, Wind speed, Wind Direction, Relative Humidity, Sea Temperature, Precipitation, Surface Albedo, Could Coverage, and a Modified Priestly-Taylor index. Also, the dry deposition speed for particulate matters emitted from fossil fuel combustion was used. This indicator varies based on the source and size distribution of particulate matter production. Appropriate data were gathered based on the Jim Pederson study [30]. Table A.1 shows the data sources for each model input and is presented in Appendix A.
As described above, there are several emission sources in the region. These emission sources were categorized into 3 area emission sources (Pars 1 Refineries, Pars 2 Petrochemical Complexes), one line source (flare line in the foothills) and a point source of Sarooj Kangan cement production plant. The amount of PM$_{10}$ emission in all facilities is calculated based on the industrial complexes actual production rates [31] and the emission factors derived from international emission factor estimation reports including ECOINVENT [32], EMEP/EEA emission inventory guidebook 2013, PlastisEurope 2012 reports [33-36], and other research studies such as Delucchi’s study for methanol production emission factors [37]. For some emission sources, such as flare line based on the in site observations, some assumptions of the rate of soot emission were also used. Also, for the cement production plant, based on the Ferraris study it is assumed that 40% of the particulate matter emissions have a size of less than 10 µm [38].

Emission estimation results for the active polluting sources in the region and the overall emission from each source category are available upon request.

One other important input to the model was the background ambient PM$_{10}$ concentration. Boushehr province in Iran, as many other Western and Southern provinces in Iran, experiences a high amount of natural dust concentrations during the year. It routinely goes above the national air quality standard of 50 µg/m$^3$ for half of the year[39, 40]. Fig. 2 shows the monthly averaged particulate matter concentration in Boushehr province in the 2005 to 2013 period, as the background concentration input to the model.²

![Fig. 2 Input background concentrations of PM$_{10}$ in the region][39]

### 4. Model Results and Discussion

#### 4.1. Current Situation

² Natural dust in the region has a 95% size distribution of 1.2 to 8.4 µm with an average of 4.9 ± 0.6 µm. As this size distribution fits the PM$_{10}$ specifications, the reported concentrations were assumed as background concentrations.
Using the above mentioned input data and dry deposition, background concentration and complex terrain options of the ADMS 5.1 software, the current concentration fluctuations during a sample year (2014) were assessed. Fig. 3 shows the geographically maximum ground level 24 hour averaged concentration of PM$_{10}$ for each day and for a monthly average meteorological situation.

Except for May and December in which the monthly average meteorological data represents the average monthly concentrations, the above diagram shows that the monthly average meteorological situation may be a good representative of higher daily concentrations in the month. As the goal of this study is to assess the standard emission limit for the special situation of the Assaluyeh region, higher concentrations during the year are of importance, and thus monthly averaged meteorological data may be a good basis for model runs.

Fig. 4 below shows the dispersion of the pollutants in the region stemmed from wind speed, wind direction and the complex northern terrains.
Except for August when the prevailing wind is toward the North, during the rest of the year the pollutants are distributed in a southeastern direction of the industrial zone where mangrove vegetation and some residential sectors exist. As it is shown, the geographically maximum concentrations occur above the Pars 1 refineries downstream of the petrochemical complexes (which are the worst polluters in the region).

4.2. Standard Situation
There are two types of environmental air quality standards of criteria pollutants. The primary standards are set to address the health of sensitive populations such as asthmatic, children and
elders. In contrast, the secondary standards are set to protect the health condition of public welfare components such as animals, vegetation and buildings [41]. The primary standards are more restrictive and are assumed to be the subjected limit for environmental regulations. As it is shown in Fig. 5, the maximum ground level of 24 hour average concentration at the most polluted point is always more than the primary standard limits regulated by US environmental organizations (150 µg/m³)[41] as well as standards set by European Commission (EC) and Iranian Department of Environment (IRI DOE) air quality environmental standards (50 µg/m³) [42, 43].

![Graph showing Concentrations in the current situation and back calculated of emission levels versus the standard limits](image)

In the above diagram, the narrow curve on the top represents the worst situation that could happen based on the most vulnerable daily meteorological conditions in each month (the maximum concentration both temporally and geographically). Due to the low frequency of such a condition happening in each month (as presented in Fig. 3) this curve cannot be used for environmental regulation. The bold black line shows the current geographically maximum daily concentration based on the monthly averaged meteorological condition. The most effective factor in changing the concentrations is the wind speed. Higher wind speeds in May and lower ones in September to November contribute to PM₁₀ concentration fluctuations. Furthermore, higher cloud coverage from November to February leads to a decrease in PM₁₀ concentrations in comparison to hot dry days of May to September. This behavior is due to the fact that during high sun radiation, the wind speed must be high to avoid instability and high concentrations. So, in the summer time the rise in wind speed lessens the pollutant concentration. On the other hand, in lower radiative months the rise in wind speed results in less stability and more pollution. It is also obvious that lower wind speed and slight precipitation in November to February cause a rapid decrease in the natural dust storms and haze concentrations in the region.

To back calculate the standard emission levels, the same curve for fewer amounts of emission are drawn to assess the maximum emission limit guaranteeing the ambient air quality standards. As it is shown, due to the presence of background natural haze concentrations, even with no industrial activity, the national or European air quality standards cannot be met. However, by
reducing emissions down to 35% of the current situation the environmental air condition set by the United States Environmental Protection Agency (US EPA) could be met.

4.3. Validation

Many validation reports for common air dispersion modeling using ADMS have been published and presented in the developer website [29]. In many of such these reports and studies the fitness to the actual measured data for a specific source or region is examined. Comparing the competitive models, ADMS shows higher accuracy. [44, 45].

Incidentally, there are a few measurement records available from air quality monitoring stations in the refineries. The below accumulative percentage histogram shows the frequency distribution of recorded values from June in Pars 1 refineries in comparison with the simulated values.

Fig 6. Histogram of recorded in site values versus the simulated values

As it is depicted in the Fig. 6 above, the recorded PM$_{10}$ concentrations and simulated values in June are fairly consistent which shows a good fit to the frequency distribution in the above diagram. However, for lesser concentrations, the frequency of occurrence is underestimated. This underestimation is a common problem in many PM$_{10}$ dispersion modeling studies due to underestimation of emission rates or overestimation of deposition rates [44, 46]. Also, in general, the modeling outputs will often be underestimated, specifically in the case of assessment of the highest probable concentrations for environmental regulations, as the meteorological data are usually recorded as averaged values for a period of time, thus missing the hourly worst meteorological conditions. Another explanation for this underestimation is that air dispersion models are steady-state models unable to track the accumulation of the pollutant in the region for long term inversions (such as the fumigation effect in coastline areas).

Trajectory of the particulate matters with the help of HYSPLIT$^3$ developed by the US NOAA$^4$ may provide an appropriate means for testing dispersion patterns [47, 48]. The results of back

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$^3$ Hybrid Single Particle Lagrangian Integrated Trajectory Model

$^4$ United States National Ocean and Atmospheric Administration
trajectory calculations show that pollutant retention time reaches a maximum level when emission takes place in the autumn. Results in Fig. 7 show that the intense accumulation of pollutants takes place in September, November and December daytime when the pollutants remain in the region for longer periods and at lower heights from the ground.

![Fig 7. Model outputs for A: January and B: December. (The results show high accumulation potential in December midnights in lower heights on land while the dispersion is quick and toward the sea in January.)](image)

The HYSPLIT online dispersion model results also shows the same dispersion behaviour for PM$_{10}$ emitted in the region (Fig. 8).

![Fig 8. Dispersion models outputs for Using HYSPLIT online software (B) in comparison to the ADMS model output (A) for a sample month (December 2014)](image)

It is worth mention that the HYSPLIT interface takes into account few source or emission specification data. Thus the modelled quantities are not reliable enough. However using its online meteorological and topographic data, it is useful to assess the dispersion behaviour of the pollutants in the region.

### 4.4. Gap Analysis

As mentioned before, due to high natural haze concentrations in the region under all emission circumstances, national ambient air quality standards cannot be met. It should be noted that according to the modeling results, although all the units are operating within the national
standard emission limits [49], there is a 65% emission reduction needed to guarantee the US EPA ambient air quality standards.

Some industrial activities in the region, such as natural gas production upstream facilities in Pars 1 and Pars 2 (aside from their share in flare line pollution), make little contributions to the total emission. Also, the Sarooj Kangan cement plant, which is an important polluting source in the Pars 2 zone, does not have any effect on the geographically Maximum concentrations occurring in the Pars 1 zone.

Intensified large amounts of uncontrolled gas flares and petrochemical plants processes are the two main sources of such pollution. Reducing flaring gas as well as using soot formation control techniques may decrease the amount of PM emissions significantly. Rahimpour and his research team have discussed the emission reductions from flare gas recovery in upstream facilities [9]. Also, managing the internal feed and product exchange between the complexes may reduce intermittent gas flaring in upstream and downstream sectors. Shutdown optimization and usage of storage tanks to prevent excess feed in overhaul periods is another flare prevention technique [50]. Moreover due to the controllable nature of the PM$_{10}$ emission via developed control techniques, some effective environmental retrofit policies toward BATs have been suggested for petrochemical plants such as stack emission control technologies, flue gas heat recoveries, steam/air adjustments in combustion chambers and steam system optimization in ammonia plants [7, 51].

As some 91% of total emissions are occurring in the Pars 1 territory and the adverse environmental impacts are being seen there, it is recommended to make the 65% reductions within the Pars 1 region. Due to the nature of the process, the Pardis petrochemical complex producing Urea and Ammonia products is responsible for some 46% of PM$_{10}$ emissions among petrochemical plants. Restricted environmental regulations on this plant along with cutting the flaring emission up to 90% may lead to a 35% reduction in the Maximum PM$_{10}$ concentration in the region depicted in Fig. 9.

![Fig 9. Effect of 90% flare emission cut and controlling the Pardis petrochemical complex emissions](image)

It is worth mentioning that the effect of emission reduction in the production facilities only changes the concentration distribution in the region while the dispersion pattern remains the same. Fig. 10 shows the spreader concentration distribution in a 90% emission reduction case.
5. Conclusion

The main idea of this research was to show that the current environmental regulations on emission rates are not a guarantor of local ambient air standards, and hence to address the need for local environmental regulations based on common environmental risk assessment tools and methodologies. The PM$_{10}$, as the most controversial and damaging pollutant in the Assaluyhe region, was chosen as a sample for case study and the results were validated with in situ recorded concentrations. The interpretation of the concentration variations during the year was presented. The back calculation of standard situations to assess the total emission level studied here shows a need for an emission reduction of 65% within the Pars 1 territory.

According to the modeling results, some process retrofits may significantly reduce the PM$_{10}$ concentrations in the region. Due to the nature of its process, Pardis (the Urea/Ammonia producing plant) accounts for about 46% of total PM$_{10}$ emission in the region. Controlling PM$_{10}$ emissions from this plant may contribute to high emission reductions. Also, reduction of uncontrolled gas flares in the foothills of the northern mountain range is a cost effective and influential step. Development of polluting plants in the Pars 1 zone must cease but natural gas production refineries may be developed as they contribute little to the current pollution and have a high priority for the country due to the competitive opportunity of gas production from the South Pars gas field.

Also, these results suggest the appropriate time for annual overhaul of processes that may ease the burden of environmental pollution. Results illustrate that the best time periods for exceptional operations could be spring (especially April and May) when the existence of high wind speed, wind direction and cloud coverage may cause a suitable meteorological condition.

6. Recommended Further Studies

This research was done to examine the procedure of local environmental regulatory for emission level standards. More accurate modeling based on actual emission is recommended for further studies. Findings by this process of local standard estimation could then provide appropriate information for identifying the permissible level of emission from each emission source in future studies. Also, similar to other environmental studies, implementation of these results need economic incentives which may be achieved by using integrated assessment models starting with
environmental impact assessments to evaluate external social/economic damages, costs and benefits. This is also recommended to be the subject of further studies.

**Acknowledgements**

As mentioned in the text, many data sources were used to gather the required meteorological and geographical inputs for the model. The ASTER GDEM data source for geographical data and the Research Data Archive is managed by the Data Support Section of the Computational and Information Systems Laboratory at the National Center for Atmospheric Research in Boulder, Colorado. The Ecoinvent center was used as the provider of the local and global emission factor data bases. Also, thanks to the CERC center for providing the ADMS 5.1 model to promote environmental research activities. Finally, the authors are thankful for the scientific assistance of Dr. Mohammad Sadegh Hassanvand, Assistant Professor of the Center for Environmental Research of Tehran University of Medical Science and Dr. Andrea Mues, Project Scientist at the Center of Sustainable Interactions with the Atmosphere (SIWA) of Potsdam Institute for Advanced Sustainability Studies e.V..

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Appendix A: Data sources

Data sources used for gathering required meteorological and geographical data. Levels of the industrial activities in the region were gathered from Sharif Energy Research Institute (SERI) internal reports.

Table A.1. Sources of data used in this research

<table>
<thead>
<tr>
<th>Data</th>
<th>Data Source</th>
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<tbody>
<tr>
<td>Monthly averaged meteorological data</td>
<td>Atmosphere Science Data Center NASA[53]</td>
</tr>
<tr>
<td>Hourly could coverage data</td>
<td>NOAA Global Climate Station Summaries[54]5</td>
</tr>
<tr>
<td>Topographic map of the modeled region</td>
<td>ASTER GDEM[55]</td>
</tr>
<tr>
<td>Surface roughness map of the modeled region</td>
<td>NCAR/CISL/Data Support Section[54]6</td>
</tr>
<tr>
<td>PM10 emission factors for activities within the region</td>
<td>Ecoinvent Center[32]7</td>
</tr>
<tr>
<td>Monthly wind roses</td>
<td>Meteo· Mobile Aviation Weather[52]</td>
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<tr>
<td>Sea temperature</td>
<td>Neha Nandkeolyar et al., 2013[56]</td>
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<tr>
<td>Priestley-Taylor index for the region</td>
<td>Abdelkrim Khaled et al., 2014[57]</td>
</tr>
<tr>
<td>Background PM10 concentration in the region</td>
<td>Mandana Shobariky, 2014[39]</td>
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5 The Research Data Archive is managed by the Data Support Section of the Computational and Information Systems Labor

atory at the National Center for Atmospheric Research in Boulder, Colorado.

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7 Ecoinvent not-for-profit association which started off as a joint initiative of the ETH Domain and Swiss Federal offices
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