Air pollution distribution in Arak city considering the effects of neighboring pollutant industries and urban traffics

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Abstract
Having heavy impacts on human’s life, pollution adversely influences life. In this paper, a comprehensive model of the Arak’s air pollution for different pollutant chemicals NOx, CO, and SO2 is developed. Here, all effective fixed and mobile sources of pollution are within 50 km distance of the city. The topology of ground surface and also climate patterns of different local areas were carefully considered to accurately model the distribution of pollution. Then, comparing the results with data taken from the ambient air monitoring, the model was validated. According to our findings maximum of NOx concentration in Arak city, Iran was 7.7 times of standard value. This figure is 2.2 and 17.5 times for CO and SO2 pollutants. Share of industry, for spring season, is 51%, 86% and 100% for NOx, CO, and SO2, respectively. Moreover, IRALCO itself has 31% share in total NOx pollution, while its share for CO and SO2 pollution dramatically increases to 85% and 100%, respectively.

Keywords Air pollution · Arak · Emission · Vehicle · Industry · NOx · CO · SO2

Introduction
Considering the ever-increasing consumption of energy, population boom, fast-pace development, and industrialization, air pollution seems inevitable in many countries around the globe. According to WHO, it reports 91% of world’s population currently live in areas with air quality higher than standard. However, the adverse trend of air quality in many areas can aggregate the health condition of the human being. As WHO reported in 2017, around 4.9 million people annually die due to being in contact with polluted air. In Iran, these data stand for 46.2 people per 100,000 of population giving a total number of 13,000 people [1].

Air pollution would be defined as the presence of certain amount of one or more pollutants, e.g., dust, particles, concentrated smoke, gas, mist, disgusting odor, and steam, in the open air. The definition also implies that characteristics of the polluted air are known continuously with the ability to prognosticate that it can endanger life of different species including human being, flora, and fauna or jeopardize individual properties or adversely interfere a decent way of life.

According to the report of Peel et al. being exposed to NOx pollutants and breathing, it can cause the malfunctioning of the immunity system, increase in allergy especially in those with asthma, higher cough frequency, and decrease in long performance [2]. Kampa et al. reported that CO can mount on hemoglobin, and by changing its chemical properties, the capacity of oxygen transmission decreases. This descent in oxygen availability can affect the functioning of different limbs worse especially brain and heart which can result in a disturbed concentration, very slow reflexes, and confusion. Apart from lung inflammation, a systematic inflammatory variation occurs with particles and accordingly influences blood coagulation [3]. SOx can be also oxidized and produce sulfuric acid which can cause issues such as shortage in-breath and injuries to the asthma [4].

The history of public attention to air pollution has roots in middle ages, and therefore, such an issue with its associated laws is not new at all. For instance, Edward I in 1307 banned the application of the coal in lime furnaces due to the fact that furnaces were polluting London’s weather. Today, the adverse consequences of air pollution make air quality considerations inevitable as the first financial priorities in many nations. A study by Taksibi et al. compared different approaches for evaluation of environmental cost-effectiveness of different scenarios of energy policies. They focused on the Tehran metropolitan. A general policy is to stop high
posed model outputs and measured data [9]. There are data. Results show a great correlation between the proportion of the pollutants and traffic load, initial pollution data, and meteorology at different times of the day. These studies have demonstrated the importance of traffic data on air pollution [6]. Mobile source emission markedly increases small-particle pollution, PM$_{2.5}$, in urban areas. In another study, the adverse health effects of PM$_{2.5}$ emission from 2000 taxi cars on weekends in Peken, China were investigated. Results showed that PM$_{2.5}$ emission from transportation vehicles was higher during the week than the weekend. This finding helps to develop logical public health protocols pertained to PM$_{2.5}$ emission [7]. Tayarani et al. investigated the exposure to the small-particle pollutants caused by traffic vehicles during the day in a vast area of the urban Georgia, Atlanta, and found that 51% of the people exposed to such pollution are endangered [8].

Ghanbari Fard et al. used a neural network and a nonlinear model based on state space for modeling of the influence of the urban traffic on air pollution of Shiraz city in Iran. They investigated the behavior of the urban air pollution for a period of the 24 h by applying Kalman and developed Kalman filters. This modeling is based on the relation between the concentration of the pollutants and traffic load, initial pollution data, and meteorology data. Results show a great correlation between the proposed model outputs and measured data [9]. There are plenty of studies pertaining to the effect of polluting industries in different corners of the world. Torrente et al. considered different environmental risks, e.g., gas emission by the dug wastes of Panama, and reported that solid waste as little as only 47 g from 1.5 million Panama City would endanger the health of the 73,600 of the people who live in the area [10]. William et al. studied the emission pattern of Ammonia/Nitrogen from a chicken farm in the eastern coast of Meryland. The coverage area of the model was 134 km in 230 km with a gridded network of 2 km in 2 km. Monitoring of the ammonia concentration was performed in 23 different locations, in the eastern coast of Maryland, in two intervals within September and October 2017 for the sake of calibration. Modeling results suggested that 72.4% of ammonia emission from feeding chickens deposited back to the domain [11]. Faride Etabi et al. considered the emission behavior of the pollutants of the fourth refinery of south Pars within the 10 km$^2$ area under investigation and showed VOC pollutants presence in adjacent cities. In further consideration of emission of the volatile organic compounds in the area, it was found that north-west wind stream (315°) in the first half of the year 2009 affected pollutant emission, whereas in the second half of that year, east-south wind stream (315°) was influential. Therefore, over the course of the year 2009, a symmetric emission pattern was observed [12].

SO$_2$ emission of Ramin Power Plant in Ahwaz, Iran was modeled by Iman Momeni et al. They found the patterns based on the meteorology. They compared the concentration of SO$_2$ with global standards and found that concentration of such pollutant was lower than standard limit defined by Iran’s department of environment [13]. In another study, Nourpour et al. modeled the emission pattern of different pollutants, and fine particles from the stacks of Ilam cement factory. Due to the presence of the foreign particles from the western areas, it was essential to specify the exact contribution of this factory; so, samples were measured at four different locations around the factory using SKC pumps. Results suggested that the pollution of the air caused by the stack outputs is much lower than the threshold of a standard clean air [14]. Estimation of volatile organic compounds from fuel storage tanks, modeled by TANKS model, was performed by Bahman Ramavandi et al. using AERMOD model in 10 km$^2$ vast area according to 1-h standards in a grid distance of 200 m. Comparing the model results with monitoring station’s measured data reported by WHO, EPA, and Iran National Standard Organization showed that existed pollution in many areas is higher than the limits of the standards [15].

Mousavi et al. studied the air pollution resulted by three power plants in Mashhad, Iran using Gaussian model. Results showed that Mashhad and Shariati power plants are quite effective on Mashhad city air pollution, whereas Toos power plant seemed to be neutral. Thus, considering the superior wind stream direction over Mashhad city, it can be inferred that the location of two Mashhad and Shariati power plants is inappropriate, and in contrast, Toos power plant’s location was perfectly selected [16].

Since, COVID-19 global pandemic human activities have been decreased. Studying the concentration of CO, PM$_{2.5}$, PM$_{10}$, SO$_2$, ozone, and NO$_2$ over a month showed a reduction in the air quality index (AQI) by 44%, 33%, 29%, 15%, and 32% in north, south, east, center, and west of India, respectively [17].

A comprehensive study of ambient air quality (AAQ) in three cities of Turkey, Çanakkale area, was performed between August 2013 and 2014. AAQ measurement for bio-aerosol, VOCs, PMs, CO$_2$, and CO was carried out for a whole year. Using AERMOD modeling system, it was found that industries were responsible for NO$_x$ and SO$_2$ pollutants and vehicles were dominant for PM$_{10}$ and CO pollutants [18].
Overall, many studies are available focusing on air pollution in different cities to reduce the especial pollutants [4, 9, 19–28].

Previously, the calibrated models were also established for the known pollutants in a specified city. The objective was to quantitatively obtain the sources of unknown pollutants in the future. Mahmoud Bady et al. used inverse methods to ascertain the source of pollutants in urban areas. Such a method was only used for simple cases as it possesses practical limitations [29].

According to presented studies, one of the best modeling tools with a very little error for different pollutants is AERMOD software package and the best period of study is seemingly a year with hour-to-hour data updates. Arak, the capital city of Markazi province in Iran, is a metropolis and is a large city, in the middle of Iran, with population of 520,994 in 2017 which makes it 18th populated city of Iran. It is among the most industrialized cities of Iran quantitatively, and in terms of variety of industrial products, it is the first. As long as the presence of major industries is concerned, it is the second city of Iran. Containing major energy-related equipment manufacturer (more than 80% of total volume of such production), largest aluminum manufacturer of Iran, largest equipment manufacturer of Iran, largest train compartment, wagon and locomotive manufacturer of Middle East, largest combine manufacturer of Middle East, largest fuel producer of Iran, and also large mine industries, Arak is known as the industrial capital of Iran. Arak air is among the most polluted ones in the country. Different contributors like growth in population, increase in number of vehicles, speedy industrialization, and presence of the different companies cause this city to be placed among eighth most polluted cities of Iran. In 2009 Arak was the 79th most polluted city in the globe. Air in Arak is more polluted than Tehran, capital of Iran, in terms of pollution contributors. The existence of enormous volume of pollution in this city reveals that a high percentage of pollution is concentrated over a very small area which makes it very dangerous for human life.

Traffic congestion is a problematic issue in Arak. Reasons for heavy traffic jams in Arak include ever-increasing number of vehicles, inappropriate streets, lack of allocating residential areas for widening urban roads, lack of public support for lowering traffic, weak public transportation system, and the lack of united urban management system. The number of cars in 2014 was about 148,950 in the city of Arak which means that there is a car for every four citizens. To control the traffic issue, many opinions have been already emerged like an integrated plan for Arak city traffic, building Amirkabir highway in the city, training traffic culture to the public, and traffic smart control system though performing many of these plans were given up later [30].

According to the aforementioned, considering the condition of air pollution in Arak, the precise investigation of this issue is must, so that from the air pollution modeling of Arak, the controlling policies can be obtained. The complication of Arak air pollution modeling is the geographical location of it, because as it can be seen from Fig. 1, it is surrounded by the tall mountains. Moreover, there are many types of different industries like refinery, petrochemical, power plant, and aluminum production companies all are concentrated in this land. Finally, the presence of the worn-out cars, traffic congestion, outdated traffic space, and residential areas worsens the air pollution of this city.

In this paper, the air pollution all over the area of the city is investigated based on the released annual report of the present industries, and the details of the vehicle traffic and meteorology data were modeled and contemplated for three different pollution types of NO\(_x\), CO, and SO\(_x\). The results from the proposed model were then compared with the real measured data of different measuring stations. Finally, the importance of each of the key industrial sectors as well as vehicles on each of the pollutants was analyzed and suggestions for reduction of each presented.

### Modeling

Environment protection agency of the US prepared different air pollution models which are integrated in AERMOD software which is endorsed software by EPA, and therefore, it is superior to other available air pollution software packages. This software used Gaussian and dual Gaussian methods in their distribution models and it also uses different algorithms based on meteorological characteristics of the area. Here, the concentration of air pollutants can be modeled in different daily, monthly and yearly periods, and it can consider different pollution sources in the vast urban and rural areas with different geological characteristics [31].

The modeled area is shown in Fig. 1.

#### Model input data

Three data sets have been needed to model the air pollution as follows:

1. Data of fixed and mobile pollutant sources and the values of emission
2. Meteorology data of the area of study including low and high atmosphere data
3. Topography data including the height and depth of mountains and valleys hourly data of low atmosphere taken from meteorology data as well as high atmosphere data measured by Radiosonde and air boundary layers data, e.g., convective boundary
layer, planetary boundary layer, and inversion, and model inputs, can be obtained (Table 1). This model needs minimally time data, cloudiness coefficient, temperature, humidity ratio, pressure, wind direction, and wind speed. Moreover, high atmospheric data, including pressure, temperature, humidity, and wind, are measured by specific balloons, and are included in the model. Such data are measured by the Meteorology Organization located in Arak and are applied in the present study. Acquired data are for the year 2017. The wind rose plot of Arak city is presented in Fig. 2.

Here, some considerations are important to distinguish flora and the type of the land as it is referred to municipality laws as presented in Table 2.

The data of geographical ruggedness were digitally taken using satellites and aerial images, and data of SRTM1/SRTM3 with 90 m × 90 m resolution according to WGS 84 standard were applied (Fig. 3). Here, the west–south point with coordination of 35,000,0781 m and 37,558,343 m was considered as the reference where it includes of 50 km × 30 km land area. Grid of receivers is selected at the elevation of 5 m from the ground surface. Such elevation is ordinary for the environmental measuring systems called online monitoring sets. This similarity provides a reasonable ground for comparing the results provided here with real measured data.

**Results**

**Air quality standard**

Considering the air quality standard of environment protection organization, according to Table 4, the emission pattern of NO\textsubscript{x} and SO\textsubscript{2} for the period of an hour and of CO for 8 h was performed for all 365 days of the sonar year of 2017.

Air quality standard is shown in Table 3.

The distributions of fixed pollutant sources considered in the proposed model are listed in Table 4 and Fig. 4.
Grid steady

To assure the independence of the model from the considered grid network and achieving the optimum network, primarily, a network with grid size of 50 km in length and 30 km in width was considered. Total grids of 10,000 covered the whole area. Then, number of grids increased to 90,000 in the next steps to achieve more accurate responses. Later, 250,000 fine grids were considered and pollutant concentration was achieved. Finally, another grid pattern was considered. Here, general gridding was considered for the whole considered area with 10,000 grids and finer grids with total number of 22,500 were considered for covering the city itself. Here, the average grid size was 115 m in longitudinal direction and 69 m in perpendicular direction, whereas for the case of 250,000 grids, this distance would be 100 m and 72 m, respectively (Fig. 5). Comparing the combined gridding with fine 250,000 gridding, the maximum discrepancy of 7% was found, while the average discrepancy was as low as 2%. Considering analysis time, the combined gridding plan seems favorable as it is nine times faster than 250,000 gridding system. The presented comparative data are presented in Table 5 for the case of NO\textsubscript{x} pollutant.

Validation

To validate the accuracy of the modeling, the resulted concentrations for different days of the year were compared with corresponding measured values of hourly monitoring stations of the environment protection organization. Table 6 shows the results as well as date considered for different ambient air monitoring stations.

Distribution of pollutants in Arak metropolitan

Maximum concentration of NO\textsubscript{x} in spring

Figure 6 shows the distribution contour of NO\textsubscript{x} for the spring season. According to the contours presented in Fig. 6 and data listed in Table 7, pollutant concentration for spring season was undesired for Arak and in 12 points in the city within zone A, and in no case, the concentration was lower than the allowable limit. In most cases, the concentration of NO\textsubscript{x} was in the range of 1000–5000 µg/m\textsuperscript{3}, and for the worst case at station 3, it was 5380 µg/m\textsuperscript{3} which is 27 times higher than the maximum allowable limit. This concentration is very detrimental to human health. The analysis of the distribution pattern reveals that in spring, much of the pollution coincides with those locations with heavier vehicle traffic. This inference is approved with considering concentrations of 5100 and 1900 µg/m\textsuperscript{3} for points A\textsubscript{2} and A\textsubscript{3}, respectively. The pollutant NO\textsubscript{x}, in spring, is that much high that it adversely
affects the ecosystem even outside of the residential areas, e.g., Meyghan lake. As can be clear from Fig. 6 over zone B, the presence of this pollutant is very concentrated up to 363,390 µg/m³. The white areas in the contour are attributed to the presence of the high mountains that does not let pollution expand. Comparing the contour with the superior wind stream, it can be implied that pollution moves from the west–south area to the city center. Within area B, the condition of Mohajeran city or worse than Arak city within area A. On average the concentration of NOₓ for the spring season was between 5000 and 55,000 µg/m³.

The share of vehicle traffic over NOₓ in the area A is 85%. Overall, 65% of pollutant NOₓ was produced by vehicles. This shows the importance of this factor over NOₓ in spring. Moreover, it can be implied that in spring, IRALCO and Arak Petrochemical Complex (ARPC) were quite effective in the presence of NOₓ over Arak city.

**Maximum concentration of NOₓ in summer**

According to the presented contour for summer in Fig. 7, it can be said the harmful concentration of NOₓ still present over the city, though it is less severe than spring. In 11 points of the zone A, the pollution is higher than the standard threshold, and on average, the condition improves about 38%. In points with heavy vehicle traffic like Shohada square with 1760 µg/m³, point A₂, and also point A₃

| Midday or noon-time Albedo (normalized) | Daytime Bowen ratio (normalized) | Surface Roughness length | Section angle | Land use type |
|----------------------------------------|---------------------------------|--------------------------|---------------|---------------|
| 0.2075                                 | 1.65                            | 1                        | 0°–180°       | Urban         |
| 0.3275                                 | 6                               | 0.2625                   | 180°–360°     | Rural         |
with 5020 µg/m³, the values do not considerably change in comparison with spring as they were 1900 µg/m³ and 5100 µg/m³, respectively. Therefore, it can be concluded that much of the concentration in these areas was due to the traffic of vehicles. Another important point is that, during spring, the NOₓ pollution caused by Arak Petrochemical

Table 3  Air quality standard [30]

| Ppm  | µg/m³ | Period (h) | Pollutants |
|------|-------|------------|------------|
| 9    | 10,000| 8          | CO         |
| 0.075| 196   | 1          | SO₂        |
| 0.1  | 200   | 1          | NO₂        |

Table 4  The points considered

| Upstream point with heavy urban traffic | Station #1 |
|----------------------------------------|------------|
| Point with average urban traffic       | Station #2 |
| Point with average urban traffic       | Station #3 |
| Point with heavy urban traffic         | A₁         |
| Heavy urban traffic point              | A₂         |
| Heavy urban traffic point              | A₃         |
| Wind downstream point in the vicinity of industry | B₁ |
| Point downstream of the superior wind direction near the city exit | B₂ |
| Heavy urban traffic point              | B₃         |
| Point upstream of the superior wind-university of Arak | B₄ |
| Point upstream of the superior wind    | C₁         |
complex reaches the city, while in summer, this is not true anymore which proves the influence of phenomena such as air inversion and weather change from spring to summer. However, IRALCO still worsen the quality of air in terms of NO\textsubscript{x} concentration. In zone B, the condition is different from spring where the calm weather, as well as the presence of high mountains cause a lower distribution of the pollutants, e.g., NO\textsubscript{x} does not reach Meyghan ecosystem. This condition of calm weather affects the concentration of zone B similarly, so that contrary to the spring, in summer condition of Mohajeran city within zone B is better than zone A. In Mohajeran city, the NO\textsubscript{x} concentration in summer is in the range of 200–1000 µg/m\textsuperscript{3} which experiences a huge improvement in comparison with spring.

**Maximum NO\textsubscript{x} concentration in fall**

According to the contour (Fig. 8) presented for fall, one can infer that Arak experiences a polluted condition where 11 points possess concentrations higher than the allowable limit. It should be noted, however, that the concentration at the city center, Shohada square, within point A\textsubscript{2} decreases for about 35%, in comparison with spring, and reaches to 1233 µg/m\textsuperscript{3} which is attributed to the meteorology patterns and temperature. Overall, the pollution shows 39% decrease in comparison with spring. Moreover, the contribution of industries in zone B markedly descends as Mohajeran city has clean air in terms of NO\textsubscript{x} pollutant. Within zone A, due to air inversion in fall, the concentration of NO\textsubscript{x} increases at some points. For instance for station 2, the concentration becomes 1.7 times in comparison with summer. Moreover, the concentration increases in Meyghan desert. Maximum concentration occurs in zone A with 14152 µg/m\textsuperscript{3}. Similar to other seasons, at points with heavy vehicle traffic, vehicles are the main contributors to the pollution. For example, at point B\textsubscript{5}, the effect of vehicles is 93% in fall. IRALCO stays a pollutant industry in fall.
Maximum NO\textsubscript{x} concentration in winter

Generally, the contour of NO\textsubscript{x} distribution reveals that 91% of considered points experience concentration higher than the allowable limit, and therefore, the condition is not desired in the city (Table 7; Fig. 9). In some points, studied relative improvements up to 83% in comparison with fall can be seen. For some points, an increase was observed. Overall, a 180% reduction in concentration of NO\textsubscript{x} can be seen in comparison with spring. Pollution-contributor industries in winter include IRALCO, ARPC, and WagonPars, and vehicles are still major sources of NO\textsubscript{x} emission, e.g., it holds for 83% of NO\textsubscript{x} pollution in point B5. Moreover, zone B, the condition of Mohajeran city almost reaches to the not-allowable condition with 178–700 µg/m\textsuperscript{3}. For the case of zone A, an unfavorable condition exists in Arak due to the combined effect of heavy vehicle traffic and air inversion and meteorological patterns in winter. In some areas, this pollution penetrates to the Meyghan ecosystem.

Maximum concentration of SO\textsubscript{2} in spring

Considering the contour presented in Fig. 10 and also data listed in Table 8, it can be seen that for spring, all areas are in harsh condition where, on average, the concentration of SO\textsubscript{2} is 36 times higher than the allowable limit which is catastrophic for the health of citizens. Comparing different zones, it can be said that maximum concentration was for the zone A with IRALCO as the major contributor. The maximum value is 90,284 µg/m\textsuperscript{3} which is 460 times higher than 196 µg/m\textsuperscript{3} as the standard limit which occurred in zone A. This zone coincides with the crowded area of the study which can lead to a disastrous state for citizen’s health. Though, other industries would emit SO\textsubscript{2} located in zone B, their effect would be negligible on Arak within zone A. However, they seem quite effective on the condition of Mohajeran city in zone B with a concentration in the range of 196–1000 µg/m\textsuperscript{3}. Finally, point B5 has the concentration 77 times higher than the standard limit.
Maximum concentration of SO$_2$ in summer

Considering the contour (Fig. 11) of SO$_2$ concentration in summer, it can be implied that almost all studied points are in alarm condition. On average, the concentration reaches to 2656 µg/m$^3$, 13 times higher than the standard limit. For the city center, Shohada square, within point A$_2$, this can get up to 26 times higher-than-standard limit. Considering the contribution of vehicles, one can state that almost all pollution is caused by industries, especially IRALCO. The emission pattern of SO$_2$ produced by IRALCO proves that the highest concentration of 35,157 µg/m$^3$ which is 180 times higher than the standard limit lies in zone A. On the contrary, the effect of industries fades away in zone B, where in Mohajeran city, the SO$_2$ concentration is in the range of 196–500 µg/m$^3$.

Maximum concentration of SO$_2$ in fall

Considering contour (Fig. 12) and values of SO$_2$ concentration in fall, it can be implied that all points possess a critical condition. In some points, condition is improved and some it is worsen. On average, an improvement of about 8% can be observed. Comparing the results, it can be said that the concentration in this season is lower than summer which proves the effect of climate pattern on pollution distribution. The role of vehicles is negligible. Although a portion of pollutant is produced by the Shazand refinery (IKORC), IRALCO is the pioneer in pollution producing in Arak. Maximum concentration reaches 70,619 µg/m$^3$, 360 times higher than the standard limit located in area A. Due to a specific climate pattern and air inversion phenomenon, part of the pollution in this section is transmitted to other areas and lower is the pollution in area A. Area B is in a better condition in comparison with area A and concentration in Mohajeran city is in the range of 196–700 µg/m$^3$.

Maximum concentration of SO$_2$ in winter

Similarly, considering contour (Fig. 13) and values of SO$_2$ concentration in winter shows the critical condition for all areas. In 83% of the points, a promotion occurs in comparison with fall, and in other points, the situation aggregates. Generally, 37% reduction in concentration is obvious in the urban areas. Influence of the vehicles is negligible and IRALCO is the first pollution contributor. It is noteworthy that pollution from the Shazand refinery (IKORC), in this season, adversely affects the air quality of Arak. Generally, it can be stated that winter is the best season for the minimum concentration in area A which can be proved from Table 8 the worst point is B$_3$ with 3090 µg/m$^3$ which is due
Table 6  Comparison of concentrations resulted from the proposed model and real measured values of different stations

| Item               | Location        | x   | y          | Maximum concentration resulted from model | Maximum concentration measured | date    |
|--------------------|-----------------|-----|------------|-------------------------------------------|-------------------------------|---------|
| **NO\textsubscript{x} standard (200 µg/m\textsuperscript{3})** | Station #1      | 382,726 | 3774,239 | 407                                       | 419.55                        | 21-Dec  |
|                    | Station #2      | 377,877 | 3771,538 | 22.7                                      | 29.69                         | 08-Feb  |
|                    | Station #3      | 379,815 | 3774,746 | 1840                                      | 1840.96                       | 24-Oct  |
| **CO standard (1000 µg/m\textsuperscript{3})**   | Station #1      | 382,726 | 3774,239 | 21,400                                    | –                             | 09-Sep  |
|                    | Station #2      | 377,877 | 3771,538 | 6448.79                                   | 6458.9                        | 22-Jan  |
|                    | Station #3      | 379,815 | 3774,746 | 5386.86                                   | 6722.29                       | 23-Jan  |
| **SO\textsubscript{2} standard (196 µg/m\textsuperscript{3})** | Station #1      | 382,726 | 3774,239 | 125.69                                    | –                             | 10-May  |
|                    | Station #2      | 377,877 | 3771,538 | 56.46                                     | 64.97                         | 10-May  |
|                    | Station #3      | 379,815 | 3774,746 | 121.36                                    | –                             | 10-May  |

Fig. 6  NO\textsubscript{x} distribution in spring
Table 7  Concentration of NO$_x$ (air quality standard for NO$_x$ is 200 µg/m$^3$)

| Item | NO$_x$ measurement location | Concentration in spring µg/m$^3$ | Concentration in summer µg/m$^3$ | Concentration in fall µg/m$^3$ | Concentration in winter µg/m$^3$ |
|------|-----------------------------|----------------------------------|----------------------------------|-------------------------------|-------------------------------|
| 1    | Station #1                  | 382,726.2                        | 985                              | 869                           | 1140                          | 375                           |
| 2    | Station #2                  | 377,876.7                        | 1393                             | 392                           | 1520                          | 608                           |
| 3    | Station #3                  | 379,814.9                        | 5380                             | 2260                          | 2870                          | 2071                          |
| 4    | A$_1$                       | 378,845.2                        | 4180                             | 1091                          | 3250                          | 2380                          |
| 5    | A$_2$                       | 379,039                          | 1900                             | 1760                          | 1233                          | 1413                          |
| 6    | A$_3$                       | 380,039.6                        | 5100                             | 5020                          | 3360                          | 5420                          |
| 7    | B$_1$                       | 384,971.4                        | 719                              | 709                           | 328                           | 273                           |
| 8    | B$_2$                       | 378,029.07                       | 1870                             | 1340                          | 1881                          | 1210                          |
| 9    | B$_3$                       | 387,140.8                        | 637                              | 605                           | 297                           | 207                           |
| 10   | B$_4$                       | 373,957.6                        | 935                              | 41.9                          | 52.3                          | 192                           |
| 11   | B$_5$                       | 377,108.9                        | 886                              | 221                           | 226                           | 251                           |
| 12   | C$_1$                       | 36,707.9                         | 1880                             | 712                           | 325                           | 295                           |

Fig. 7  NO$_x$ distribution in summer
to the closeness to IRALCO and superior wind stream. The maximum concentration is 32,417 µg/m³ which is 165 times higher than the standard limit.

**Maximum concentration of CO in spring**

Considering the values of CO concentration in spring (Table 9; Fig. 14), it can be stated that 83% of considered points experience higher-than-standard pollution. On average, the influence of the vehicles is 21%. Maximum concentration occurs in Shohada square, point A2, about 57,032 µg/m³, 5.7 times higher than the standard limit. It also can be concluded that IRALCO is the major polluter and devastates the condition in area A, so that even Meyghan ecosystem is affected. The highest concentration in area A equals 724,334 µg/m³, 72.4 times of the standard allowable limit, while the condition is acceptable in area B where Mohajeran city has a favorable condition.

**Maximum concentration of CO in summer**

Considering contours (Fig. 15) of CO concentration in summer, it can be inferred that for 75% of points, the concentration was higher than allowable value. In summer, on average, a total reduction of 62%, in comparison with spring, can be observed for the whole area which is due to the climate pattern and change in the production of the industries. Vehicles are influential but less than IRALCO where, around its...
vicinity, the condition is intolerable. Though the condition for area A is a little better comparing with spring, maximum concentration lays in this area with 209,850 µg/m³, 21 times of allowable value. Moreover, 31,300 µg/m³ was the concentration for both A₁ and B₁ points. The source of pollution for the former is the vehicle and for the latter is IRALCO considering the superior wind stream and short distance to IRALCO. The most severe condition occurs in point A₃ where it is located in lower geographical location with its high elevation surrounding which can be seen as a big pit which hinders the streams of wind and therefore higher pollution presents. Again, condition in area B is ideal and industries do not affect Mohajeran city.

**Maximum concentration of CO in fall**

Considering shown contours (Fig. 16) of CO concentration in fall, it can be observed that 75% of the considered points are under an unfavorable condition. On average, the concentration of CO has a 20% reduction in comparison with summer. However, the highest concentration increases by about 20% and reaches 249,325 µg/m³ which is attributed to the changes in industries’ production. Again, vehicles and IRALLCO are influential. More specifically, IRALCO is responsible for the worse condition in area A. Even its pollution reaches the Meyghan ecosystem. As presented before
Fig. 10  Distribution pattern of SO$_2$ in spring

Table 8  Concentration of SO$_2$ (air quality standard for SO$_2$ is 196 µg/m$^3$)

| Item | SO$_2$ measurement location | $X$ | $y$ | Concentration in spring $\mu$g/m$^3$ | Concentration in summer $\mu$g/m$^3$ | Concentration in fall $\mu$g/m$^3$ | Concentration in winter $\mu$g/m$^3$ |
|------|-----------------------------|-----|-----|--------------------------------------|--------------------------------------|------------------------------------|--------------------------------------|
| 1    | Station #1                  | 382,726.2 | 3774,239.4 | 3580 | 2092 | 2200 | 1720 |
| 2    | Station #2                  | 377,876.7 | 3771,538.3 | 13,200 | 1910 | 1680 | 1180 |
| 3    | Station #3                  | 379,814.9 | 3774,746.4 | 3310 | 1910 | 2510 | 1710 |
| 4    | A$_1$                       | 378,845.2 | 3772,814.1 | 10,700 | 4020 | 2650 | 1783 |
| 5    | A$_2$                       | 379,039   | 3772,515.5 | 11,100 | 5280 | 2702 | 1774 |
| 6    | A$_3$                       | 380,039.6 | 3772,178.6 | 7472 | 3350 | 2690 | 1670 |
| 7    | B$_1$                       | 384,971.4 | 3770,472.2 | 3910 | 3104 | 3521 | 1670 |
| 8    | B$_2$                       | 378,029.07 | 3771,914.33 | 10,600 | 2621 | 1992 | 1170 |
| 9    | B$_3$                       | 387,140.8 | 3770,803.4 | 4640 | 3064 | 3510 | 3090 |
| 10   | B$_4$                       | 373,957.6 | 3771,549   | 1170 | 804 | 387 | 680 |
| 11   | B$_5$                       | 377,108.9 | 3773,397.7 | 15,500 | 3300 | 2430 | 1624 |
| 12   | C$_1$                       | 36,707.9  | 376,483.9 | 2090 | 421 | 656 | 2721 |
in the case of summer, the most severe condition presents for point A3. Despite area A in the harsh condition, area B is clean and Mohajeran city has favorable weather.

**Maximum concentration of CO in winter**

Considering the presented contour (Fig. 17) and CO concentration (Table 9), it can be stated that 58% of points are unallowably polluted standard-wise in winter. In winter, on average, 25% reduction in concentration is observed comparing to fall. On the contrary, the highest concentration increases by about 36% and is 340,417 µg/m³, 34 times higher than the standard allowable limit which belongs to point A1. Though vehicles are contributing to the pollution, IRALCO pollutant emission makes Arak’s air condition more severe. It also adversely affects Meyghan ecosystem. Area B is safe from industrial impact and has clean weather.

**Determination the share of vehicles and industries in air pollution of Arak**

NOx modeling was performed for spring and fall seasons. As can be seen in Table 10, the share of industries was a little for some points, e.g., 9% contribution volume of total pollution in station 3. However, for points, like those in points B4 and C1, where there is very light vehicle traffic, the share of industries approaches to even 100%. The average concentration in these points is 733 µg/m³ which is 3.6 times
higher than the standard limit. Therefore, industries and their modification must be considered the issue of air pollution is taken into account. Point C₁ has the maximum concentration due to the fact it is near industries like Refinery, ARPC, and Shazand Power plant. The second point is B₄ which proves a marked influence of industries on air pollution of Arak. On average, the share of the industries gets to be near 51%.

In fall, since points with maximum concentration coincide with no remarkable effect of mobile sources, cars, it can be seen that the pollutant amount really decreases, and from the share of 51%, here, industries contribute only to the 23% of the pollution. Similar to spring, for points C₁ and B₄, 100% of pollution is caused by industry. However, for points like A₁ and station 3, it can be said that mobile pollutant sources are the main contributors to the pollution and traffic control regulation can decrease the pollution in this area. The average produced concentration caused by industries is about 73 µg/m³ which contained 36% of total pollution of clean air.

Modeling of the CO concentration for spring excluding mobile pollutant sources is presented in Table 11. It can be observed that on the contrary to NOₓ where major contributors were vehicles, for the case of CO majority of pollution is caused by fixed sources as the share of industries reaches 86%. The maximum concentration caused by industries occurs in city center, Shohada square, point A₂,
which is 48,727 µg/m³, 4.8 times higher than the standard limit. Moreover, minimum concentration was at point C₁ with 1970 µg/m³ below the standard limit. Considering the location of this point, it can be inferred that the contribution of ARPC and Shazand refinery (IKORC) and Shazand power plant is negligible. On the contrary, the major contributor is IRALCO. Again, if mobile sources like cars are excluded, 83% of studied points experience a higher dosage of pollutants than the standard levels. The average concentration in the area is 27,587 µg/m³, 2.7 times higher than the standard limit.

Modeling CO concentration for summer shows a slight reduction in the share of industries in comparison with spring from 86 to 78%. This is due to the variation of climate and different productions of the industries. Maximum pollution belongs to point B₁ equal to 31,300 µg/m³, 3.1 times higher than the standard limit. Considering the concentration values and location of the measurement, it can be inferred that as locations get higher distance from IRALCO, the concentration reduces, and therefore, IRALCO is the main pollution maker of CO. Moreover, considering the concentration at C₁ and B₁ values, considering the superior wind stream, it is clear that industries in area B are ineffective. The total average of CO concentration over the area is 14,393 µg/m³ which is 1.4 times higher than the standard limit.
With modeling the concentration of SO_2 for both spring and summer (Table 12), a very interesting point can be highlighted. This reveals the 100% share of the industries and a negligible effect of mobile sources. As previously mentioned, the air pollution problem of Arak is mainly rooted in industries. Therefore, the first reference for modification would be industries. Considering the locations and values, it is discernable that industries are very influential over two areas A and B.

Bearing in mind the major contribution of IRALCO in all studied pollutants, it was decided to model the effect of only IRALCO on ARAK air pollution. It would be also interesting to see what would happen if the pollution produced by IRALCO becomes half of its current value? In the following, this notion is more investigated.

For the case of NO_x modeling was performed only for spring and fall, because the pollution was maximized in these two seasons. Table 13 shows the concentration for 12 points of the city.

As was expected, IRALCO possesses a high percentage share for the NO_x, on average 31%, which would cause a lot of health problems for citizens. More intriguing is the fact that even with the assumption of no mobile pollutant source, the crowded area of the city, e.g., Shohada square, at point A_2, is heavily polluted with about 647 µg/m^3 which is almost three times higher-than-standard limit and contains almost 34% of the total concentration.

**Fig. 14** Distribution pattern of CO in spring
In the fall, the effect of IRALCO on Arak remarkably reduces and it becomes 8% of the total concentration. This reduction is attributed to the fact that some stacks were out of service and they had zero discharge. In this season, IRALCO does not have that adverse influence on Arak air pollution and its performance is assessed acceptable.

Now, analysis with half of the IRALCO’s pollution is discussed. For spring, seven points out of total 12 points again have higher pollutant concentrations which not desired. On average, it produces on average 228 µg/m³ over the area which is still higher than the standard limit.

For the fall season, reducing the pollution in half would provide cleaner air for citizens, though even with the current rated pollution, there was no urgent condition in terms of NOₓ concentration.

Modeling of CO was performed for only spring and fall, because they possess the highest dosage of this pollutant. Table 14 lists the results for 12 measuring points.
Comparing the concentration values, it can be inferred that the major reason of the pollution was IRALCO Company. On average, the percentage of contribution of IRALCO over the whole area of study was about 85% which shows the real impact of this company on pollution in this season. The maximum pollutant produced is at Shohada square at point A2 about 48,719 µg/m³, 4.8 times higher than the allowable level. 83% of studied points experience higher-than-standard levels of pollution where the only reason is IRALCO. The average of the points has the concentration of 27,419 µg/m³, 2.7 times higher than the standard limit.

Modeling CO in summer again confirms the major contribution of IRALCO with 77% on average. The highest concentration occurs at point B1 with 31,300 µg/m³, 3.1 times higher than allowable threshold. Overall, 66% of the studied points have a concentration higher than the permitted value.

With making the emission volume of IRALCO half, in spring, 58% of the points still experience, on average,
Fig. 17  Distribution pattern of CO in winter

Table 9  Concentration of CO (air quality standard for CO is 10,000 µg/m³)

| Item | CO measurement location | x   | y   | Concentration in spring µg/m³ | Concentration in summer µg/m³ | Concentration in fall µg/m³ | Concentration in winter µg/m³ |
|------|-------------------------|-----|-----|-------------------------------|-------------------------------|-----------------------------|-------------------------------|
| 1    | Station #1              | 382,726.2 | 3774,239.4 | 19,200                      | 18,200                      | 13,500                      | 9673                          |
| 2    | Station #2              | 377,876.7 | 3771,538.3 | 46,121                      | 8740                         | 18,719                      | 7261                          |
| 3    | Station #3              | 379,814.9 | 3774,746.4 | 39,200                      | 49,646                      | 27,248                      | 38,316                        |
| 4    | A1                      | 379,039   | 3772,814.1 | 49,646                      | 31,300                      | 24,700                      | 15,347                        |
| 5    | A2                      | 380,039.6 | 3772,178.6 | 78,027                      | 49,800                      | 49,800                      | 15,300                        |
| 6    | A3                      | 384,971.4 | 3770,472.2 | 23,137                      | 31,300                      | 24,700                      | 15,300                        |
| 7    | B1                      | 378,029.07| 3771,914.33| 47,100                      | 47,100                      | 16,548                      | 7701                          |
| 8    | B2                      | 387,140.8 | 3770,803.4 | 18,448                      | 22,822                      | 22,400                      | 13,323                        |
| 9    | B3                      | 37,3957.6 | 3771,549   | 4640                        | 3970                        | 2820                        | 3940                          |
| 10   | B4                      | 37,7108.9 | 3773,397.7 | 36,849                      | 28,414                      | 11,036                      | 11,800                        |
| 11   | C1                      | 36,707.9  | 376,483.9  | 1971                        | 2083                        | 1512                        | 1004                          |
Though improvement is undeniable, again, air suffers from pollution. In summer, however, only three measuring points experience a higher value of concentration. Totally, on average, the concentration was 7461 µg/m³ which lower than the standard limit which is favorable.

For the case of SO₂ modeling was only performed with more critical seasons namely spring and summer. Table 15 presents different concentration for 12 measuring points within the city. Considering the results, IRALCO is the only responsible with 100% share of the pollution. The impact of this industry is striking as, on average, for spring and summer the concentration of SO₂ was 37 and 13.5 times higher than the standard level respectively. Moreover, cutting IRALCO pollution volume to half no promising result is imaginable as, in this state for spring and summer, the average concentration becomes 21 and 6.7 times higher-than-standard limit, respectively.

| Item | Measurement location only for industries | X       | Y       | Concentration in spring µg/m³ | Industries-caused concentration in spring µg/m³ | Share of industries from total concentration (%) | Concentration in fall µg/m³ | Industries-caused concentration in fall µg/m³ | Share of industries from total concentration (%) |
|------|----------------------------------------|---------|---------|-------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------|-----------------------------------------------|-----------------------------------------------|
| 1    | Station #1                             | 382,726.2 | 3774,239.4 | 985                           | 418                                           | 42                                            | 1140                       | 45.1                                         | 4                                             |
| 2    | Station #2                             | 377,876.7 | 3771,538.3 | 1393                          | 721                                           | 52                                            | 1520                       | 48.4                                         | 3                                             |
| 3    | Station #3                             | 379,814.9 | 3774,746.4 | 5380                          | 500                                           | 9                                             | 2870                       | 57.8                                         | 2                                             |
| 4    | A₁                                    | 378,845.2 | 3772,814.1 | 4180                          | 699                                           | 17                                            | 3250                       | 47.8                                         | 1                                             |
| 5    | A₂                                    | 379,039   | 3772,515.5 | 1900                          | 701                                           | 37                                            | 1233                       | 49                                           | 4                                             |
| 6    | A₃                                    | 380,039.6 | 3772,178.6 | 5100                          | 753                                           | 15                                            | 3360                       | 55.3                                         | 2                                             |
| 7    | B₁                                    | 384,971.4 | 3770,472.2 | 719                           | 537                                           | 75                                            | 328                        | 42.5                                         | 13                                            |
| 8    | B₂                                    | 378,029.07| 3771,914.33| 1870                          | 603                                           | 32                                            | 1881                       | 49.9                                         | 3                                             |
| 9    | B₃                                    | 387,140.8 | 3770,803.4 | 637                           | 350                                           | 55                                            | 297                        | 63.7                                         | 21                                            |
| 10   | B₄                                    | 373,957.6 | 3771,549   | 935                           | 935                                           | 100                                           | 52.3                       | 100                                          | 100                                           |
| 11   | B₅                                    | 377,108.9 | 3773,397.7 | 886                           | 703                                           | 79                                            | 226                        | 41.1                                         | 18                                            |
| 12   | C₁                                    | 36,707.9  | 376,483.9  | 1880                          | 1880                                          | 100                                           | 325                        | 100                                          | 100                                           |

| Item | Measurement location only for industries | X       | Y       | Concentration in spring µg/m³ | Industries-caused concentration in spring µg/m³ | Share of industries from total concentration (%) | Concentration in fall µg/m³ | Industries-caused concentration in fall µg/m³ | Share of industries from total concentration (%) |
|------|----------------------------------------|---------|---------|-------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------|-----------------------------------------------|-----------------------------------------------|
| 1    | Station #1                             | 382,726.2 | 3774,239.4 | 985                           | 418                                           | 42                                            | 1140                       | 45.1                                         | 4                                             |
| 2    | Station #2                             | 377,876.7 | 3771,538.3 | 1393                          | 721                                           | 52                                            | 1520                       | 48.4                                         | 3                                             |
| 3    | Station #3                             | 379,814.9 | 3774,746.4 | 5380                          | 500                                           | 9                                             | 2870                       | 57.8                                         | 2                                             |
| 4    | A₁                                    | 378,845.2 | 3772,814.1 | 4180                          | 699                                           | 17                                            | 3250                       | 47.8                                         | 1                                             |
| 5    | A₂                                    | 379,039   | 3772,515.5 | 1900                          | 701                                           | 37                                            | 1233                       | 49                                           | 4                                             |
| 6    | A₃                                    | 380,039.6 | 3772,178.6 | 5100                          | 753                                           | 15                                            | 3360                       | 55.3                                         | 2                                             |
| 7    | B₁                                    | 384,971.4 | 3770,472.2 | 719                           | 537                                           | 75                                            | 328                        | 42.5                                         | 13                                            |
| 8    | B₂                                    | 378,029.07| 3771,914.33| 1870                          | 603                                           | 32                                            | 1881                       | 49.9                                         | 3                                             |
| 9    | B₃                                    | 387,140.8 | 3770,803.4 | 637                           | 350                                           | 55                                            | 297                        | 63.7                                         | 21                                            |
| 10   | B₄                                    | 373,957.6 | 3771,549   | 935                           | 935                                           | 100                                           | 52.3                       | 100                                          | 100                                           |
| 11   | B₅                                    | 377,108.9 | 3773,397.7 | 886                           | 703                                           | 79                                            | 226                        | 41.1                                         | 18                                            |
| 12   | C₁                                    | 36,707.9  | 376,483.9  | 1880                          | 1880                                          | 100                                           | 325                        | 100                                          | 100                                           |

12,913 µg/m³, 1.29 times of allowable limit. Though improvement is undeniable, again, air suffers from pollution. In summer, however, only three measuring points experience a higher value of concentration. Totally, on average, the concentration was 7461 µg/m³ which lower than the standard limit which is favorable.

For the case of SO₂ modeling was only performed with more critical seasons namely spring and summer. Table 15 presents different concentration for 12 measuring points within the city. Considering the results, IRALCO is the only responsible with 100% share of the pollution. The impact of this industry is striking as, on average, for spring and summer the concentration of SO₂ was 37 and 13.5 times higher than the standard level respectively. Moreover, cutting IRALCO pollution volume to half no promising result is imaginable as, in this state for spring and summer, the average concentration becomes 21 and 6.7 times higher-than-standard limit, respectively.
Conclusion

Considering the concentration of NO\textsubscript{x}, there are three contributing factors for air pollution of Arak, namely cars, IRALCO, and Arak Petrochemical company (ARPC). For the first factor, different amendments like developing public transportation and supportive policies for more usage of clean vehicles like electricity motorbikes, scooters, or bicycles. Considering traffic restriction policies especially for city center and widening current roads or building new highways is also beneficial to reduce traffic jams. For the second factor, the immediate measure would be to transform the physical location of the company to the distant place corresponding to the town. Pollution came out of this company in springs, falls, and winters, is devastating to the health of citizens, and though costly and ineffective, it should be followed immediately. For the third factor, it was proved that the pollution emitted by this company can reach the city especially in springs and winters. Therefore, it can be advised to reduce the capacity of production during this time. Using advanced filtration is another alternative.

Considering the concentration of CO, there are two major contributing factors for air pollution of Arak, namely cars and IRALCO.

For the first factor modification of roads and traffic intersections, the development of clean public transportation, CNG-combustion public transportation vehicle, improving management of passenger terminal, making traffic control systems smart, ruling out worn-out vehicle from the transportation loops specifically buses, minibuses, and taxies, conducting urban traffic policies like specifying restrict traffic zones, facilitation electronic state to reduce inner city travels, and establishing cars technical diagnosis centers can be consulted.

For the second-factor relocation of the factory, renovation of the old production lines including reduction and anodizing lines can be mentioned.

Considering the concentration of SO\textsubscript{2}, there are two major contributing factors that can be considered for air pollution of Arak, namely Refinery and IRALCO. For the first time, installation of new filtration systems or reduction of the production capacity can be advised. For the second factor, similar aforementioned can be considered.

The air pollution is important problem in many cities. In all reduction strategies, it is expected that the process optimized, so the production pollutant is reduced. In some cases, as Arak city, the results show that the pollutant is few times of standard and any modification strategies could not yield to appropriate level of pollutants. Thus, the only solution is restrictions, for example, limitation of factories production, transfer of factories far from the city, and applying traffic plan. Finally, in this research, it is tried to prove that the pollution could not be decreased unless the restriction will be applied, so the author hope it will be found by the reader.

It should be noticed that authors are currently investigating other pollutants like PM2.5, PM10, and HF, and Benzene derivatives to introduce a comprehensive pollution reduction plan for air pollution of Arak. Moreover, presented study should be repeated for 5-year intervals to more accurately evaluate pollution reduction statistics.

| Item | SO\textsubscript{2} Measurement location only for industries | x | Y | Concentration in spring \(\mu g/m^3\) | Industries-caused concentration in spring \(\mu g/m^3\) | Share of industries from total concentration (%) | Concentration in fall \(\mu g/m^3\) | Industries-caused concentration in fall \(\mu g/m^3\) | Share of industries from total concentration (%) |
|------|-------------------------------------------------|----|----|----------------------------|--------------------------|-------------------------------|----------------------------|--------------------------|----------------------------|
| 1    | Station #1                                      | 382726.2 | 3774,239.4 | 3580                         | 3580                      | 100                           | 2092                      | 2092                      | 100                        |
| 2    | Station #2                                      | 377,876.7 | 3771,538.3 | 11,100                       | 11,100                    | 100                           | 5280                      | 5280                      | 100                        |
| 3    | Station #3                                      | 379,814.9 | 3774,746.4 | 3310                         | 3310                      | 100                           | 1910                      | 1910                      | 100                        |
| 4    | A\textsubscript{1}                              | 378,845.2 | 3772,814.1 | 10,700                       | 10,700                    | 100                           | 4020                      | 4020                      | 100                        |
| 5    | A\textsubscript{2}                              | 379,039   | 3772,515.5 | 11,100                       | 11,100                    | 100                           | 5280                      | 5280                      | 100                        |
| 6    | A\textsubscript{3}                              | 380,039.6 | 3772,718.6 | 10,700                       | 10,700                    | 100                           | 5280                      | 5280                      | 100                        |
| 7    | B\textsubscript{1}                              | 384,971.4 | 3770,472.2 | 3910                         | 3910                      | 100                           | 3104                      | 3104                      | 100                        |
| 8    | B\textsubscript{2}                              | 378,029.07 | 3771,914.3 | 10,600                       | 10,600                    | 100                           | 2621                      | 2621                      | 100                        |
| 9    | B\textsubscript{3}                              | 387,140.8 | 3770,803.4 | 4640                         | 4640                      | 100                           | 3064                      | 3064                      | 100                        |
| 10   | B\textsubscript{4}                              | 373,957.6 | 3771,549   | 1170                         | 1170                      | 100                           | 804                       | 804                       | 100                        |
| 11   | B\textsubscript{5}                              | 377,108.9 | 3773,397.7 | 15,500                       | 15,500                    | 100                           | 3300                      | 3300                      | 100                        |
| 12   | C\textsubscript{1}                              | 36,707.9 | 376,483.9  | 2090                         | 2090                      | 100                           | 421                       | 421                       | 100                        |
### Table 13  IRALCO produced concentration of NO\(_x\)

| Item | NO\(_x\) Measurement location only for industries | x   | y   | Concentration in spring \(\mu g/m^3\) | Industries-caused concentration in spring \(\mu g/m^3\) | Share of industries from total concentration (%) | IRALCO produced concentration if the pollutant concentration becomes half \(\mu g/m^3\) | Concentration in fall \(\mu g/m^3\) | Industries-caused concentration in fall \(\mu g/m^3\) | Share of industries from total concentration (%) | Share of industries from total concentration \(\mu g/m^3\) |
|------|-------------------------------------------------|-----|-----|---------------------------------------|-------------------------------------------------|-----------------------------------------------|---------------------------------------------|---------------------------------|-----------------------------------|-----------------------------------------------|---------------------------------------------|
| 1    | Station #1                                       | 382726 | 3774239.4 | 985                               | 235                                 | 24                                         | 117                                     | 1140   | 48.1                              | 4                                           | 24.1                                         |
| 2    | Station #2                                       | 377877 | 3771538.3 | 1393                               | 674                                 | 48                                         | 337                                     | 1520   | 26.3                              | 2                                           | 13.1                                         |
| 3    | Station #3                                       | 379815 | 3774746.4 | 5380                               | 315                                 | 6                                          | 157                                     | 2870   | 25.8                              | 1                                           | 12.9                                         |
| 4    | A\(_1\)                                          | 378845.2 | 3772814.1 | 4180                               | 637                                 | 15                                         | 347                                     | 3250   | 98                                | 3                                           | 30.5                                         |
| 5    | A\(_2\)                                          | 379039 | 3772515.5 | 1900                               | 647                                 | 34                                         | 323                                     | 1233   | 129                               | 10                                          | 64.3                                         |
| 6    | A\(_3\)                                          | 380040 | 3772178.6 | 5100                               | 722                                 | 14                                         | 361                                     | 3360   | 83                                | 2                                           | 41.5                                         |
| 7    | B\(_1\)                                          | 384971 | 3770472.2 | 719                                | 536                                 | 75                                         | 268                                     | 328    | 73.1                              | 22                                          | 36.6                                         |
| 8    | B\(_2\)                                          | 378029 | 3771914.33 | 1870                              | 581                                 | 31                                         | 290                                     | 1881   | 19.7                              | 1                                           | 9.85                                         |
| 9    | B\(_3\)                                          | 387141 | 3770803.4 | 637                                | 285                                 | 45                                         | 142                                     | 297    | 56.4                              | 19                                          | 28.2                                         |
| 10   | B\(_4\)                                          | 373958 | 3771549   | 935                                | 66.5                                 | 7                                          | 33.5                                    | 52.3    | 9.72                              | 19                                          | 4.86                                         |
| 11   | B\(_5\)                                          | 377109 | 3773397.7 | 886                                | 680                                 | 77                                         | 340                                     | 226    | 22.9                              | 10                                          | 11.5                                         |
| 12   | C\(_1\)                                          | 36707.9 | 376483.9  | 1880                               | 39.6                                 | 2                                          | 19.8                                    | 325    | 4.76                              | 1                                           | 2.38                                         |

### Table 14  IRALCO produced concentration of CO

| Item | CO Measurement location only for industries | x   | y   | Concentration in spring \(\mu g/m^3\) | Industries-caused concentration in spring \(\mu g/m^3\) | Share of industries from total concentration (%) | IRALCO produced concentration if the pollutant concentration becomes half \(\mu g/m^3\) | Concentration in fall \(\mu g/m^3\) | Industries-caused concentration in fall \(\mu g/m^3\) | Share of industries from total concentration (%) | Share of industries from total concentration \(\mu g/m^3\) |
|------|-----------------------------------------------|-----|-----|---------------------------------------|-------------------------------------------------|-----------------------------------------------|---------------------------------------------|---------------------------------|-----------------------------------|-----------------------------------------------|---------------------------------------------|
| 1    | Station #1                                       | 382726.2 | 3774239.4 | 19,200                             | 19,200                                          | 100                                          | 8980                                     | 18,200 | 18,200                            | 100                                          | 9100                                         |
| 2    | Station #2                                       | 377877 | 3771538.3 | 46,121                             | 42,200                                          | 91                                           | 20,506                                    | 8740    | 7890                              | 90                                           | 3944                                         |
| 3    | Station #3                                       | 379814.9 | 3774746.4 | 39,200                             | 18,443                                          | 47                                           | 7820                                     | 18,719 | 9260                              | 49                                           | 4630                                         |
| 4    | A\(_1\)                                          | 378845.2 | 3772814.1 | 49,646                             | 39,300                                          | 79                                           | 19,000                                    | 31,300 | 17,417                            | 56                                           | 8710                                         |
| 5    | A\(_2\)                                          | 379039 | 3772515.5 | 57,032                             | 48,719                                          | 85                                           | 23,100                                    | 26,500 | 22,132                            | 84                                           | 11100                                        |
| 6    | A\(_3\)                                          | 380039.6 | 3772178.6 | 78,027                             | 45,200                                          | 58                                           | 20,324                                    | 49,800  | 18,235                            | 37                                           | 9120                                         |
| 7    | B\(_1\)                                          | 384971.4 | 3770472.2 | 23,137                             | 23,137                                          | 100                                          | 10,100                                    | 31,300  | 31,300                            | 100                                          | 15629                                        |
| 8    | B\(_2\)                                          | 378029.07 | 3771914.33 | 47,100                            | 35,339                                          | 75                                           | 17,100                                    | 17,400  | 11,520                            | 66                                           | 5760                                         |
| 9    | B\(_3\)                                          | 387140.8 | 3770803.4 | 18,448                             | 16,200                                          | 88                                           | 7760                                     | 22,822  | 22,800                            | 100                                          | 11400                                        |
| 10   | B\(_4\)                                          | 373957.6 | 3771549   | 4640                                | 4520                                             | 97                                           | 2130                                     | 3970    | 3880                              | 98                                           | 1940                                         |
| 11   | B\(_5\)                                          | 377108.9 | 377397.7  | 36,849                             | 34,800                                          | 94                                           | 172,00                                   | 28,414  | 14,400                            | 51                                           | 7180                                         |
| 12   | C\(_1\)                                          | 36707.9 | 376483.9  | 1971                                | 1970                                             | 100                                          | 935                                      | 2083    | 2030                              | 97                                           | 1020                                         |
### Table 15: IRALCO produced concentration of SO₂

| Item | SO₂ Measurement location | Concentration in spring µg/m³ | Share of industries from total concentration (%) | Concentration in fall µg/m³ | Share of industries from total concentration (%) | IRALCO produced concentration of SO₂ µg/m³ |
|------|--------------------------|-------------------------------|-----------------------------------------------|---------------------------|-----------------------------------------------|------------------------------------------|
| x    | y                        |                               |                                               |                           |                                               |                                          |
| 1    | 3                      | 38787876.7                    | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 2    | 3                      | 37732234.9                    | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 3    | 2                      | 37747464.1                    | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 4    | 2                      | 37771538.3                    | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 5    | 1                      | 3772814.1                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 6    | 1                      | 37721786.6                    | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 7    | 1                      | 3772281.1                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 8    | 1                      | 3773583.4                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 9    | 1                      | 3774583.4                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 10   | 1                      | 3775158.6                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 11   | 1                      | 3775758.6                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |
| 12   | 1                      | 3776383.4                     | 13,200                                        | 3580                      | 100                                           | 28166                                    |

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