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DEVELOPING A METHOD FOR POLLUTANT EMISSION RATE CAUSED BY FUEL CONSUMPTION FROM INDUSTRIAL TOWNS

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ABSTRACT:

Introduction: Predicting the concentration and emission rates of air pollutants before constructing industrial towns via modeling can be an appropriate method for determining the industrial towns' construction sites. For this purpose, it is necessary to compile proper information about fuel consumption rate by industrial units in various groups.
Materials and methods: In order to obtain the average fuel consumption in different groups, some questionnaires were prepared, then, filled in 5 industrial towns. Subsequently, using the AP - 42 emission factors, the production rate of various pollutants produced by these industrial groups was estimated. Later, the collected data were used to investigate the effect of constructing phase-II of Baharan Industrial Town, Hamadan, on the area's weather in an area of 15*15 km^2 using AERMOD.
Results: Based on the results derived from the questionnaires, the highest natural gas consumption rate was related to the food and textile zones with the estimated average consumption rates of 0.023532 (m^3 / ha.s) and 0.021785 (m^3 / ha.s), respectively. However, the lowest rate was related to the non - metallic minerals zone with the estimated average consumption rate of 0.00097 (m^3/ ha.s).
Conclusions: Zoning the modeling results indicated that constructing phase-II of Baharan Industrial Town, Hamadan, would not increase the average concentration of air pollutants in the area to above the standard level.

INTRODUCTION

In order to properly manage air quality in the area and investigate its ecological capability in receiving air pollutants, it is very important to specify the pollutants' type and rate from various resources and investigate their effects [1, 2]. Industrial Towns, as the major bases of production centers, play a very important role in the industrial development of Asian countries. These industrial towns are designed to concentrate indus-

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trial factories and are aimed to accomplish high production and productivity in order to achieve the industrial objectives [3 - 6]. Air pollution resources in the industrial units include boilers, fuel combustion in furnaces, diesel generators, heat generation, and emission due to the combustion of fossil fuels. So far, several studies have been conducted around the world on the measurement of the pollutants' emission dispersion as well as modeling of the common pollutants resulted from urban and industrial resources using dispersive models [7 - 11]; however, all of these studies have been conducted in order to simulate and investigate the resources after constructing the industrial towns [12 - 14]. Importance of the pre-construction evaluation of air pollutants for an industrial project is better revealed when closeness of the industries to cities, roads, highways, and other industries has a severe impact on the air pollution of the area due to the collective effect of the pollutants. Thus, novel measures must be taken in the new industries' location policies. The mathematical models of air pollution dispersion can be used to investigate the pollutants' emission , monitoring, evaluate dangers resulted from these pollutants in the area, and help manage the pollutants [10]. In 2004, after 14 years of investigation, EPA approved AERMOD as the most applicable software for atmospheric emissions. The great gap in modeling the emission of air pollutants before constructing the industrial towns is the lack of sufficient information about the fuel consumption rate per hectare of various industrial groups. That is because before establishing and exploiting the industries in the industrial towns, their exact type in each industrial group, amount of the primary material consumption, amount of the manufactured product, and consequently the fuel consumption rate in these industries are not clear and the available pre- construction information only includes the surface area allocated to each industrial group. Therefore, regarding the importance of the evaluation of air pollutants rate before the construction of industrial towns, the present study is indeed the first attempt seeking to provide a comprehensive and applicable method for estimating the common air pollutants' emission rate and dispersion in the industrial towns' construction sites by obtaining the fuel consumption rate per hectare of the industrial zone. Results of the present work on the estimation of fuel consumption rate in different industrial groups can be also used for other Industrial towns.

In this research, due to the evaluation of air pollutants before the construction of the industrial units, it was impossible to perform environmental monitoring of the pollutants; however, in many of the previous studies in this regard conducted using AERMOD, it has been observed that AERMOD results have a significant relationship with those of the environmental monitoring [7, 15, 16]. Comparing the model's concentration distribution with the observations indicated that, with a few exceptions, the AERMOD performance was superior to other models in 17 study fields [17, 18]. This study was conducted in 2017 and in the second phase of Hamandan Baharan industrial town.

MATERIALS AND METHODS

Calculating fuel consumption rate by industrial units

In the present study, in order to investigate the fuel consumption rate per hectare of different industrial groups, some questionnaires were developed and, then, completed in 5 under-exploitation industrial groups. These questionnaires investigated the industrial units' information on the type of industrial group, surface area of the industrial unit's manufacturing department, as well as the primary and secondary fuel type and consumption rate. The results derived from these questionnaires were then processed in EXCEL. The average fuel consumption rate for each industrial unit was different from that of other units; however, in this study, the average fuel consumption rate of different industrial units in each industrial group was used in the relevant calculations. The industrial towns, in which the questionnaires were completed, and the number of questionnaires completed in each industrial town were as follows: Rajaei industrial town (88 completed questionnaires), and Salimi (106 completed questionnaires), Foreign investment (72 completed questionnaires) in East Azerbaijan province, Eivanaki industrial town (76 completed questionnaires) in Semnan Province, and phase-I of Baharan industrial town (52 completed questionnaires) in Hamadan province.

According to the reports published by SCI (Statistical Center of Iran), 10 out of 23 main industrial groups have major contribution to the fuel consumption in the industry so that more than 97.50 % of the total natural gas consumption is consumed by these 10 groups and the remaining 13 groups consume only 5.47 % of the total energy of the industrial sector [19] . These 10 industrial groups include foods and drinking products, textile products, paper products, chemical products, plastic products, fundamental metals, other non - metallic mineral products, coke production, metallic products, except machinery, as well as vehicle and motor products. On this basis, 6 out of 7 industrial groups investigated in this study, including foods and drinking products, textile products, cellulosic products, chemical products, metallic mineral products, and non-metallic mineral products, were selected from among the 10 mostly-used ones. Therefore, the industries with higher consumption rate, which had the greatest contribution to the air pollution, were investigated in this study.

Emission coefficient of different fuels

The air pollutants' emission rate must be estimated via direct test on exhaust gas at the smoke column output or by transferring the output air sample from stack and or emissions factors [20]. However, in this research, due to evaluation of the air pollutants rate before constructing phase-II of Baharan industrial town and, consequently, the relevant industrial units, the method proposed by EPA, namely Compilation of Air Pollutant Emission Factors (AP-42), was used. Table 1 presents the emission coefficient values for different types of possible fuels.

Atmospheric emissions model

The AERMOD models the plume at stable state and can be also used to determine the concentration of various pollutants in rural and urban areas, flat and rough areas, surface emission, and at heights from point, volumetric resources [21-25]. Therefore, it is proposed for simulating the pollutants dispersion in up to 50 km areas [18, 26]. The use of AERMOD model is based on the application of three information categories, including: 1) information on the features of stack and pollution dispersion, 2) meteorological data of the studied area, which is processed by Aer-

Table 1. The values of emission factors for different fuels (kg / m^3)

Fuel type	CO	NO_2	TSP	SO_2
Natural Gas	134×10^{-3}	4.48×10^{-3}	1.22×10^{-4}	9.6×10^{-6}
Liquid fuel with sulfur less than 1%	0.6	6	1.2	18

met preprocessor, and 3) topographic information of the studied area, which is processed by Aermap preprocessor [27, 28]. AERMOD requires a specific information category for each type of the pollution resources. For the resources of the present research, which were considered as point resources, features of the stacks and exhaust gas were presented in Table 2.

Meteorological information of studied area

The meteorological investigations were performed using the data and statistics of synoptic station in Hamadan airport with the longitude of 48.53, latitude of 34.85, and height of 1749 from sea level. The meteorological information of the years 2016 obtained from the Hamadan Synoptic station was analyzed in Excel then, the annual Wind rose of the area was depicted using the preprocessor unit of AERRMET - 8.9.0.

Modeling area

Baharan industrial town in Bahar county, Hamadan province, is located on 12 km of Hamadan-Kermanshah road at the longitude of 48°30' and latitude of 34°30' to 35°. In the present study, the effect of the pollutants resulted from the development of phase-II of Baharan industrial town on five cities close to the industrial town was investigated. The geographical specifications of these cities were presented in Table 3. Finally, using ArcGIS, results of various pollutants' emission modeling were provided by AERMOD as the pollutants' emission zoning maps. The AcrGIS was used since it is more applicable than AERMOD in demonstrating the pollutants emission as well as features of the area [29]. In AcrGIS, interpolation was performed using the IDW (Inverse Distance Weighted) method.

RESULTS AND DISCUSSION

Results of estimating fuel consumption rate and resulted pollutants of industrial units

The results of the questionnaires completed in the studied industrial towns were presented in Table 4, in order to estimate the average consumption of various fuels (gas and gasoline) per square meter of different industrial groups. As can be seen in this table, the average natural gas consumption rate had the highest and lowest values in the food

Table 2. Characteristic of the hypothetical stack and exhausted gas

Stack height (m)	Stack diameter (m)	Exit gas velocity (m/s)	Exit gas temperature (k˚)
20	1	0.381972	353.15

Table 3. Characteristics of the studied cities around the study area

Area of study	Longitude (UTM)	Latitude (UTM)	Maximum elevation from the mean sea(m)	Population
Lalejin	269736.7463	3873234.685	1714	13963
Salehabad	257609.5844	3867941.888	1773	8350
Bahar	266260.6545	3865875.315	5017	25865
Hamadan	271607.3305	3852895.017	1318	401281
Meryanj	267837.3802	3857314.23	1789	9523

and non - metallic minerals groups with the consumption rate of 0.023532 (m^3 / ha.s) and 0.00097 (m^3 / ha.s), respectively. Furthermore, the food 0.0135 (m^3 / ha.s) and non - metallic minerals 0.000263 (m^3 / ha.s) zones had the highest and lowest gasoline consumption rates, respectively.

The amount of the pollutants probably emitted from phase-II of Baharan industrial town was calculated based on the average consumption rate of different fuels obtained from the questionnaires and also considering the emission factors related to different types of fuels. Finally, the total amounts of different pollutants resulted from gas and gasoline in g / s . ha were added up and the total amount of the pollutants was presented in Table 5.

Calculations of pollutants' emission modeling in case of constructing phase - II of Baharan industrial town in Hamadan

In Table 6, the total amount of pollutants resulted from fuel consumption in different industrial units in case of constructing phase-II of Baharan industrial town was calculated considering the surface area of different industrial groups. Then, in order to consider the effect of surface area of the industrial groups on the dispersion of the pollutants, some hypothetical dispersion points were assumed instead of a single dispersion point in each industrial group so that the emitted pollutants of the food, electricity, textile, metals, cellulose, chemicals, and non - metallic minerals groups were emitted through several points or the hypothetical stacks.

Table 4. Average of the consumption of various fuels in different industrial zones

Industrial group	Average natural gas consumption (m^3 / ha.s)	Average diesel consumption (m^3 / ha.s)
Food	0.023532	0.0135
Electricity	0.00739	0.00585
Textile	0.021785	0.0606
Metals	0.01122	0.00364
Cellulose	0.018705	0.00452
Chemicals	0.012069	0.00352
Non-Metallic Minerals	0.00097	0.000263

Table 5. Amount of the total pollutants resulted from fuel consumption in the industrial zones (g / s.ha)

Industrial group	CO	NOx	TSP	PM_{10}	SO_2
Food	0.039728	0.18643	0.019072	0.013898	0.243249
Electricity	0.013442	0.068198	0.00792	0.005773	0.10534
Textile	0.065633	0.461133	0.075365	0.054993	1.090818
Metals	0.017263	0.072093	0.005734	0.004174	0.065589
Cellulose	0.027849	0.110891	0.007701	0.005602	0.081461
Chemicals	0.01833	0.075168	0.005692	0.004143	0.063416
Non - metallic minerals	0.001461	0.005921	0.000434	0.000316	0.004742

Accordingly, the total values of pollutants emission from each industrial group were divided by the number of dispersion points to obtain the share (contribution) of each dispersion point. The data of production and dispersion of pollutants in g /s for each dispersion point are provided in Table 7.

The data in the above - mentioned tables, the meteorological information, DEM map of the area, as well as the information of other pollutants were imported into the AERMOD. Then, using ArcGIS, the emission modeling or distribution patterns of different pollutants resulted from the construction of phase-II of Baharan industrial town along with the location of the cities and villages as well as the topography of the area were prepared as the pollutants emission zoning maps, which are presented in Fig. 1.

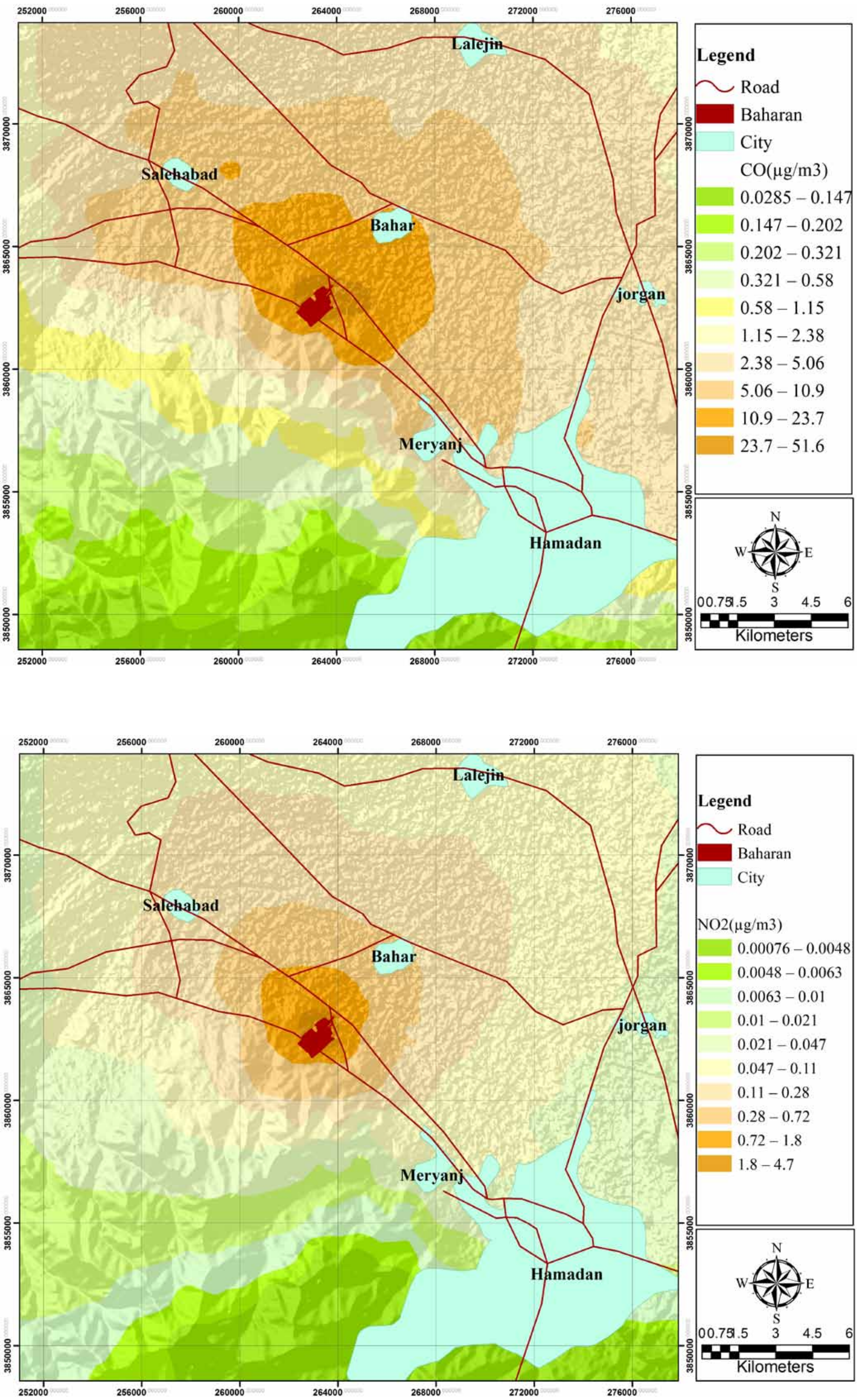
The simulation results showed that the maximum pollution concentration would occur in short-term periods (e.g. 1 h) at flat areas and close to Baharan industrial town. On the other hand, in a study that was modeled the SO_2 emission from the Ramin power plant in Ahwaz, was observed that the SO_2 concentration would not be increased in the surrounding area up to the distance of 650 m from the stack [30]. However, beyond this distance, concentration of the pollutants in the environment would be increased so that the maximum concentration would occur at the distance of 4100 - 9000 km from the power plant. The difference between the results of these studies could be due to the difference of the stacks used in the two industries because stacks of the power plants are commonly very taller (100 - 200 m) than those of the industrial units (20 m) and are capable of emitting the pollutants to the environments farther than their production point[31].

Table 6. Total amount of the pollutants resulted from fuel consumption in industrial units considering the area of each industrial groups in the Π - phase of Baharan industrial town (g / s)

Industrial group	Area (ha)	CO	NO_x	TSP	PM_{10}	SO_2
Food	5.4	0.214529	1.006724	0.102991	0.075049	1.313546
Electricity	3.5	0.047045	0.238694	0.027718	0.020207	0.36869
Textile	1.7	0.111576	0.783926	0.128121	0.093489	1.854391
Metals	8.6	0.148458	0.620001	0.049315	0.035897	0.564066
Cellulose	3.3	0.091901	0.365942	0.025412	0.018486	0.26882
Chemicals	6.5	0.119148	0.488594	0.037001	0.026927	0.412203
Non - metallic minerals	10	0.014609	0.059214	0.004338	0.003156	0.047418

Table 7. Amount of the emitted pollutants from each emission points (g / s)

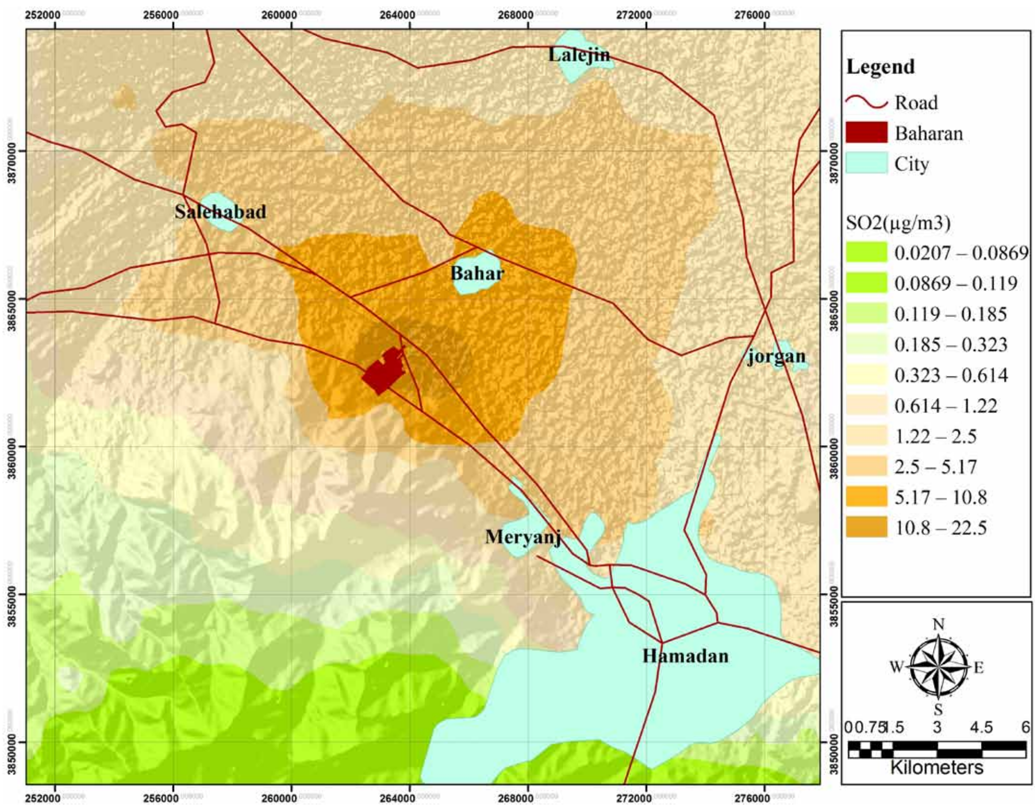
Industrial group	Number stack	CO	NO_x	TSP	PM_{10}	SO_2
Food	6	0.035754814	0.167787395	0.0171652	0.012508147	0.218924375
Electricity	4	0.01176133	0.059673415	0.006929608	0.005051759	0.092172488
Textile	2	0.05578776	0.391963159	0.064060291	0.046744384	0.927195585
Metals	9	0.016495301	0.068889008	0.005479416	0.003988609	0.062673946
Cellulose	4	0.02297517	0.091485414	0.006353098	0.004621404	0.067204951
Chemicals	7	0.017021165	0.069799134	0.005285799	0.003846754	0.058886212
Non - Metallic Minerals	11	0.001328095	0.005383046	0.000394357	0.000286946	0.00431074



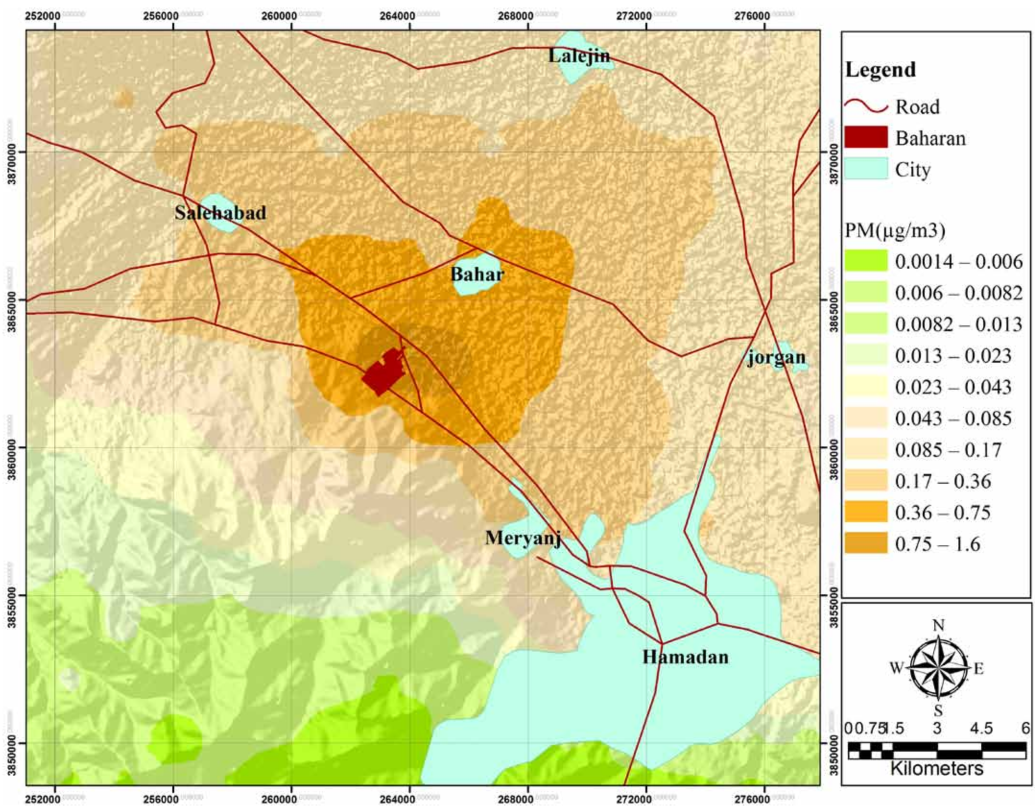
(a)

(b)

Fig1 . Distribution patterns of pollutants around the Baharan industrial town (a **)** maximum 8 h average concentration of CO; (b) maximum annual average concentration of NO_2, (c) maximum 24 h average concentration of SO_2; (d) maximum 24 h average concentration of PM_{10}; (e) maximum 24 h average concentration of TSP

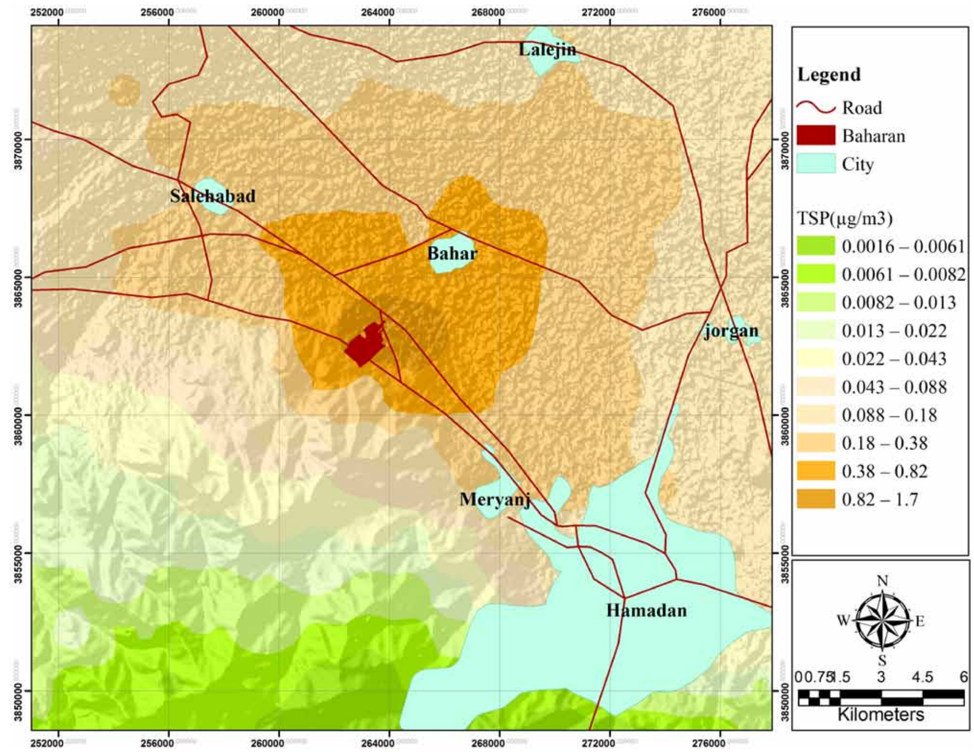


(c)



(d)

Fig1 . Distribution patterns of pollutants around the Baharan industrial town (a **)** maximum 8 h average concentration of CO; (b) maximum annual average concentration of NO_2, (c) maximum 24 h average concentration of SO_2; (d) maximum 24 h average concentration of PM_{10}; (e) maximum 24 h average concentration of TSP



(e)

Fig1 . Distribution patterns of pollutants around the Baharan industrial town (a) maximum 8 h average concentration of CO; (b) maximum annual average concentration of NO_2, (c) maximum 24 h average concentration of SO_2; (d) maximum 24 h average concentration of PM_{10}; (e) maximum 24 h average concentration of TSP

Table 8. Spatial variations of pollutants due to the construction of the Π -phase of Baharan industrial town

		Iran Environmental Protection Organization Standards (μg /m^3) - 2015				
		CO - 8 h	SO_2 - 24 h	NO_2 - Annual	PM_{10} - 24 h	TSP - 24 h
City	Distance of industrial town (km)	10000	395	100	360	-
Lalejin	9	5.06-10.9	2.5-5.17	0.114-0.285	0.174-0.361	0.182-0.385
Hamadan	12	2.38-5.06	1.22-2.5	0.02-0.047	0.085-0.174	0.088-0.182
Meryanj	7	5.06-10.9	2.5-5.17	0.02-0.114	0.085-0.174	0.088-0.182
Bahar	4	10.9-23.7	5.17-10.8	0.28-0.723	0.361-0.751	0.385-0.818
Saleabad	8	5.06-10.9	2.5-5.17	0.114-0.285	0.174-0.361	0.182-0.385

Area wind rose

Fig. 2 shows the wind rose of the area, which has been prepared in WRPLOT View Freeware-7.0.0 software using the meteorological data of the Hamadan airport station. The dominant wind direction of the studied area in yearly period is southeastward so that 19 % of the winds blew toward the area from a 264^o corner.

Modeling results

Results of executing the AERMOD model were obtained as the aligned curves of the pollutants’

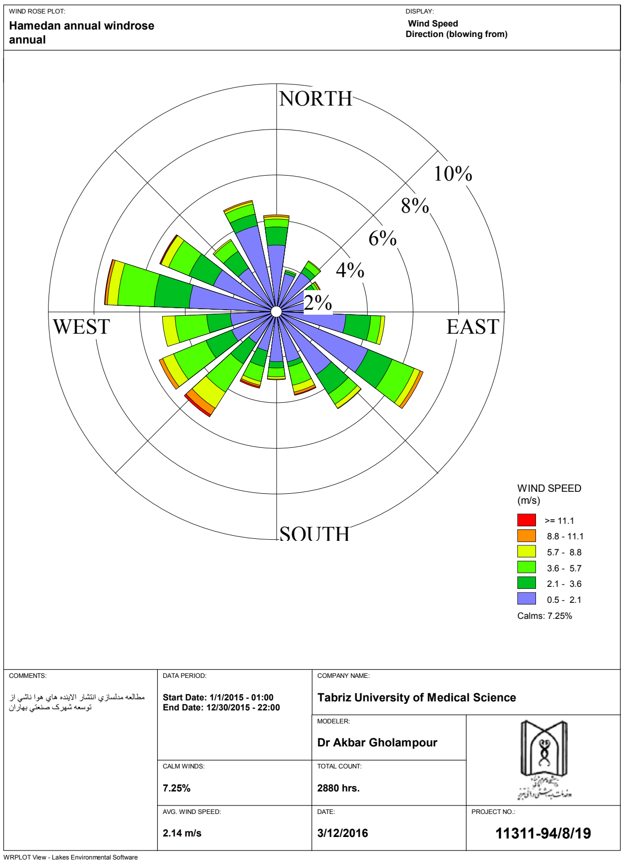


Fig. 2. Wind rose of Hamadan synoptic station

concentration in the receiver network. In the present study, the CO concentration was examined in an average 8 h annual period. According to the findings of AERMOD, the maximum CO concentration was 84 µg / m^3 at the geographical coordinates of 3862374.81 and 262792.31, which was less than the standard value (10000 µg / m^3) determined for clean air. In 24 h period, the maximum concentration of SO_2, PM_{10}, and TSP at the geographical coordinates of (262792.31 and 3862374.81) was predicted to be equal to 29.3, 1.52, and 2.08 µg / m^3, respectively. Furthermore, for CO_2 pollutant in the monthly period and at the geographical coordinates of (262792.31 and 3862374.81), the maximum concentration of 3646 µg / m^3 was predicted; however, for NO_X at the same geographical coordinates, the maximum concentration was predicted to equal 7.05 µg / m^3. In the present study, investigation of the maximum concentration of the pollutants at 1 h, 8 h 24 h, monthly and annual indicated that concentration of the studied pollutants would remain below the specified standards. In another study, investigation the time - variations of the SO_2 concentration showed that most of the studied areas had insignificant changes during the study period from 1996 to 2002, and the annual SO_2 concentration was increased only in some of these areas during the period [29]. Table 8 shows the pollutants' concentration range in five cities around the studied area derived from GIS system, which includes estimations of the average annual, monthly, and hourly concentrations of the pollutants. Accordingly, the concentration of the pollutants in these cities was very insignificant and much less than the standard values. Several studies have been conducted on the dispersion of the pollutants from point resources that have consistent results with the present study [11, 16].

CONCLUSIONS

In general, based on the findings of the present work, the following can be concluded:

- The maximum fuel consumption rate in the industrial towns which the questionnaires were completed, and consequently phase-II of Baharan industrial town was related to natural gas.
- Due to the high consumption rate of natural gas in Baharan industrial town compared to other fuels, the concentration of NO_2 pollutant resulted from the Baharan industrial town was higher than other investigated pollutants such as particles, SO_2, and CO.
- The food and textile groups and the non - metallic minerals group had the maximum and the minimum fuel consumption rates per hectare of the industrial group, respectively.
- Bahar city with the distance of 4 km from the

Baharan industrial town will receive the highest concentration of the pollutants resulted from the construction of phase-II of Baharan industrial town.

• By comparing the results of the pollutants' concentration in long - and short – term periods with the Iran Environmental Protection Organization Standards, it can be found out that even in the case of activity of all the industrial groups, the maximum concentration values will be very insignificant for the 24 h, 1 h, and annual periods.

• Constructing phase-II of Baharan industrial town will have no long - and short - term adverse effects on the surrounding environment of the industrial Towns as well as nearby close cities and villages.

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COMPETING INTERESTS

The authors confirm that there is no competing interest for this research.

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ETHICAL CONSIDERATIONS

The local ethical review committee of the Tabriz University of Medical Sciences approved the study (Ethical No.B/240). Compliance with ethical standards.

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