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PM_{10} and CO dispersion modeling of emissions from four thermal power plants in Mashhad, Iran

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Abstract. This study evaluates the exposure level of (PM_{10}) and carbon monoxide (CO) particulate matter that originates from four power plants in Mashhad, Iran using air pollution dispersion Model. A combined use of AREMOD (The American Meteorological Society/Environmental Protection Agency Regulatory Model), ArcGIS, and health risk assessment was considered to estimate the pollution level in thirteen municipal receptors in Mashhad. The results demonstrated the long-range transport of pollutants from the power plants and their high potential to impose significant health impacts on residential receptors. Almost 80000 inhabitants of the city are exposed to PM_{10} concentration ranging between 50–75 $\mu g/m^3$, and 100000 are exposed to CO concentration ranging between 40–45 $\mu g/m^3$. Approximately, 1200 hectares of the city is exposed to PM_{10} concentration ranging from 40 to 50 $\mu g/m^3$ and 370 hectares of the city area exposed to CO concentration between 50–75 $\mu g/m^3$. A comparison between the simulated and observed concentrations of pollutants shows an insignificant overestimation by the model.

1. Introduction

More than 60% of the world population will live in metropolitan areas by 2050 [1]. Rapid urbanization and industrialization of developing countries is responsible for high air pollution [2–6]. In fact, air pollution crisis has become a humanitarian catastrophe due to poor city planning. The energy produced by fuel combustion such as fossil fuel power accounts for much of the worldwide air pollution, generating 85% of airborne inhalable particulate pollution [7–10]. A significant number of studies have made efforts to shed light on the harmful impacts of the emission of air pollution from power plants and its close association to global warming and health impacts [11–14]. Air contaminants such as toxic gas and particulate matter emitted from power plants can be dispersed over large areas in the surroundings of these stationary pollution sources, which cause harmful impacts on the human health and environment [15]. Exposure to high levels of particulate matter ($PM_{2.5}$ and PM_{10}) leads to adverse health risks, particularly for those who live nearby the PM sources [16]. Moreover, exposure to the ambient particulate matter (PM_{10}) has shown its impact in the form of short- and long-term impacts on mortality and morbidity for several reasons [17–20]. Carbon monoxide (CO) is another well-known air contaminant that originates from the partial oxidation of fossil fuel compounds such as incomplete combustion of Mazut in burners of the thermal and gas power plants. While power plants are not expected to be the main sources of CO, small changes in the efficiency of fuel combustion could have a positive impact on the CO emissions reduction [21]. The AERMOD has been described as a more refined dispersion model

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in complex and simple terrains for determining the impact of air pollutants emanating from industrial sources on receptors [22]. Presently, AERMOD as an alternative to ISC is the preferred dispersion model by USEPA [23].

The main objective of this study is to apply AERMOD model as a prognostic tool to facilitate the prediction of plume concentration and dispersion emitted from the four power plants near Mashhad, Iran. This study predicts the level of exposure to pollutants over the thirteen receptors of the city. In fact, the effect of burning fossil fuels such as Mazut in burners of the power plants in urban air pollution and its health risk assessment on the residents has been simulated. Mashhad and its countryside are characterized by an area of 625 km^2, and the whole area has been analyzed for the exposure assessment based on three approaches:

1. Estimation of exposure to pollutants in each subdivision of the metropolitan area (receptors);
2. Estimation of the city population exposure to pollutants;
3. Estimation of exposure to pollutants in the areas.

2. Study area

Mashhad is the second most populous city in Iran and is home to more than three million permanent inhabitants, which include 3.8 percent of the total population of the country [24]. *Mashhad* is located at 36.20° North latitude and 59.35° East longitude between the two mountain ranges of Binalood and Hezar Masjed. The city is on the verge of a severe environmental crisis due to its rapid expansion, urbanization, and industrialization. Such a disaster results from emissions from the four fossil fuel power plants (Figure 1, black dots): (1) Ferdowsi power plant (36.4542° N, 59.5669° E), (2) Tous power plant (36.4542° N, 59.5669° E), (3) Shariati power plant (36.2379° N, 59.7314° E), and (4) Mashhad power plant (36.2713° N, 59.6508° E). The thirteen metropolitan areas of Mashhad city have been marked by shaded color (Figure 1). One of the areas, Saman, is not divided by number. Locations of the environmental monitoring stations have been marked by red dots. The pollutants such as PM_{10}, CO, SO_2, NO_2, and O_3 were collected from the mentioned stations. Physical characterizations and emission properties of the different units (stacks) of the power plants are listed in Table 1. Ferdowsi is a natural gas power plant with a production capacity of 954 MW, which is located in North West of Mashhad city, and includes six stacks of 159 MW of gas. The second power plant, Tous, is located very close to Ferdowsi in the western section of the city. Tous is a thermal power plant with a production capacity of 600 MW and has 4 steam units of 150 MW. Shariati is a combined cycle power plant in the eastern part of Mashhad with a production capacity of 500 MW. Shariati power plant consists of 6 gas turbine units, each with a power of 25 MW, a 100-MW steam unit, and one combined cycle unit including two gas turbines, each of which holds a capacity of 123.4 MW. This power plant uses natural gas as its primary source and, then, gas oil as backup fuel. The last plant, Mashhad, including thermal power plants with a capacity of 308 MW, is located in the southeast part of the city. Mashhad power plant was once located outside the city, but now is located close to the downtown due to its expansion and urbanization. This power plant consists of eight power generation, four steam, and four natural gas units. The physical characterization and emissions

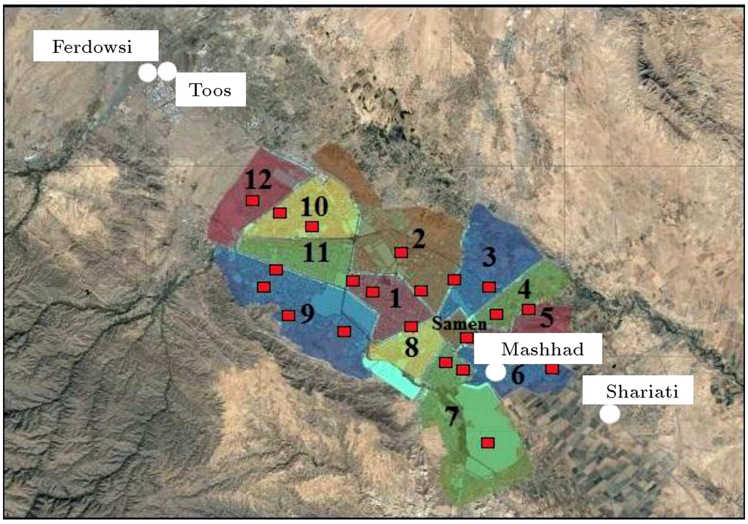

Figure 1. Map of the thirteen sub-metropolitan areas in Mashhad city (color shaded areas), four power plants (white rectangles), and the air pollution monitoring stations (red points).

Table 1. Physical characterizations and emissions properties of the power plants stacks.

Power plants	Unit	Stack height (m)	Stack plant location		Exhaust gas temp. (°C)	Exhaust gas velocity (ms^{-1})	Stack diameter (m)	CO mass flow (gr/s)	PM_{10} mass flow (gr/s)
			X (m)	Y (m)					
Ferdowsi-gas	1	23	715412.51	4036262.59	530	31.6	5	124	93
Ferdowsi-gas	2	23	715385.51	4036288.87	530	31.6	5	124	93
Ferdowsi-gas	3	23	715358.85	4036315.56	530	31.6	5	124	93
Ferdowsi-gas	4	23	715333.05	4036341.41	530	31.6	5	124	93
Ferdowsi	5	23	715305.97	4033630.15	530	31.6	5	124	93
Ferdowsi	6	23	715279.65	4036393.59	530	31.6	5	124	93
Toos-steam	1	100	716066.75	4036215.92	110–140	20	3	30	22.22
Toos-steam	2	100	716070.21	4036212.33	110–140	20	3	30	22.22
Toos-steam	3	100	716125.62	4036159.25	110–140	20	3	30	22.22
Toos-steam	4	100	716129.83	4036155.95	110–140	20	3	30	22.22
Mashhad-steam	1	50	737982.91	4017289.98	130–150	7.5	3	13.25	8
Mashhad-steam	2	50	738007.42	4017278.51	130–150	7.5	3	13.25	8
Mashhad-gas	1	50	738078.24	4017289.50	530	9	3	13.33	10
Mashhad-gas	2	50	738094.26	4017281.63	530	9	3	13.33	10
Shariati-gas	1	10	745427.90	4013846.05	550	31	2	19.5	14.6
Shariati-gas	2	10	745441.34	4013830.53	550	31	2	19.5	14.6
Shariati-gas	3	10	745450.79	4013818.65	550	31	2	19.5	14.6
Shariati-gas	4	10	745463.62	4013803.56	550	31	2	19.5	14.6
Shariati-gas	5	10	745472.86	4013791.93	550	31	2	19.5	14.6
Shariati-gas	6	10	745485.34	4013776.69	550	31	2	19.5	14.6
Shariati-steam	1	50	745495.32	4013691.55	110–130	14	4.5	44	33
Shariati-steam	2	50	745531.89	4013646.50	110–130	14	4.5	44	33

from the stacks associated with each power plant are shown in Table 1.

The simulated concentration of PM_{10} and CO close to stacks and over the city was compared to the national industrial emission standards. Air quality standard permit for PM_{10} and CO emission from stacks of power plants is listed in Table 2.

3. Meteorological data

This study incorporated the hourly surface and upper-air meteorological data in the AERMOD model as inputs. Wind velocity, temperature, pressure, dew point, and solar radiation were observed at each site. The ground-level and upper-air data were obtained from the nearest weather station in Mashhad city. Upper-air data only involve temperature, pressure, and relative humidity parameters. The meteorology data over the years 2015–2016 were pre-processed, which coincided with the time periods of the field measurements at each site for use in AERMOD. Figure 2 displays the wind rose diagram of Mashhad based on the records collected from July 2nd 2001 to Apr 12, 2018. This wind rose shows that the wind in Mashhad often blows from the

Table 2. Iran emission limit guidelines for PM_{10} and CO from the fossil fuel power plant.

Pollutant sources	Pollutants	Unit of measurement	Allowable emissions rate/24 hour		Fuel type
			Level 1	Level 2	
Stacks and	PM_{10}	mg/Nm^3	100	150	Coal
Heat transfer devices	CO	mg/Nm^3	150	200	–

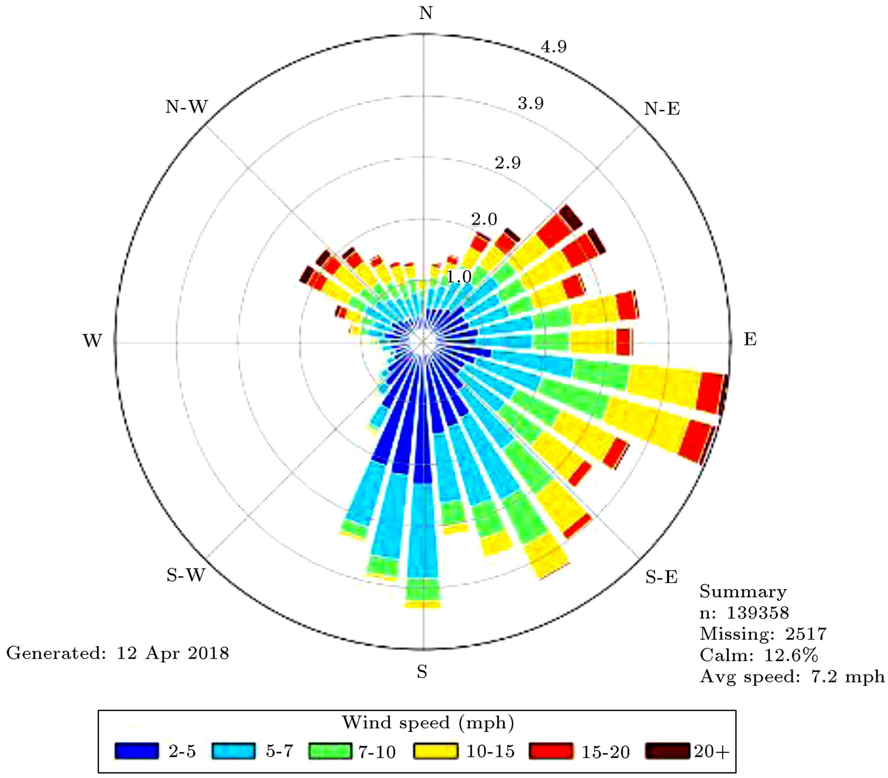

Figure 2. Wind rose plot in Mashhad (36.20°N and 59.35°E) from Jul 02, 2001 to Apr 12, 2018.

east-southeast (ESE) and, also, blows from the ESE at a speed of 15–20 mph approximately %10 of the times. In addition, this diagram shows that the wind rarely blows from the west and north.

4. Modeling part

Air pollution modeling is simulated as a programmed and interactive series of computational moduli with the ability to transform one set of databases such as meteorology, geography, and emissions into other datasets like concentration, depositions, or health harm [25]. The Gaussian plume dispersion model is used as the most frequent air pollution model to estimate the concentration of a contaminant at a certain point due to its simplicity [25]. AERMOD is a steady-state Gaussian plume model that incorporates air distribution based on planetary boundary layer turbulence (the lowest part of the atmosphere or surface layer) structure and scaling concept (over both surface and mixed layer scaling) including accurate spatio-temporal predictions and treatments, as well as simple and complex terrains [26]. Further, AERMOD has gained popularity in a number of countries such as China [27], Thailand, and Malaysia as a standard tool to predict transport and dispersion of pollutants such as particulate matter and toxic gas from stationary sources like power plants into the air [28]. In this study, the modeling package (ISC-AERMOD view, version 4.5) was performed to simulate the transport and dispersion of PM_{10} and CO over Mashhad city. The source types include four power plants close to the city. Parameters like geographic coordinates of the plants, type of power units, height and diameter of the stacks, temperature, flow, and velocity of exhaust gases, and the mass flow of the pollutants in the air dispersion pollution model were used. The raw data including surface roughness, albedo, and Bowen's ratio were processed by AERMET, AERMAP, AERMINUTE, and AERSURFACE to be used in the AERMOD model. ArcGIS software was used as a data analyzer tool to assess the exposure to PM_{10} and CO pollution. This software is a powerful tool for managing spatial and temporal data.

5. Statistical evaluation of the model performance

To determine the reliability of PM_{10} and CO concentration through the dispersion model, the four statistical indicators including the Index Of Agreement (IOA), Fractional Bias (FB), Normalized Mean Square Error (NMSE), and Root Mean Square Error (RMSE) were used. The formulas used to derive these four indicators are given in Eqs. (1)–(5):

$$IOA = 1 - \frac{\sum \left(P_i - \bar{O}_l\right)^2}{\sum \left(|P_i - P_l| + \left|O_i - \bar{O}_l\right|\right)^2}, \quad (1)$$

$$FB = \frac{(\bar{O}_i - \bar{P}_i)}{5(\bar{O}_i + \bar{P}_i)}, \quad (2)$$

$$NMSE = \frac{\overline{(\bar{O}_l - \bar{P}_l)}}{(\overline{O_l P_l})}, \quad (3)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2}, \quad (4)$$

$$R = \frac{\overline{O_l - \bar{O}_l} - \overline{P_l - \bar{P}_l}}{\sigma P_i \sigma O_i}, \quad (5)$$

where N represents the number of data, P_i and O_i are the predicted and observed concentrations, respectively, and $\bar{P}_l$ and $\bar{O}_l$ are the mean values of the predicted and observed concentrations, respectively. Likewise, σP_i and σO_i are the standard deviations of predictions and observations.

6. Results

6.1. Distribution of pollutants

Spatial distributions of the mean concentration of PM_{10} and CO during 2015, 2016 are shown in Figure 3. The maximum concentrations of PM_{10} and CO over Ferdowsi, i.e., the biggest power plant with a capacity of 900 MW, were found to be about 1250 μg/m^3 and 738 μg/m^3 during the one-hour average of emissions over a year, respectively. Moreover, the maximum concentration of PM_{10} was reduced to 850 μg/m^3 at a distance of 700 m from this source and, then, to 50 μg/m^3 at 12 km. Moreover, a CO concentration of 50 μg/m^3 was calculated at 14 km downwind of this source. As expected, the maximum concentrations of PM_{10} and CO were found in areas close to each power plant. The spatial patterns of PM_{10} and CO at Ferdowsi and Touse plants show two different plume pathways: southward and southeastward (Figure 3). The plume that moves toward the southeast directly affects the entire city, and these power plants strongly affect the exposure level of the pollutants in subareas 1, 9, 10, and 11.

Mashhad power plant is unfortunately located inside the city on the border of two subdivisions: subdivisions 5 and 6. This power plant has 4 stacks (2 steam and 2 gas), and the emission of PM_{10} and CO is lower than that from other plants (Table 1). Nevertheless, the exposure level of the pollutants is too high because of the closeness and density of human populations in this part of the city. Moreover, the last power plant, Shariati, is located in the southeast of the city and very close to Mashhad power plant. The plume rises in the downwind direction (Figure 2) from its stacks and, then, merges with Mashhad plumes in subdivisions 5 and 6. Even though Shariati and Mashhad are significantly weaker than Ferdowsi and Tous, the exposure level of the pollutants in subdivisions 5, 6, and 7 is high because of their locations.

6.2. Exposure assessment of PM_{10} and CO

This study conducts the exposure assessment based on three approaches using ArcGIS: (1) estimation of exposure to pollutants in each Metropolitan area (receptor), (2) estimation of the city population exposure to pollutants, and (3) estimation of exposure to pollutants in the areas. In the first approach, the city was divided into thirteen metropolitan areas (receptors), and exposure to PM_{10} concentration for each of district receptors was estimated. Receptor 9 with about 75000 population was found to have the highest level of PM_{10} exposure, whose concentration ranges are from 45 to 50 μg/m^3 and from 50 to 75 μg/m^3 (Figure 4(a)). Moreover, high-risk exposure to PM_{10} was found in receptors 1, 10, and 11. Those areas were impacted by Ferdowsi and Tous power plants. Furthermore, receptors 5, 6, and 7 with 75000 inhabitants were recognized as the second group with high-level exposure to PM_{10}. These areas were impacted by Mashhad and Shariati power plants (Figure 4(a)). Figure 4(b) shows the prediction of the exposure level of CO concentration over the 13 district receptors. Receptor 2 with about 440000 population has the highest level of exposure to CO in the concentration range of 15–25 μg/m^3. Moreover, receptor 9 with about 75000 population was predicted to have experienced the highest exposure level to CO in the range of 20–25 μg/m^3. Moreover, the inhabitants in receptors 1, 6, 7, 10, and 11 experienced relatively high and different levels of exposure to CO emissions.

In the second approach, this study considered the exposure of the city population to PM_{10} and CO concentrations. Figure 5(a) indicates that 80000 inhabitants of the city were exposed to PM_{10} concentration, ranging from 50 to 75 μg/m^3. Finally, about 220000 of the inhabitants were exposed to PM_{10} concentration, ranging from 40 to 50 μg/m^3. Figure 5(b) shows about 80000 inhabitants of the city exposed to CO concentration, ranging from 45 to 50 μg/m^3. Most of the population live in receptor 6. Furthermore, about 100000 of the inhabitants were exposed to CO concentration between 40-45 μg/m^3, and most of them are located in receptors 6, 10, and 11.

In the last approach, this study found those areas exposed to PM_{10} and CO concentrations. Practically, 540 hectares of the city area was exposed to PM_{10} concentration of 50–75 μg/m^3. In addition, 1200 hectares of the city was exposed to PM_{10} concentration, ranging from 40 to 50 μg/m^3, whereas almost 2340 hectares of the city was not exposed to PM_{10} (Figure 6(a)). Approximately 370 hectares of the city area was exposed to CO concentration (between 50-75 μg/m^3),

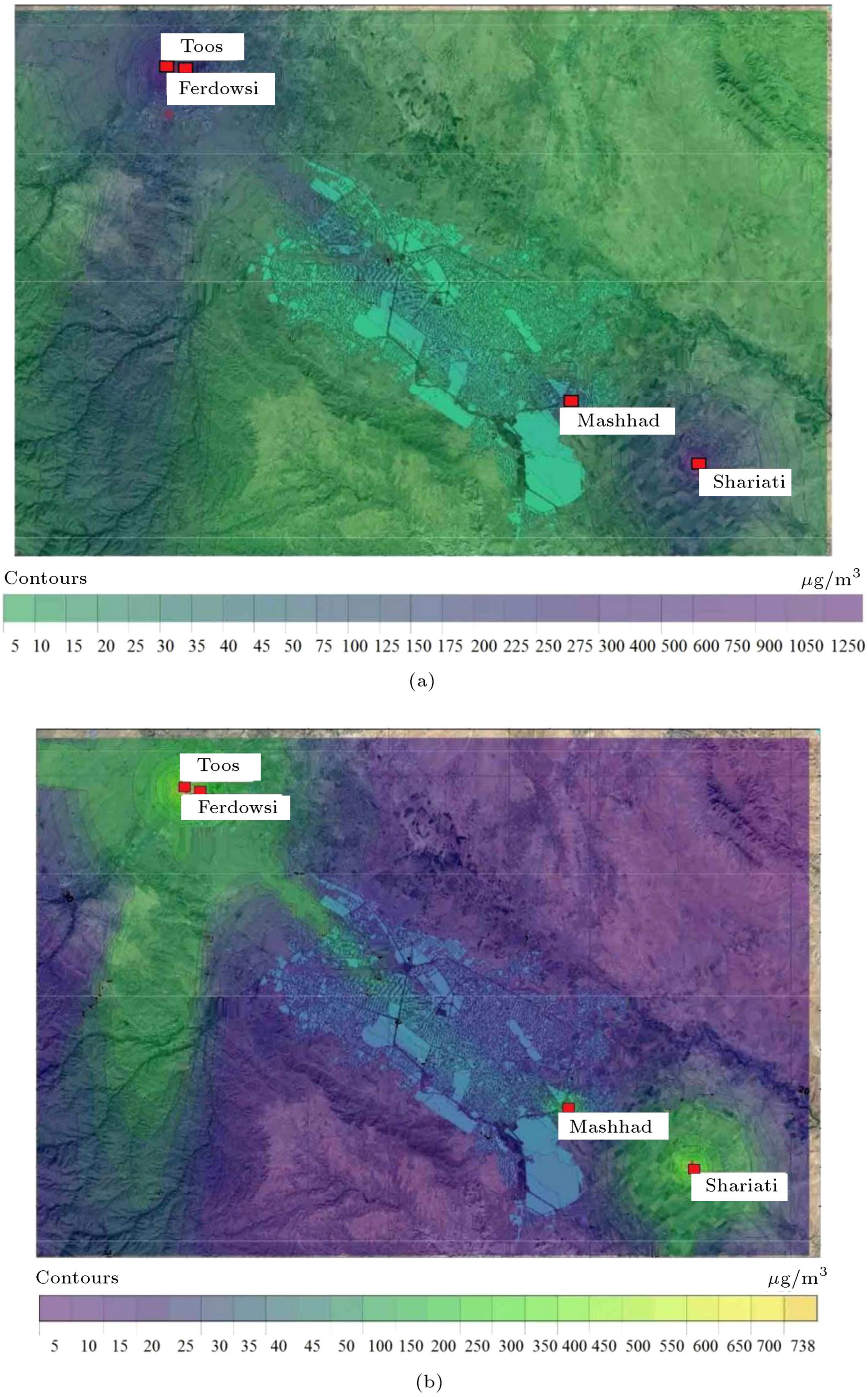

Figure 3. (a) Distribution of PM_{10} concentration and (b) distribution of CO concentration, emitted from the power four plants over Mashhad.

while 1400 hectares of the city area was not exposed to CO (Figure 6(b)).

6.3. Evaluation of AERMOD model

As expected, CO concentrations simulated using AERMOD were closer to the observed concentrations than to the PM_{10} concentration distributions, because the secondary PM_{10} sources were not included in this study such as the generation of PM_{10} by human activities (burning of fossil fuels by vehicles and industrial). Moreover, PM_{10} can be generated through natural processes like forest fires and volcanoes, and it can be transported over thousands of kilometers during dust events (Gupta and Mohan, 2013). Table 3 shows the values of IOA, FB, NMSE, and RMSE. The IOA varies from 0.0 to 1.0, and IOA values above 0.5

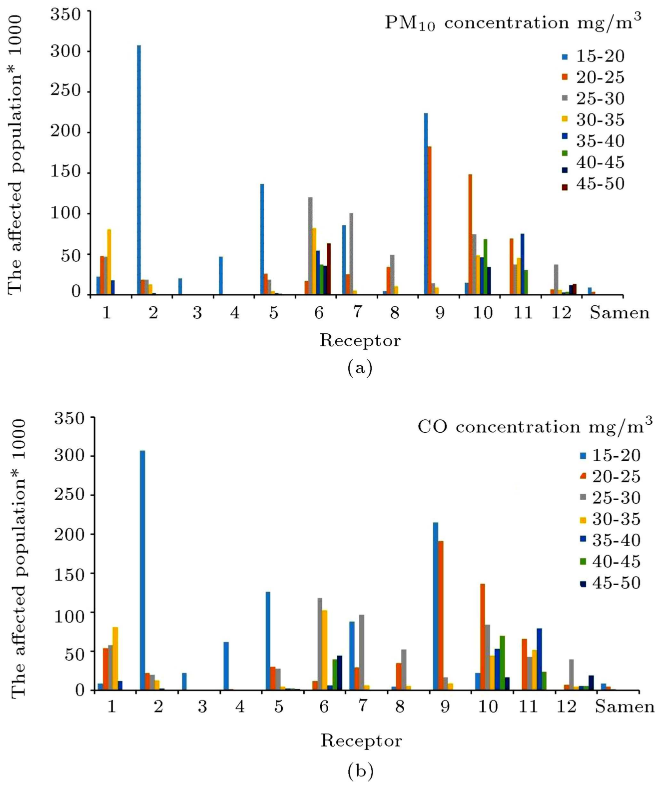

Figure 4. Exposure of district receptors areas to (a) PM_{10} concentration and (b) CO concentration.

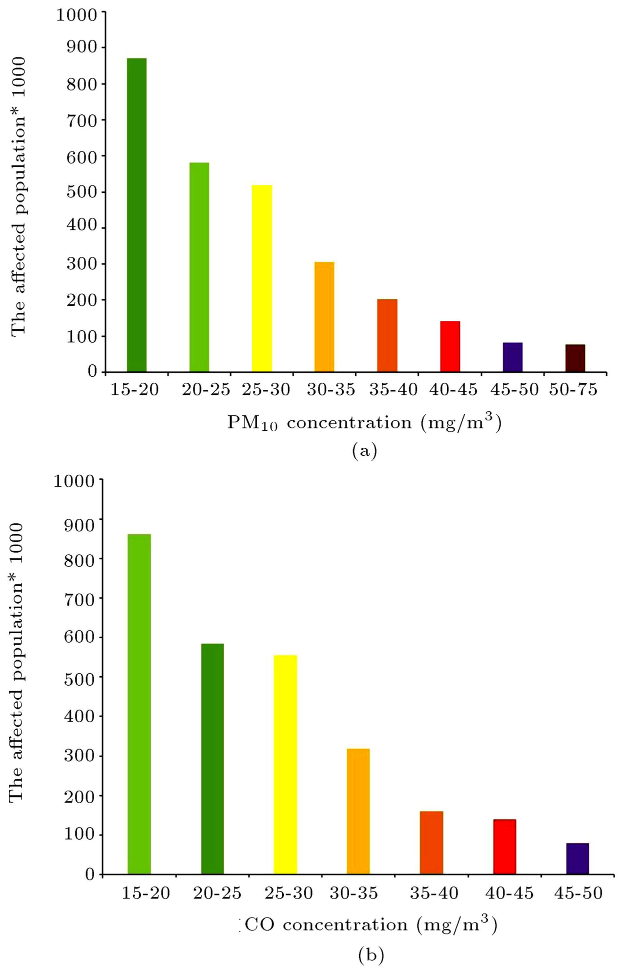

Figure 5. Exposure of the city population to (a) PM_{10} concentration and (b) CO concentration.

are considered as accurate predictions. According to Table 3, IOA has been calculated by about 0.470582 and 0.675789 for PM_{10} and CO, respectively. FB values can vary between +2 and −2; values of zero represent the ideal model, and negative and positive FB values represent overpredictions and underpredictions, respectively [29]. In this study, FB has been estimated to be very close to zero. The NMSE shows the scatter in the dataset, and the smaller values of NMSE represent better model performance. The RMSE values of PM_{10} and CO were calculated to be about 0.0561 and 0.1213, respectively. The RMSE value should be close to zero for high accuracy. The validity of the AERMOD model output has been evaluated using the scatter plot between the concentrations of simulated and observed pollutants (Figure 7). The R-squared (r^2) for PM_{10} and CO was calculated as 0.7177 and 0.8159, respectively. The high values of R-squared (close to one) demonstrate the high performance of the AERMOD model. A comparison between the simulated and observed data shows little overestimation by the model for both pollutants. The concentrations of air pollutants were affected by stack heights and meteorological conditions. Therefore, industrial plants should consider adjusting stack heights and outlet velocities to reduce the ambient air concentrations of pollutants in vulnerable receptors located near the plants.

Table 3. The values of IOA, FB, NMSE, and RMSE.

No.	IOA	FB	NMSE	RMSE
PM_{10}	0.470582	0.1431	0.00681	0.0561
CO	0.675789	0.1441	0.00681	0.1213

7. Conclusion

This study implemented an air quality dispersion model to determine the level of pollutants (PM_{10} and CO) emitted from the stacks of the four power plants in Mashhad city in Iran. The results indicated that the spatial patterns of pollutants released from Ferdowsi and Tous power plants had two different pathways: southward and southeastward. The southeast plume directly affected the city, and the exposure level of the pollutants in receptors 1, 9, 10 and 11 was highly impacted (20–45 $\mu g/m^3$) by those power plants. Unfortunately, Mashhad city has been expanding more and more toward Ferdowsi and Tous due to the lack of a comprehensive urban planning. Moreover, the expo-

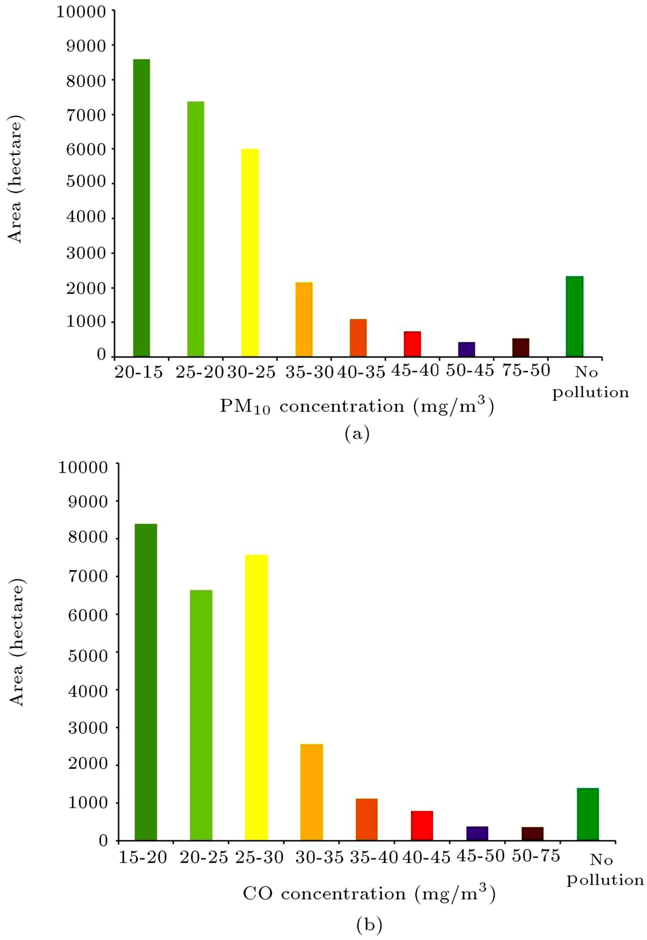

Figure 6. The exposure level of areas (in hectare) to pollutants: (a) PM_{10} concentration and (b) CO concentration.

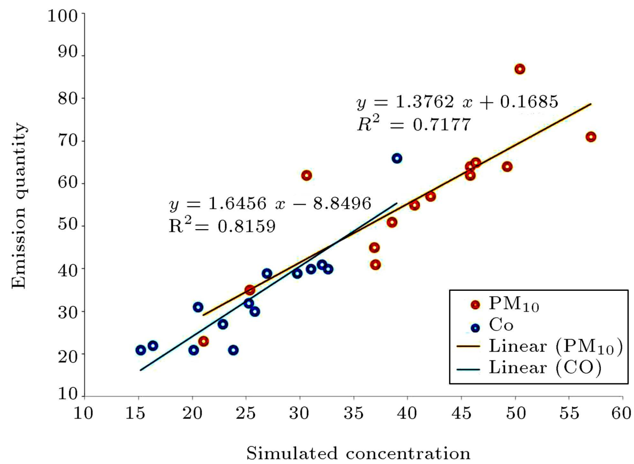

Figure 7. Scatter plot between simulated and observed: PM_{10} concentration (orange line) and CO concentration (blue line).

sure level of the population to pollutions will be high due to the relatively large population in those areas. Two other power plants, Mashhad and Shariati, are located very close to the city. Although the emission from Shariati and Mashhad power plants is lower than that from Ferdowsi and Tous, the exposure level of the pollutants is relatively high (20-30 $\mu g/m^3$) in receptors 5, 6, and 7 because of their proximity to the city. Shariati is located on the south-eastern side and the plume rises in the downwind direction from its stacks and, then, merges with Mashhad plumes in receptors 5 and 6. This study also estimated the population exposure level of PM_{10} and CO concentrations over the thirteen district receptors of the city. The receptors located in the northwestern, central, and southeastern parts of Mashhad were found to be more polluted than others. Receptor 9 with about 75000 population showed the highest exposure to PM_{10} ranging between 45-50 $\mu g/m^3$ and 50-75 $\mu g/m^3$ and the highest exposure level to CO in the range of 20–25 $\mu g/m^3$. Receptor 2 with about 440000 population showed the highest exposure to CO in the concentration range of 15-20 $\mu g/m^3$.

References

1. UN "World urbanization prospects: the 2014 revision highlights (ST/ESA/SER.A/352)", Department of Economic and Social Affairs, Population Division, Texas, USA (2014).

2. Kampa, M. and Castanas, E. "Human health effects of air pollution", *Environment Pollutant*, **151**, pp. 362–367 (2007).

3. Liu H.Y., Bartonova, A., Schindler, M., et al. "Respiratory disease in relation to outdoor air pollution in Kanpur, India", *Archives of Environmental & Occupational Health*, **68**, pp. 204–217 (2018).

4. Moshammer, H., Bartonova, A., Hanke, W., et al. "Air pollution: A threat to the health of our children", *Acta Paediatr*, **95**, pp. 93–105 (2006).

5. Oak Ridge National Laboratory, *Environmental Quality and the U.S. Power Sector: Air Quality, Water Quality, Land Use and Environmental Justice ORNL*, Energy and Transportation Science Division, USA (2017).

6. Shahmohamadi, P., Cubasch, U., Sodoudi, S., et al. *Mitigating Urban Heat Island Effects in Tehran Metropolitan Area*, 2nd Ed., Intech Open press (2012).

7. International Energy Agency (IEA) Weo, *Special Report Energy and Air Pollution*, International Energy Agency, Paris, France (2016).

8. Perera, F. "Pollution from fossil-fuel combustion is the leading environmental threat to global pediatric health and equity: Solutions exist", *International Journal of Environmental Research and Public Health*, **15**(1), pp. 16–21 (2017).

9. Pope, C.A. "Mortality effects of longer term exposures to fine particulate air pollution: review of recent epidemiological evidence", *Inhalation Toxicology International Forum for Respiratory Research*, **19**, pp. 33–38 (2007).

10. Awasthia, S., Khareb, M., and Gargav, P. "General plume dispersion model (GPDM) for point source emission", *Environmental Modeling and Assessment*, **11**, pp. 267–276 (2006).

11. Mahboob, A. and Makshoof, A. "Dispersion modeling of noxious pollutants from thermal power plants", *Turkish Journal of Engineering and Environmental Sciences*, **34**, pp. 105–120 (2009).

12. Watts, N., Adger, W.N., Agnolucci, P., et al. "Health and climate change: Policy responses to protect public health", *The Lancet*, **386**, pp. 1861–1914 (2015).

13. World Health Organization, Regional Office for Europe Health Effects of Particulate Matter-Policy Implications for Countries in Eastern Europe, Caucasus and Central Asia, Denmark (2017).

14. World Health Organization, *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*, Denmark (2017).

15. Ehrlich, C., Noll, G., Kalkoff, W.D., et al. "PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ emissions from industrial plants, results from measurement programs in Germany" *Atmospheric Environment*, **41**(29), pp. 6236–6254 (2007).

16. Henschel, S.A., Zeka, R., Tertre, A., et al. "Air pollution interventions and their impact on public health", *International Journal of Public Health*, **57**, pp. 757–768 (2012).

17. Cristina, M., Cervino, M., and Gianicolo, E.A. "Secondary particulate matter originating from an industrial source and its impact on population health", *International Journal of Environmental Research and Public*, **12**(7), pp. 7667–7681 (2015).

18. Posada, E., and Gomez, M. "The effect of sulfur in diesel fuel on PM2.5 in Medellin (slides)", In: *Proceedings of the 8th International Conference Air Quality-Science and Application*, Athens (2012).

19. Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., et al. "Effects of long-term exposure to air pollution on natural-cause mortality: An analysis of 22 European cohorts within the multicentre ESCAPE project", *The Lancet*, **383**, pp. 785–795 (2014).

20. Gupta, M., and Mohan, M. "Assessment of contribution to PM_{10} concentrations from long-range transport of pollutants using WRF/Chem over a subtropical urban airshed", *Atmospheric Pollution Research*, **4**, pp. 405–410 (2013).

21. Nicks, D.K., Holloway, J.S., Ryerson, T.B., et al. "Fossil-fueled power plants as a source of atmospheric carbon monoxide", *The Royal Society of Chemistry*, **11**, pp. 175–192 (2002).

22. Teggi, S., Costanzini, S., Ghermandi, G., et al. "A GIS-based atmospheric dispersion model for pollutants emitted by complex source areas", *Science of the Total Environment*, **610**, pp. 175–190 (2018).

23. Abril, G.A., Diez, S.C., Pignata, M.L., et al. "Particulate matter concentrations originating from industrial and urban sources: Validation of atmospheric dispersion modeling results", *Atmospheric Pollution Research*, **7**, pp. 180–189 (2016).

24. "Report on a selection of population indices in Mashhad based on general census data of population and housing", Statistics Center. Mashhad, Iran (2016), http://amar.mashhad.ir.

25. Azapagic, A., Chalabi, Z., Fletcher, T., et al. "An integrated approach to assessing the environmental and health impacts of pollution in the urban environment: Methodology and a case study", *Process Safety and Environmental Protection*, **91**, pp. 508–520 (2013).

26. North American Power Plant Air Emissions (NAPPAE), "Particulate matter emissions report", Texas, USA (2005).

27. Ma, J., Yi, H., Tang, X., et al. "Application of AERMOD on near future air quality simulation under the latest national emission control policy of China: A case study on an industrial city", *Journal of Environmental Sciences*, **25**, pp. 1608–1617 (2013).

28. Mokhtar, M.M., Hassim, M.H., and Taib, R.M., "Health risk assessment of emissions from a coal-fired power plant using AERMOD modelling", *Process Safety and Environmental Protection*, **92**, pp. 2–11 (2014).

29. Chang, S.Y., Vizuete, W., Valencia, A., et al. "A modeling framework for characterizing near-road air pollutant concentration at community scales", *Science of the Total Environment*, **538**, pp. 905–921 (2015).

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