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Modeling of CO and NO_x produced by vehicles in Mashhad, 2012

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Abstract

Background: In large cities, the share of vehicles in air pollutants emissions is nearly 70% that is mainly due to use of fossil fuels. Environmental simulation has many advantages such as accuracy and speed of modeling. Present study was conducted to create a model of air pollution [Carbon Monoxide (CO) and Nitrogen Oxides (NO_x)] from vehicles in fifty following years, in Mashhad.

Methods: According to the collected data from license plate, traffic and transportation organizations, modeling of CO and NO_x was performed by STELLA software. Hence, five strategies, including reduction in the number of imported vehicles and the proportion of distance traveled by vehicles, increase in the number of junked vehicles, application of Euro 4 standards instead of Euro 3 and a combination of their application, were applied in the model.

Results: In the current condition, CO and NO_x concentrations are 27,894 and 2,121, and after 50 years they would be 26,227,930 and 2,070,011 ton/year, respectively. Applying the aforementioned strategies, their concentrations were declined approximately (35% and 35%), (50% and 50%), (16% and 16%), (7% and 47%) and (75% and 85%), correspondingly.

Conclusion: Developed model showed that if the present condition remains stable, air quality will be more and more undesirable in the 50 following years. However, application of the second method, reduction of the distance traveled, was the most effective strategy in reducing the amounts of ones, so it will be better that this strategy is considered in the administrative policies. Nevertheless, as far as possible all of them ought to be taken advantage of.

Keywords: Modeling, Air pollution, CO, NO_x, Mashhad

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Introduction

Air pollution is a notable environmental threat for human health, and its impacts on economic activities carry on to be a global anxiety. Air pollution is the presence of one or more pollutants or the blend of them in atmosphere for a certain period of time (1). Air pollution is composed of industrial progression, cities enlargement, population accumulation, increasing motorist vehicles, increasing the use of oil production, and in some cases, regional and topography circumstances (2). Although technology improvement plays an important role to decline vehicles emissions, decrease of air pollution will remain as a challenge owing to increase transportation demand (3). Numerous pollutants, such as CO, NO_x, SO_x, O_3, and dust the combination of which forms photochemical smog are produced in cities (4). Based on conducted studies, the share of vehicles in air pollutants emissions is nearly 70% in metropolises that is mainly due to use of fossil fuels, also CO and NO_x were known as the most common pollutants produced in vehicles (5). Since pollutants have a destructive effect on human health, animals, plants, and buildings, they cause types of cancers, optical diseases, breath disorders, genetic mutation, and also environmental problems such as acid rain and ozone layer depletion. Determination of the real concentrations of the pollutants and description of air quality in comparison with standards are effective ways to control air quality (6). Nowadays, modeling in many scientific fields, especially environmental science is vastly used among which air pollution modeling is also placed (7). Modeling is transformation of statistical concepts to mathematical relations which is necessary for perception of a process. In fact, cause and effect relations among variables can obviously be evaluated by a model. Development of mathematical model requires skill, talent, experience, creativity, and innovation. Mathematical models can be used in research, development, design, and engineering economics. Mathematical modeling often requires numerous assumptions that are reasonable as possible. Most complicated models that have minimal assumptions for their development require a lot of time in order to simulate. When evaluating the results of the model, limitations imposed by assumptions should be considered (8). In many countries as well as Iran, plenty of studies have been conducted about modeling of air pollution. Modeling and prediction of carcinogenic polycyclic aromatic compounds and ozone concentration have been performed in Tehran and Mashhad, respectively (9,10). In a study in Greece and Finland, multiple regression model was used for prediction of NO_x and PM_{10} concentrations, which were compared with those of artificial neural network model (11). Modeling the spread of pollutants can show the effects of different parameters changes in production and emission of pollutants. Environmental simulation in the form of environmental models, particularly done by modern computers, has many advantages such as modeling accuracy and speed. A model can simulate the effects of new programs and ideas without spending time in the real world. Mashhad city is located in the northeast of Iran and between Binalood and Hezar Masjed mountain ranges. It is the capital of Khorasan Razavi province with 204 square kilometer area and attitude of 985 meters above the sea level. According to the 2011 census, its population was nearly 3,070,000 (12). The most important factor of air pollution in Mashhad, like all other Iranian metropolises, is transportation, so management of this problem requires a special attention. Present study was conducted to create a model of air pollution (CO and NO_x) from vehicles in fifty following years, in Mashhad.

Methods

This cross-sectional study was carried out for modeling the concentration of CO and NO_x produced by vehicles except diesel vehicles, buses, and minibuses in the next 50 years, using STELLA 8 software in Mashhad city. Data of vehicles were collected from license plate, Traffic and transportation organizations. STELLA software was used as a tool for dynamic simulation. To design dynamic systems model, in design page of the software, the figures of systems can easily be drawn using specific toolbars. After you draw figures, the software makes a convert of drawn figures to mathematical equations. To draw the general plane of system, the related icon was selected from the top of page and transferred into design page. In order to achieve desired system, these icons are displaced to achieve desired system. After drawing the general plane of system and determination of its equations in window environment, the simulation results can be shown as figures or tables. After completing the model, it can be implemented by referring to Stella table of contents and selecting Run or pressing on Ctrl-R keys. Also, with selection of Time space from Run, during the time period which has been considered for implementation of model, a change can be made in the calculations. First to run this model, the entire considered vehicles of Mashhad (514183) were classified into four groups by age, including up to 5, 5-10, 10-15, and over 15 years. For each one of the groups, a stock and a converter coefficient with regard to the number of junked vehicles including 0.002, 0.004, 0.007 and 0.013, respectively, were considered. It is necessary to mention that 18,000, the number of imported vehicles in that year, were added to the first stock. In this way, a system diagram was created on canvas and then transformed into mathematical relationships by STELLA. At the end of modeling, concentrations of the aforementioned pollutants were predicted in the following fifty years. Then to improve the future air quality, five strategies, including decreasing the number of imported vehicles and amount of distance traveled by vehicles, increasing the number of junked vehicles, applying Euro 4 standards instead of Euro 3, and combined application of these strategies, were applied in the software and influence of each was evaluated. The illustrative features of the developed model in the present study are exposed in Figure 1.

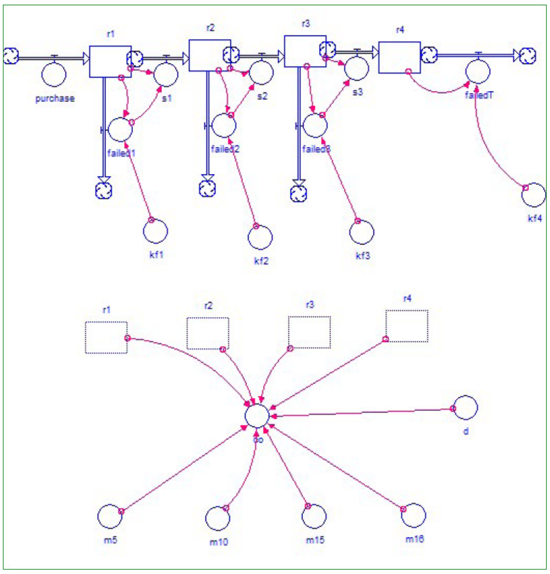

Figure 1. Dynamic model of air pollution for simulating the concentrations of CO and NO_x produced by vehicles using STELLA

Results

The results of STELLA software prediction for CO and NO_x, which were obtained based on aforementioned strategies over following fifty years have been presented in Tables 1 and 2, correspondingly.

In the first strategy, the is reduction of imported vehicles, if the number of bought vehicles decreases to half of its initial number (from 18,000 to 9,000), the amounts of CO and NO_x will be based on third columns of Tables 1 and 2, respectively. With application of this strategy, the amounts of CO and NO_x will be declined to nearly 9 million tons (from 26 to 17) and approximately 0.7 million tons (from 2 to 1.3), in that order.

In the second strategy, that is increasing the number of junked vehicles, with a double increase of convert coefficients from 0.002, 0.004, 0.007 and 0.013 to 0.004, 0.008, 0.014 and 0.026, junking rate can be augmented in the software. In this way, the amounts of CO and NO_x will be based on the forth column of Tables 1 and 2, correspondingly, and decrease of pollutants concentrations can be clearly observed; that is, the proportions of CO and NOx will be declined to almost 4 million tons (from 26 to 22) and 0.3 million tons (from 2 to 1.7), respectively.

In the third strategy, which is reduction of distance traveled by vehicles, if the amount of annual distance traveled by vehicles plummet to half of its initial proportion (from 20,000 to 10,000 km), as they have been presented in the fifth columns of Tables 1 and 2, the amount of CO and NOx will be plunged to half (from 26 and 2 to 13 and 1.03 million tons), correspondingly, in the next fifty years.

In the forth strategy, application of Euro 4 standards instead of Euro 3, if Euro 4 standards the application of which is necessary for cars since 2012 are replaced instead of Euro 3 in m5, m10, m15 and m16 converters, the amount of CO and NOx will be decreased approximately to 2 and 1 million tons, in that order, as it has been shown in the sixth columns of Tables 1 and 2. The Euro 4 and Euro 3 standards are displayed in Table 3.

In the fifth strategy, combined application of aforementioned strategies, if the number of imported vehicles along with annual distance traveled by vehicles are decreased, the number of junked vehicles is augmented, and Euro 4 standards are replaced instead of Euro 3, the amount of CO and NO_x will be fallen back based on the seventh columns of Tables 1 and 2, respectively. As it is observed, 74.74% and 85.5% decline can be the effects of this strategy in decreasing these two pollutants, in that order.

Discussion

According to the obtained model, if conditions of this present study do not change, life will be impossible in the future years owing to the increasing proportion of pollutants. In this study, the sensible result of each considered

Table 1. Amounts of CO in different conditions up to 50 next years (ton/year)

1	2	3	4	5	6	7
Year	Amount of CO with current conditions (2012)	Amount of CO with decline of imported vehicles	Amount of CO with increase of junked vehicles	Amount of CO with decrease of distance traveled	Amount of CO with application of Euro 4 standards instead of Euro 3	Amount of CO with combination of these four strategies
2012	27894	27894	27894	13947	23010	11505
2022	657353	570763	633867	328677	604292	253018
2032	2879861	2227775	2681220	1439931	2666909	956868
2042	7458985	5339300	6716488	3729493	6920845	2216682
2052	15053702	10197139	13123998	7526851	13978827	4094289
2062	26227930	17048996	22155481	13113965	24365203	6625708

Table 2. Amounts of NO_x in different conditions up to 50 next years (ton/year)

1	2	3	4	5	6	7
Year	Amount of NO_x with current conditions (2012)	Amount of NO_x with decline of imported vehicles	Amount of NO_x with increase of junked vehicles	Amount of NO_x with decrease of distance traveled	Amount of NO_x with application of Euro 4 standards instead of Euro 3	Amount of NO_x with combination of these four strategies
2012	2121	2121	2121	1060	1131	566
2022	51704	44924	49852	25852	27575	11531
2032	227056	175687	211381	113528	121097	43431
2042	588459	421282	529855	294230	313845	100506
2052	1187938	804744	1035615	593969	633567	185555
2062	2070011	1345629	1748534	1035006	1104006	300210

Table 3. Euro 4 and 3 standards for vehicles emissions (g/km)

		Euro 4 standards	Euro 3 standards	Convertor
CO	For vehicles up to 5 years old	1	2.3	m_5
	For vehicles over 5 years old	2.65	2.85	m_{10}
NO_x	For vehicles up to 5 years old	0.08	0.15	m_{15}
	For vehicles over 5 years old	0.12	0.225	m_{16}

2.85 and 0.225 have been calculated from the ratio between American and Euro 3 standards.

2.65 and 0.12 have been calculated from the ratio between American and Euro 4 standards.

strategy is shown by the obtained model. As the five proposed approaches were applied to the model in this study, the best strategy that had the lowest pollutants produced was the reduction of distance traveled by vehicles. In the following studies, modeling has been used for predicting future air quality as well. In a study by Saide *et al* (13), PM_{10} and $PM_{2.5}$ pollutions have been predicated by WRF-chem CO tracer in overnight steady-state conditions. The forecasting system has been based on precisely-simulating CO as a $PM_{10}/PM_{2.5}$ surrogate, since there is a strong correlation (over 0.95) amongst these pollutants. Therefore, the PM has been estimated by particular forecasting CO. Eventually, with regard to the simulations, forecasts which can be achieved by the system are proposed here. In fact, this is the largest merit of the presented systems (13). In another study by Banerjee *et al* (14), NO_2 concentration in Pantnagar (India) was determined by two mathematical models including Gaussian and combined models that are used for linear and industrial resources, respectively. These models illustrated that contribution of NO_2 produced in industries and vehicles is nearly 45-70% and 9-39%, correspondingly, and in air quality control, annual average of NO_2 is 32.6 μg/m^3. Thus, with statistical analysis, the accuracy of the model was obtained 61.9% (14). In the same study by Voukantsis *et al* (15), principle component analysis and artificial neural networks were used for the comparison of air pollution patterns of Thessaloniki and Helsinki and control of data in these regions. Then air quality forecast models were developed in the mentioned regions. Also forecasting model of PM_{10} and $PM_{2.5}$ concentrations was used for the following day predictions and the agreement index of daily data was measured. According to the model, the average of PM_{10} was between 0.8 and 0.85 that has been improved in comparison with prior studies prediction of quality parameters. In other words, performance of the model was evaluated by comparison of the obtained results from this model and the real condition, that indicates the results are pleased. In the present study, forecasting of CO and NO_x concentrations was performed by condition in 2012 (15).

Conclusion

To sum up, the amounts of the pollutants will decrease by applying each of the four main strategies listed above. Since the obtained results from the present study have proven that the greatest decline (nearly 50% in the quantity of CO and NO_x) was achieved by applying the third approach which is the reduction of the distance traveled by vehicles, so it will be better that this strategy is considered in the administrative policies. However, it needs to be mentioned that the highest reduce was obtained in the last strategy that is combination of first four method. Therefore, as far as possible, all the approaches mentioned above should be applied to implement the pollution reduction.

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Ethical issues

We certify that all data collected during the study is presented in this manuscript and no data from the study has been or will be published separately.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors participated equally in data acquisition, analysis and interpretation. All authors reviewed and approved the manuscript.

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