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 NO_x , CO, and SO_2 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 NO_x concentration in Arak city, Iran was 7.7 times of standard value. This figure is 2.2 and 17.5 times for CO and SO_2 pollutants. Share of industry, for spring season, is 51%, 86% and 100% for NO_x , CO, and SO_2 , respectively. Moreover, IRALCO itself has 31% share in total NO_x pollution, while its share for CO and SO_2 pollution dramatically increases to 85% and 100%, respectively.

Keywords Air pollution · Arak · Emission · Vehicle · Industry · NO_x · CO · SO_2

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 NO_x 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 lung 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]. SO_x 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

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concentrations of $PM_{2.5}$ and its impact on human health. Results suggested that in conventional occupations, the primary and secondary $PM_{2.5}$ concentration would increase 30%, on average, in the period of 2010–2030. Considering some of the scenarios seeking a reduction in pollutant concentrations can reduce the average concentration of $PM_{2.5}$ up to 35% in 2020 and the number of polluted days reduces up to 20 days [5].

Pinto et al. investigated the effect of traffic data on air pollution modeling. They found that road transportation vehicles are the major contributor of the civic 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 is higher during the week than the weekend. This finding helps to develop logical public health protocols pertained to $PM_{2.5}$ emission [Tong] [7]. Tayarani et al. investigated the exposure to the small-particle pollutions caused by traffic vehicles during the day in a vast area of the urban Georgia, Atlanta, and found that 51% of the people imposed to such pollution are endangered [8].

Ghanbari Fard et al. used a neural network and a non-linear 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 other 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 km² 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].

SO₂ 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 SO₂ 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 km² 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} , SO₂, ozone, and NO₂ 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, CO₂, and CO was carried out for a whole year. Using AERMOD modeling system, it was found that industries were responsible for NO_x and SO₂ 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 metropolitan 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 crane 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 complicate 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:

- 1.1.1.1.1. Data of fixed and mobile pollutant sources and the values of emission
- 2.2.2.2.2. Meteorology data of the area of study including low and high atmosphere data
- 3.3.3.3.3. 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

Fig. 1 The geographical location of Arak and its surrounding industries

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 $90\text{ m} \times 90\text{ m}$ 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 $50\text{ km} \times 30\text{ km}$ 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_x and SO_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.

Table 1 Input data

Pollutant source data	Topography data	Meteorology data
Fixed source data e.g. industrial stacks including temperature and velocity of stack gas, the location, and height of stack	SRTM1/SRTM3 data with 90×90 m resolution according to WGS 84 standard	Hourly records of humidity ratio, direction and velocity of wind, temperature, and cloudiness
Mobile pollutant sources like number of cars, road space, type of consumable fuels, type of vehicles, e.g., light or heavy, the average distance vehicle covered since their production and road quality		Pressure, temperature, humidity ratio, direction, and velocity of wind in upper data
		Synoptic data
		Upper data

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_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_x in spring

Figure 6 shows the distribution contour of NO_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_x was in the range of 1000–5000 $\mu\text{g}/\text{m}^3$, and for the worst case at station 3, it was 5380 $\mu\text{g}/\text{m}^3$ 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 $\mu\text{g}/\text{m}^3$ for points A_2 and A_3 , respectively. The pollutant NO_x , in spring, is that much high that it adversely

Fig. 2 Wind rose plot of Arak city in 2017

Table 2 Input meteorology data

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

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 $363,390 \mu\text{g}/\text{m}^3$. 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 NO_x for the spring season was between 5000 and $55,000 \mu\text{g}/\text{m}^3$.

The share of vehicle traffic over NO_x in the area A_3 is 85%. Overall, 65% of pollutant NO_x was produced by vehicles. This shows the importance of this factor over NO_x in spring. Moreover, it can be implied that in spring, IRALCO and Arak Petrochemical Complex (ARPC) were quite effective in the presence of NO_x over Arak city.

Maximum concentration of NO_x in summer

According to the presented contour for summer in Fig. 7, it can be said the harmful concentration of NO_x 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 $1760 \mu\text{g}/\text{m}^3$, point A_2 , and also point A_3

Fig. 3 Ruggedness of the land under consideration

Table 3 Air quality standard [30]

Ppm	$\mu\text{g}/\text{m}^3$	Period (h)	Pollutants
9	10,000	8	CO
0.075	196	1	SO ₂
0.1	200	1	NO ₂

with $5020 \mu\text{g}/\text{m}^3$, the values do not considerably change in comparison with spring as they were $1900 \mu\text{g}/\text{m}^3$ and $5100 \mu\text{g}/\text{m}^3$, 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 NO_x pollution caused by Arak Petrochemical

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	A ₁
Heavy urban traffic point	A ₂
Heavy urban traffic point	A ₃
Wind downstream point in the vicinity of industry	B ₁
Point downstream of the superior wind direction near the city exit	B ₂
Heavy urban traffic point	B ₃
Point upstream of the superior wind-university of Arak	B ₄
Point upstream of the superior wind	C ₁

Fig. 4 Two-part receptor grid network

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_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_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_x concentration in summer is in the range of $200\text{--}1000\text{ }\mu\text{g}/\text{m}^3$ which experiences a huge improvement in comparison with spring.

Maximum NO_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_2 decreases for about 35%, in comparison with spring, and reaches to $1233\text{ }\mu\text{g}/\text{m}^3$ 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_x pollutant. Within zone A, due to air inversion in fall, the concentration of NO_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 $14152\text{ }\mu\text{g}/\text{m}^3$. Similar to other seasons, at points with heavy vehicle traffic, vehicles are the main contributors to the pollution. For example, at point B_5 , the effect of vehicles is 93% in fall. IRALCO stays a pollutant industry in fall.

Fig. 5 Schematic of the considered area with different zones

Maximum NO_x concentration in winter

Generally, the contour of NO_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_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_x emission, e.g., it holds for 83% of NO_x pollution in point B_5 . Moreover, zone B, the condition of Mohajeran city almost reaches to the not-allowable condition with $178\text{--}700\text{ }\mu\text{g}/\text{m}^3$. 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_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_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 $90,284\text{ }\mu\text{g}/\text{m}^3$ which is 460 times higher than $196\text{ }\mu\text{g}/\text{m}^3$ 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_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 $196\text{--}1000\text{ }\mu\text{g}/\text{m}^3$. Finally, point B_5 has the concentration 77 times higher than the standard limit.

Table 5 Grid network independence analysis

Item	NO _x The position for measuring pollut- ant NO _x	X	Y	Concentration in combined mesh grids μg/m ³	Concentration in mesh grid of 10,000 μg/m ³	Concentration in mesh grid of 90,000 μg/m ³	Concentration in mesh grid of 250,000 μg/m ³	Difference between mesh grids of 10,000 and 90,000 (%)	Difference between mesh grids of 90,000 and 250,000 (%)	Difference between mesh grids of 250,000 and com- bined mesh (%)
1	Station #1	382726.2	3774239.4	985	960	995	970	4	3	2
2	Station #2	377876.7	3771538.3	1550	1213	1553	1520	22	2	2
3	A ₃	380039.6	3772178.6	5100	2250	4120	5230	45	21	2
4	B ₁	384971.4	3770472.2	719	708	710	716	0	1	0
5	B ₂	378029.07	3771914.33	1530	1302	1360	1422	4	4	7
6	B ₃	387140.8	3770803.4	637	644	665	645	3	3	1
7	B ₄	373957.6	3771549.0	935	1150	900	963	22	7	3
8	B ₅	377108.9	3773397.7	886	869	847	881	3	4	1

Maximum concentration of SO₂ in summer

Considering the contour (Fig. 11) of SO₂ concentration in summer, it can be implied that almost all studied points are in alarm condition. On average, the concentration reaches to 2656 μg/m³, 13 times higher than the standard limit. For the city center, Shohada square, within point A₂, 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 SO₂ produced by IRALCO proves that the highest concentration of 35,157 μg/m³ 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 SO₂ concentration is in the range of 196–500 μg/m³.

Maximum concentration of SO₂ in fall

Considering contour (Fig. 12) and values of SO₂ 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/m³, 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/m³.

Maximum concentration of SO₂ in winter

Similarly, considering contour (Fig. 13) and values of SO₂ 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 B₃ with 3090 μg/m³ 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 _x standard (200 µg/m 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 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 ₂ standard (196 µg/m 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

PROJECT TITLE:

Nox dispersion in Spring **Fig. 6** NO_x distribution in spring

Table 7 Concentration of NO_x (air quality standard for NO_x is $200 \mu\text{g}/\text{m}^3$)

Item	NO_x measurement location	x	y	Concentration in spring $\mu\text{g}/\text{m}^3$	Concentration in summer $\mu\text{g}/\text{m}^3$	Concentration in fall $\mu\text{g}/\text{m}^3$	Concentration in winter $\mu\text{g}/\text{m}^3$
1	Station #1	382,726.2	3774,239.4	985	392	1140	375
2	Station #2	377,876.7	3771,538.3	1393	869	1520	608
3	Station #3	379,814.9	3774,746.4	5380	2260	2870	2071
4	A ₁	378,845.2	3772,814.1	4180	3091	3250	2380
5	A ₂	379,039	3772,515.5	1900	1760	1233	1413
6	A ₃	380,039.6	3772,178.6	5100	5020	3360	5420
7	B ₁	384,971.4	3770,472.2	719	709	328	273
8	B ₂	378,029.07	3771,914.33	1870	1340	1881	1210
9	B ₃	387,140.8	3770,803.4	637	605	297	207
10	B ₄	373,957.6	3771,549	935	41.9	52.3	192
11	B ₅	377,108.9	377,3397.7	886	221	226	251
12	C ₁	36,707.9	376,483.9	1880	712	325	295

PROJECT TITLE:

Nox dispersion in Summer **Fig. 7** NO_x distribution in summer

PROJECT TITLE:

Nox dispersion in Fall **Fig. 8** NO_x distribution pattern in fall

to the closeness to IRALCO and superior wind stream. The maximum concentration is $32,417 \mu\text{g}/\text{m}^3$ 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 $57,032 \mu\text{g}/\text{m}^3$, 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 $724,334 \mu\text{g}/\text{m}^3$, 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

Fig. 9 NO_x distribution pattern in winter

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 $\mu\text{g}/\text{m}^3$, 21 times of allowable value. Moreover, 31,300 $\mu\text{g}/\text{m}^3$ 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 $\mu\text{g}/\text{m}^3$ which is attributed to the changes in industries' production. Again, vehicles and IRALCO are influential. More specifically, IRALCO is responsible for the worse condition in area A. Even its pollution reaches the Meyghan ecosystem. As presented before

PROJECT TITLE:

SO₂ dispersion in spring Fig. 10 Distribution pattern of SO₂ in spring**Table 8** Concentration of SO₂ (air quality standard for SO₂ is 196 µg/m³)

Item	SO ₂ measure- ment location	X	y	Concen- tration in spring µg/m ³	Concentra- tion in sum- mer µg/m ³	Concentra- tion in fall µg/m ³	Concentra- tion in winter µg/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

Fig. 11 Distribution pattern of SO₂ in summer

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 $\mu\text{g}/\text{m}^3$, 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

NO_x 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 $\mu\text{g}/\text{m}^3$ which is 3.6 times

PROJECT TITLE:

DISPERSION SO₂ In Fall

Fig. 12 Distribution pattern of SO₂ in fall

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 $\mu\text{g}/\text{m}^3$ 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 NO_x 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,

DISPERSION SO₂ In Winter

PROJECT TITLE:

Fig. 13 Distribution pattern of SO₂ in winter

which is $48,727 \mu\text{g}/\text{m}^3$, 4.8 times higher than the standard limit. Moreover, minimum concentration was at point C₁ with $1970 \mu\text{g}/\text{m}^3$ 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 $27,587 \mu\text{g}/\text{m}^3$, 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 $31,300 \mu\text{g}/\text{m}^3$, 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 B₄ 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 $14,393 \mu\text{g}/\text{m}^3$ which is 1.4 times higher than the standard limit.

Fig. 14 Distribution pattern of CO in spring

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 $647 \mu\text{g}/\text{m}^3$ which is almost three times higher-than-standard limit and contains almost 34% of the total concentration.

Fig. 15 Distribution pattern of CO in summer

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 $228 \mu\text{g}/\text{m}^3$ 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 NO_x 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.

Fig. 16 Distribution pattern of CO in fall

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 $\mu\text{g}/\text{m}^3$)

Item	CO measure- ment location	x	y	Concen- tration in spring $\mu\text{g}/\text{m}^3$	Concentra- tion in sum- mer $\mu\text{g}/\text{m}^3$	Concentra- tion in fall $\mu\text{g}/\text{m}^3$	Concentra- tion in winter $\mu\text{g}/\text{m}^3$
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	6641	7261
3	Station #3	379,814.9	3774,746.4	39,200	18,719	17,948	14,700
4	A ₁	378,845.2	3772,814.1	49,646	31,300	27,248	38,316
5	A ₂	379,039	3772,515.5	57,032	26,500	21,100	33,308
6	A ₃	380,039.6	3772,178.6	78,027	49,800	49,800	15,347
7	B ₁	384,971.4	3770,472.2	23,137	31,300	24,700	15,300
8	B ₂	378,029.07	3771,914.33	47,100	17,400	16,548	7701
9	B ₃	387,140.8	3770,803.4	18,448	22,822	22,400	13,323
10	B ₄	37,3957.6	3771,549	4640	3970	2820	3940
11	B ₅	37,7108.9	3773,397.7	36,849	28,414	11,036	11,800
12	C ₁	36,707.9	376,483.9	1971	2083	1512	1004

Table 10 NO_x concentration caused only by industries

Item	NO _x Measure- ment location only for industries	X	Y	Concen- tration in spring µg/m ³	Industries- caused concentration in spring µg/m ³	Share of indus- tries from total concentration (%)	Concen- tration in fall µg/m ³	Industries- caused concentration in fall µg/m ³	Share of indus- tries 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	A ₁	378,845.2	3772,814.1	4180	699	17	3250	47.8	1
5	A ₂	379,039	3772,515.5	1900	701	37	1233	49	4
6	A ₃	380,039.6	3772,178.6	5100	753	15	3360	55.3	2
7	B ₁	384,971.4	3770,472.2	719	537	75	328	42.5	13
8	B ₂	378,029.07	3771,914.33	1870	603	32	1881	49.9	3
9	B ₃	387,140.8	3770,803.4	637	350	55	297	63.7	21
10	B ₄	373,957.6	3771,549	935	935	100	52.3	52.3	100
11	B ₅	377,108.9	3773,397.7	886	703	79	226	41.1	18
12	C ₁	36,707.9	376,483.9	1880	1880	100	325	325	100

Table 11 CO concentration with contribution of only industries

Item	CO Measure- ment loca- tion only for industries	x	Y	Concen- tration in spring µg/m ³	Industries- caused con- centration in spring µg/m ³	Share of indus- tries from total concentration (%)	Concen- tration in fall µg/m ³	Industries- caused concen- tration in fall µg/m ³	Share of indus- tries from total concentration (%)
1	Station #1	382,726.2	3774,239.4	19,200	19,200	100	18,200	18,200	100
2	Station #2	377,876.7	3771,538.3	46,121	42,200	91	8740	7893	90
3	Station #3	379,814.9	3774,746.4	39,200	18,446	47	18,719	9264	49
4	A ₁	378,845.2	3772,814.1	49,646	39,300	79	31,300	17,429	56
5	A ₂	379,039	3772,515.5	57,032	48,727	85	26,500	22,200	84
6	A ₃	380,039.6	3772,178.6	78,027	45,200	58	49,800	18,300	37
7	B ₁	384,971.4	3770,472.2	23,137	23,137	100	31,300	31,300	100
8	B ₂	378,029.07	3771,914.3	47,100	35,343	75	17,400	11,525	66
9	B ₃	387,140.8	3770,803.4	18,448	18,200	99	22,822	22,800	100
10	B ₄	373,957.6	3771,549	4640	4521	97	3970	3882	98
11	B ₅	377,108.9	3773,397.7	36,849	34,800	94	28,414	14,400	51
12	C ₁	36,707.9	376,483.9	1971	1970	100	2083	2080	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.

Table 12 Concentration of SO₂ when only the contribution of industries is considered

Item	SO ₂ Measure- ment loca- tion only for industries	x	Y	Concen- tration in spring $\mu\text{g}/\text{m}^3$	Industries- caused con- centration in spring $\mu\text{g}/\text{m}^3$	Share of indus- tries from total concentration (%)	Concen- tration in fall $\mu\text{g}/\text{m}^3$	Industries- caused concen- tration in fall $\mu\text{g}/\text{m}^3$	Share of indus- tries 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 ₁	378,845.2	3772,814.1	10,700	10,700	100	4020	4020	100
5	A ₂	379,039	3772,515.5	11,100	11,100	100	5280	5280	100
6	A ₃	380,039.6	3772,178.6	7472	7472	100	3350	3350	100
7	B ₁	384,971.4	3770,472.2	3910	3910	100	3104	3104	100
8	B ₂	378,029.07	3771,914.3	10,600	10,600	100	2621	2621	100
9	B ₃	387,140.8	3770,803.4	4640	4640	100	3064	3064	100
10	B ₄	373,957.6	3771,549	1170	1170	100	804	804	100
11	B ₅	377,108.9	3773,397.7	15,500	15,500	100	3300	3300	100
12	C ₁	36,707.9	376,483.9	2090	2090	100	421	421	100

Conclusion

Considering the concentration of NO_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 taxis, 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 SO₂, 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 PM_{2.5}, 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.

Table 13 IRALCO produced concentration of NO_x

Item	NO_x Measurement location only for industries	x	y	Concentration in spring $\mu\text{g}/\text{m}^3$	Industries-caused concentration in spring $\mu\text{g}/\text{m}^3$	Share of industries from total concentration (%)	IRALCO produced concentration if the pollutant becomes half $\mu\text{g}/\text{m}^3$	Concentration in fall $\mu\text{g}/\text{m}^3$	Industries-caused concentration in fall $\mu\text{g}/\text{m}^3$	Share of industries from total concentration (%)	Share of industries from total concentration $\mu\text{g}/\text{m}^3$
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 $\mu\text{g}/\text{m}^3$	Industries-caused concentration in spring $\mu\text{g}/\text{m}^3$	Share of industries from total concentration (%)	IRALCO produced concentration if the pollutant becomes half $\mu\text{g}/\text{m}^3$	Concentration in fall $\mu\text{g}/\text{m}^3$	Industries-caused concentration in fall $\mu\text{g}/\text{m}^3$	Share of industries from total concentration (%)	Share of industries from total concentration $\mu\text{g}/\text{m}^3$
1	Station #1	382726.2	3774239.4	19,200	19,200	100	8980	18,200	18,200	100	9100
2	Station #2	377876.7	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	3773397.7	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	SO ₂ Measurement location only for industries	x	y	Concentration in spring $\mu\text{g}/\text{m}^3$	Industries-caused concentration in spring $\mu\text{g}/\text{m}^3$	Share of industries concentration (%)	IRALCO produced concentration if the pollutant concentration becomes half $\mu\text{g}/\text{m}^3$	Concentration in fall $\mu\text{g}/\text{m}^3$	Industries-caused concentration in fall $\mu\text{g}/\text{m}^3$	Share of industries concentration (%)	Share of industries concentration from total concentration $\mu\text{g}/\text{m}^3$	Share of industries concentration from total concentration (%)	Share of industries concentration from total concentration $\mu\text{g}/\text{m}^3$
1	Station #1	382726.2	3774239.4	3580	3580	100	2210	2092	2092	100	1050	100	1050
2	Station #2	377876.7	3771538.3	13,200	13,200	100	7110	1910	1910	100	951	100	951
3	Station #3	379814.9	3774746.4	3310	3310	100	1984	1910	1910	100	953	100	953
4	A ₁	378845.2	3772814.1	10,700	10,700	100	6104	4020	4012	100	2010	100	2010
5	A ₂	379039	3772515.5	11,100	11,100	100	6260	5280	5260	100	2630	100	2630
6	A ₃	380039.6	3772178.6	7472	7472	100	4440	3350	3350	100	1670	100	1670
7	B ₁	384971.4	3770472.2	3910	3910	100	1954	3104	3104	100	1552	100	1552
8	B ₂	378029.07	3771914.33	10,600	10,600	100	7141	2621	2621	100	1303	100	1303
9	B ₃	387140.8	3770803.4	4640	4640	100	2590	3064	3064	100	1532	100	1532
10	B ₄	373957.6	3771549	1170	1170	100	697	804	804	100	402	100	402
11	B ₅	377108.9	3773397.7	15,500	15,500	100	9242	3300	3300	100	1650	100	1650
12	C ₁	36707.9	376483.9	2090	2090	100	363	421	421	100	208	100	208

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