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Status of CO as an air pollutant and its prediction using meteorological parameters in Tehran, Iran

Masoud Masoudi*, Mohammad Sakhaei, Farshad Behzadi

Department of Natural Resources and Environmental Engineering, Agricultural College, Shiraz University, Iran

* Corresponding author e-mail: masoudi@shirazu.ac.ir

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Abstract
In the present study air quality analyses for Carbon monoxide (CO), were conducted in Tehran, Capital of Iran. The measurements were taken in four different locations to prepare average data in the city. The average concentrations were calculated for every 24 hours, each month and each season. Results showed that the highest concentration of CO occurs generally in the morning and beginning of night while the least concentration was found at the afternoon and early morning. Monthly concentrations of CO showed the highest value in January while least value was found in July. The seasonal concentrations showed the least amounts in summer while the highest amounts in autumn. Relations between the air pollutant and some meteorological parameters were calculated statistically using the daily average data. The wind data (velocity, direction), relative humidity, temperature, sunshine periods, dew point and rainfall were considered as independent variables. The relationships between concentration of pollutant and meteorological parameters were expressed by multiple linear and nonlinear regression equations for both annual and seasonal conditions using SPSS software. RMSE test showed that among different prediction models, stepwise model is the best option.

Keywords
CO, Air pollution, Meteorological Parameters, Regression model

Introduction

Air sustains life. But the air we breathe is not pure. It contains a lot of pollutants and most of these pollutants are toxic (Sharma, 2001). While developed countries have been making progress during the last century, air quality has been getting much worse especially in developing countries air pollution exceeds all health standards. For example, in Lahore and Xian (china) Dust is ten times higher than health standards (Sharma, 2001).
Carbon monoxide (CO) is one of the seven Conventional (criteria) pollutants (including CO, SO2, particulates, hydrocarbons, nitrogen oxides, O_3 and lead). These pollutants produce the highest volume of pollutants in the air and the most serious threat for human health and welfare. Concentration on these pollutants, especially in cities, has been regulated by Clean Air Act since 1970 (W.P. Cunningham and M.A. Cunningham, 2002). CO pollution occurs primarily from emissions produced by fossil fuel powered engines, including motor vehicles and non-road engines and vehicles (such as construction equipment and boats). Higher levels of CO generally occur in areas with heavy traffic congestion.
The presence of pollutants in the atmosphere, causes a lot of problems, thus the study of pollutant' behavior is necessary (Asrari *et al.*, 2007). CO can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues. Exposure to lower levels of CO is most serious for those who suffer from heart disease, and can cause chest pain, reduce the ability to exercise, or with repeated exposures, may contribute to other cardiovascular effects. Even healthy people can be

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affected by high levels of CO. People who breathe high levels of CO can develop vision problems, reduced ability to work or learn, reduced manual dexterity, and difficulty performing complex tasks. At very high levels, CO is poisonous and can cause death.

Status of pollutants concentration and effects of meteorological and atmospheric parameters on these pollutants compose the base of following studies: Ho and Lin (1994) studied semi-statistical model for evaluating the NO_x concentration by considering source emissions and meteorological effects. Street level of NO_x and SPM in Hong Kong has been studied by Lam et al (1997). In a study, the relationship between monitored air pollutants and meteorological factors, such as wind speed, relative humidity ratio and temperature, was statistically analyzed, using SPSS. According to the results obtained through multiple linear regression analysis, for some months there was a moderate and weak relationship between the air pollutants like CO level and the meteorological factors in Trabzon city (Cuhadaroglu and Demirci, 1997).

Mandal (2000) has shown the progressive decrease of air pollution from west to east in Kolkata. Statistical modeling of ambient air pollutants in Delhi has been studied by Chelani, et al. (2001). Abdul-Wahab and Al-Alawi (2002) developed a neural network model to predict the tropospheric (surface or ground) ozone concentrations as a function of meteorological conditions and various air quality parameters. The results of this study showed that the artificial neural network (ANN) is a promising method for air pollution modeling. The observed behavior of pollution concentrations to the prevailing meteorological conditions has been studied for the period from June 13 to September 2, 1994, for the Metropolitan Area of Sao Paulo (Sánchez-Ccoyllo and Andrade, 2002). Results showed low concentrations associated with intense ventilation, precipitation and high relative humidity. While high values of concentrations prevailed due to weak ventilation, absence of precipitation and low relative humidity for some pollutants. Also for predicting CO, Sabah et al. (2003) used a statistical model.

Elminir (2005) mentioned dependence of air pollutants on meteorology over Cairo in Egypt. The results hint that, wind direction was found to have an influence not only on pollutant concentrations but also on the correlation between pollutants. As expected, the pollutants associated with traffic were at highest ambient concentration levels when wind speed was low. At higher wind speeds, dust and sand from the surrounding desert was entrained by the wind, thus contributing to ambient particulate matter levels. It was also found that, the highest average concentration for NO_2 and O_3 occurred at humidity ≤ 40% indicative for strong vertical mixing. For CO, SO_2 and PM_{10} the highest average concentrations occurred at humidity above 80%. In another research, data on the concentrations of seven air pollutants (CH_4, NMHC, CO, CO_2, NO, NO_2 and SO_2) and meteorological variables (wind speed and direction, air temperature, relative humidity and solar radiation) were used to predict the concentration of ozone in the atmosphere using both multiple linear and principal component regression methods (Abdul-Wahab *et al.*, 2005). Results show while high temperature and high solar energy tended to increase the day time ozone concentrations, the pollutants NO and SO_2 being emitted to the atmosphere were being depleted. However, the model did not predict the night time ozone concentrations as precisely as it did for the day time. Asrari et al. (2007) studied effect of meteorological factors for predicting CO. Also variations in concentration of CO in different times have been shown in this study.

Li *et al.* (2014) presented the spatial and temporal variation of Air Pollution Index (API) and examined the relationships between API and meteorological factors during 2001–2011 in Guangzhou, China. Relationships were found between API and a variety of meteorological factors. Temperature, relative humidity, precipitation and wind speed were negatively correlated with API, while diurnal temperature range and atmospheric pressure were positively correlated with API in the annual condition. Yoo *et al.* (2014) mentioned that all of the pollutants show significant negative correlations between their concentrations and rain intensity due to washout or convection. The relative effect of the precipitation on the air pollutant concentrations was estimated to be: $PM_{10} > SO_2 > NO_2 > CO > O_3$, indicating that PM_{10} was most effectively cleaned by rainfall.

The present study exhibits diurnal, monthly and seasonal variations of concentration of CO and also a statistical model that is able to predict amount of CO. This is based on multiple linear and nonlinear regression techniques. Multiple Regression estimates the coefficients of the linear and nonlinear equations, involving one or more independent variables that best predict the value of the dependent variable (CO amount in this study). So, a large statistical and graphical software package (SPSS, Software Package of Social Sciences, V. 20) as one of the best known statistical packages has been used (Kinnear, 2002).

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Materials and methods

Study Area

The research area, Tehran is the capital of Iran located between 35° 35' N to 35º 50' N latitudes 51° 05' E to 51º 35' E Longitudes and the elevation is 1280 m above the mean sea level. Area of Tehran is 730 km². It has moderate climate and residential population was 8.5 million in 2011. There are about one million cars in city and many factories and industrials place around the city. So, Tehran is one of the most polluted cities in Iran and needs to carry out an ambient air quality analysis in this city.

Figure 1. *Two photos graphs from the same place in Tehran city showing impacts of air pollution during recent years. (right one in clean condition and left one in worse condition).*

Data and methodology

Four available sampling stations in the city called, Azadi, Gholhak, Tajrish and Sorkhe-Hesar, belong to Environmental Organization of Iran were selected to represent different traffic loads and activities. Actually Environmental Organization of Iran has a good database of pollution monitoring stations throughout Iran. Most of air pollutants are monitored using a chemiluminescent gas analyzer. Two models of devices namely, Ecotec and Enviro–Tech, have been used more for measuring of air pollution in the stations.

The sampling has been performed every 30 minutes daily for each pollutant during all months of 2009 and 2010. Among the measured data in the four stations CO was chosen. Then the averages were calculated for every hour, monthly and seasonally for the four stations by Excel. Finally averages of data at four stations were used to show air pollution situation as diurnal, monthly and seasonal graphs of concentration of CO in the city. Studying correlation of CO and meteorological parameters of synoptic station of city was the next step. The meteorological parameters studied include: temperature (min, max & mean), ratio of humidity (min, max & mean), precipitation, sunshine hours, dew point (mean), wind direction (max), wind speed (max & mean) and evaporation.

In the next step, daily average data at four stations in 2010 was considered as dependent variable for statistical analysis while daily data of meteorological parameters during this year have been selected as independent variables in SPSS programme has been used for this purpose and the multiple regression equations showed that the concentration of CO depends on the kind of meteorological parameters and also give an idea about the levels of these relations. The relationship between the dependent variable and each independent variable has been considered for both linear and nonlinear techniques. The significant values in output are based on fitting a single model. Also linear regression equation was made for different seasons maybe show those relationships which are not observed using annual data. The model for predicting CO was determined using two multiple regression modeling procedures of 'enter method' and 'stepwise method'. These two models were used for predicting CO in other Iranian cities showing good results (Masoudi et al., 2017; Masoudi and Gerami, 2017; Asadifard and Masoudi, 2018). In 'enter method' all independent variables selected are added to a single regression model. In 'stepwise' which is better, all variables can be entered or removed from the model depending on the significance. Therefore only those variables which have more influence on dependent variable are observed in a regression model.

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Results and Discussion

In Figs. 2, 3 and 4, the diurnal, monthly and seasonal variations in concentration of CO have been presented. As shown in fig 2 the high concentration of CO occurs in the Morning and beginning of night. Heavy traffic during this time may be responsible for this high concentration.

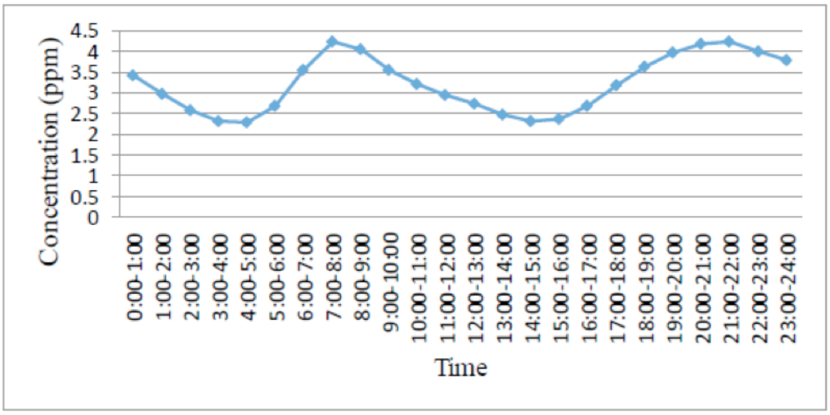

Figure 2. *Diurnal variation of CO concentration in Tehran.*

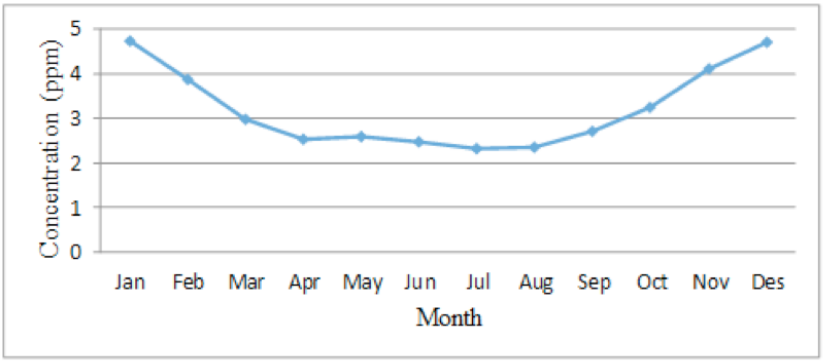

Figure 3. *Monthly variation of CO concentration in Tehran.*

Monthly concentration of CO showed the highest values in January and December and the least in July and August (Fig. 3). Seasonal concentration showed the highest values in autumn and the least in summer (Fig.4).

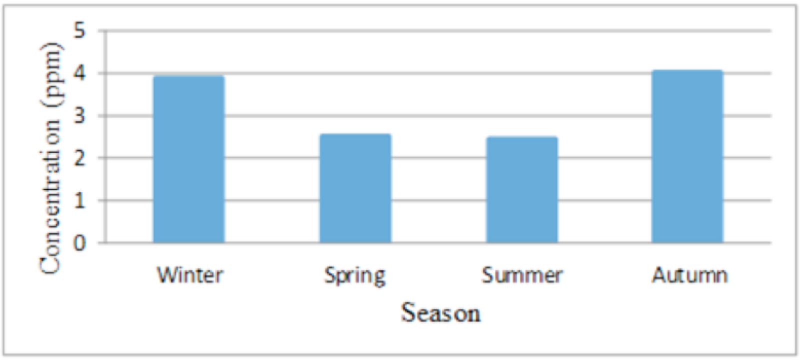

Figure 4. *Seasonal variation of CO concentration in Tehran.*

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Fortunately, all graphs showed that the concentrations of Carbon monoxide are lower than Primary Standards of Carbon monoxide (9 ppm) recommended by National Ambient Air Quality Standards (NAAQS) of USA and Iran. However these graphs are almost about annual and monthly but not about hourly conditions while these amounts is the Primary Standards for the latter condition. Therefore the real annual and monthly amounts of standards should be less than this amount and then it is assumed that some of these amounts in the figs. are more than the real standards which shows unhealthy condition. These results are almost in good agreement with results obtained in other cities like Shiraz (Ordibeheshti and Rajai poor, 2014) and Esfahan (Gerami, 2014) but differ from monthly and seasonal graphs of Ahvaz (Asadifard, 2014).

Table 1 shows the relationships between CO and other air pollutants. For example the concentration of CO shows negative correlation with O_3 and SO_2. On the other hand it shows positive correlation with NO_2, NOx and PM_{10} which are observed in emission of auto exhausts. Ozone is increased when sunlight is increased while other pollutants are related to traffic volume that is observed more in the morning and night time.

	PM10	NO2	NOX	O3	SO2
Pearson Correlation	.179**	.621**	**.816****	**-.546****	-.141**
Sig. (2-tailed)	.001	.000	.000	.000	.008
N	357	357	357	357	357

Table 1. *Correlation between air pollutants and CO.*

Therefore this negative relation is observed between ozone and other pollutant. Also SO_2 is related to industrial activity till to auto exhausts. It should be noted that all air pollution data (like: PM_{10}, NO_2, NO_X, O_3, and SO_2) were carried out in this research and all mentioned data were obtained from the main office of Environmental Organization of Iran. These results are almost in good agreement with other results regarding CO assessment in other cities like Ahvaz (Asadifard, 2014) and Esfahan (Gerami, 2014). Correlation coefficients significant at the 0.05 level are identified with a single asterisk (significant), and those significant at 0.01 level are identified with two asterisks (highly significant).

Table of analysis of variance (Table 2) shows that both regressions of 'enter' and 'stepwise' methods for annual condition are highly significant, indicating a significant relation between the different variables.

	Model	Sum of Squares	df	Mean Square	F	Sig.
Analysis of variance (a)	Regression	465.465	12	38.789	26.829**	.000
	Residual	506.028	350	1.446		
	Total	971.493	362			
	Predictors: (Constant), Rain, Wind direction (max), Wind speed (max), Wind speed (mean), Temperature (max), Temperature (min), Temperature (mean), Sunshine Hours, Ratio of Humidity (min), Ratio of Humidity (max), Ratio of Humidity (mean), Dew point. Dependent Variable: CO					

	Model	Sum of Squares	df	Mean Square	F	Sig.
Analysis of variance (b)	Regression	462.737	6	77.123	53.966**	.000
	Residual	508.756	356	1.429		
	Total	971.493	362			
	Predictors: (Constant), Wind Speed$_{(mean)}$), Dew point, Ratio of Humidity (mean), Temperature (mean), Wind speed (mean), Wind direction (max) Dependent Variable: CO					

Table 2. *Tables of analysis of variance for both regressions of 'enter' (a) and 'stepwise' (b) methods for annual condition.*

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In Tables 3 the coefficients of CO pollution model and regression lines for both enter and stepwise methods in annual condition are presented. Regression coefficients, standard errors, standardized coefficient beta, t values, and two-tailed significance level of t have been shown in the Tables.

The linear regression equations show that the CO pollution depends on the meteorological parameters and also give an idea about the levels of relations. The linear model equations after using 'enter method' and 'stepwise method' for annual condition are:

CO amount (ppm) using 'enter method' for annual condition = 10.431+(-.484) $Temperature_{(mean)}$ + (.103) $Temperature_{(max)}$ + (.155) $Temperature_{(min)}$ + (-.003) Ratio of humidity $_{(min)}$ + (-.008) Ratio of $Humidity_{(max)}$ + (-.051) Ratio of $Humidity_{(avg)}$ + (-.003) Rain + (.018) Sunshine Hours + (.003) Wind $direction_{(max)}$ + (-.045) Wind $speed_{(max)}$ + (-.117) Wind $speed_{(mean)}$ + (.209) Dew point R= 0.692 (significant at 0.01).

CO amount (ppm) using 'stepwise method' for annual condition = 10.078 + (-.117) Wind speed $_{(mean)}$ + (-.047) Wind speed $_{(max)}$ + (.003) Wind direction $_{(max)}$ + (-.222) Temperature $_{(mean)}$ + (-.059) Ratio of Humidity $_{(mean)}$ + (.202) Dew point R= 0.690 (significant at 0.01).

Results of linear regression model show that wind speed, temperature $_{(mean)}$ and ratio of humidity have reverse effect on concentration of CO. So that, when these parameters increase, the concentration of CO decreases. While, when dew point and wind direction increase (western wind), the concentration of CO significantly increases (Table 3b). Other meteorological parameters show different effects on CO amounts although these results are not significant. For example, rainfall has reverse effect on concentration of CO while temperature (max and min) shows positive relationship (Table 3a).

	Model	Unstandardized Coefficients		Standardize Coefficients	t	Sig.
		B	Std. Error	Beta		
Coefficient (a)	(Constant)	10.431	1.080		9.657	.000
	Temperature (mean)	-.484	.576	-3.240	-.840	.401
	Temperature (max)	.103	.290	.743	.354	.723
	Temperature (min)	.155	.292	.966	.532	.595
	Wind speed (mean)	-.117	.034	-.202	-3.415**	.001
	Wind speed (max)	-.045	.016	-.167	-2.754**	.006
	Wind direction (max)	.003	.001	.121	2.778**	.006
	Ratio of Humidity (mean)	-.051	.019	-.638	-2.680**	.008
	Ratio of Humidity (max)	-.008	.009	-.107	-.878	.381
	Ratio of Humidity (min)	-.003	.013	-.027	-.203	.840
	Rain	-.003	.042	-.004	-.082	.934
	Dew point	.209	.034	.644	6.094**	.000
	Sunshine Hours	.018	.028	.039	.648	.517
Coefficient (a)	(Constant)	10.078	.962		10.474	.000
	Wind speed (mean)	-.117	.034	-.202	-3.446**	.001
	Dew point	.202	.032	.621	6.368**	.000
	Ratio of Humidity (mean)	-.059	.012	-.737	-5.066**	.000
	Temperature (mean)	-.222	.028	-1.483	-7.984**	.000
	Wind speed (max)	-.047	.016	-.173	-2.945**	.003
	Wind direction (max)	.003	.001	.116	2.770**	.006
Dependent Variable: CO						

Table 3. *Coefficients of CO pollution model and regression lines for both enter* (a) *and stepwise* (b) *methods for annual condition.*

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These results are almost in good agreement with other results regarding CO measurements in other Iranian cities like Shiraz (Ordibeheshti and Rajai poor, 2014) and Esfahan (Gerami, 2014) and Ahvaz (Asadifard, 2013) and other regions (Elminir, 2005; Li *et al.* ,2014). Actually some of these events happen in real condition. Increasing in rainfall, wind speed and temperature (inversion happens in low temperatures) usually decrease most of air pollutants (Asrari et al., 2007).

The values and significance of R (multiple correlation coefficient) in both equations show capability of them in predicting CO amount. The amount of Adjusted R^2 in both equations is almost 0.47 showing that different parameters can calculate almost 47% variability of CO. This result indicates for predicting most of air pollutants like CO, we should take into consideration consumption of fossil fuel especially in motor vehicles. Half of emission of (VOC) Hydrocarbons and NOx in cities is produced by Motor vehicles. The automobile exhaust produces 75% of total air pollution. Release poisonous gases of CO (77%), NOx (8%) and Hydrocarbons (14%) (Sharma, 2001). On the other hand, R in enter method (0.692) is almost equal to stepwise method (0.690), showing no different significant. Therefore, second equation based on stepwise method can be used to predict CO in the city instead of using first equation which needs more data. On the other hand, no difference between the two R values indicates that the excluded variables in second equation have less effect on measuring of CO in the city.

Beta in Table 3 shows those independent variables (meteorological parameters) which have more effect on dependent variable (CO). The beta in the both Tables 3 shows a highly significant effect of some variables like Temperature and ratio of humidity compared to other meteorological parameters for measuring the CO which is close to the results of Masoudi *et al.* (2014) for ozone. Parameter Sig (P-value) from Table 4 shows amount of relation between CO and meteorological parameters. For example, Table 3b shows that wind speed (mean) has higher effect on CO than wind direction.

On the other hand, in Table 4 the linear regression equations of CO amount are presented for both enter and stepwise methods for different seasonal condition. Results show all of the seasonal models are significant. Stepwise methods show those meteorological parameters which are most important during these seasons for estimating the pollution. Among the models, winter models have the highest R while R of spring models shows the least. R amounts in enter methods of autumn and winter models are higher than in annual models, also indicating that relations between the pollutant and meteorological parameters are stronger than whole year during these seasons. These results are almost in good agreement with other results regarding CO assessment for different seasonal condition in other Iranian cities like Esfahan (Gerami, 2014) and Ahvaz (Asadifard, 2013) but differ a little from the results of Shiraz (Ordibeheshti and Rajai poor, 2014).

Also the nonlinear multiple regression equation of CO amount using parameters of linear stepwise method for annual condition is calculated which is significant:

CO amount (ppm) using nonlinear regression for annual condition = 6.128 × (Wind speed (mean) $^{-.476}$ + 2.820 × (2.718$^{(-.020\times \text{ Dew point})}$) + .551 × (Ratio of Humidity (mean) $^{.485}$) + 4.461 × (.976 $^{\text{Temperature (mean)}}$) + 2.718 $^{(.543+ (5.178/ \text{ Wind speed (max)})}$ + 3.342 + (-28.316/ Wind direction (max) R^2= 0.543 (significant at 0.01)

To test which annual model is better to use, RMSE (Root Mean Square of Error) is calculated for different linear models of enter and stepwise and nonlinear model. Predicted amounts using the different annual models for 30 days during 2011 are calculated and compared with observed data during those days using RMSE equation:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(O_{obs-}O_{pre})^2}{n}} \qquad [1]$$

Where: O_{obs}: observed CO value and O_{Pre}: predicted CO value using model.

The values of RMSE in both linear models of enter (1.71) and stepwise (1.69) show capability of them in predicting CO amount compared to nonlinear model value (3.6). This result which is the same as the results of Asadifard (2013) and Masoudi *et al.* (2014) indicates for predicting most of air pollutants like CO, we may take into consideration only linear models of stepwise which need less data compared to enter model and also its calculation is easier than nonlinear model.

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Season	Enter method	R	Stepwise method	R
Spring	= -.093 + (-.723) Tmean + (.433) Tmax + (.319) Tmin + (-.042) WSmean + (-.002) WSmax + (.001) WDmax + (.032) RHmean + (-.011) RHmax + (.040) RHmin + (-.076) Rain + (-.049) Dew + (.021) sunshine	.508 (significant at 0.01)	= 2.202 + (-.041) WSmean + (.031) sunshine	.343 (significant at 0.05)
Summer	= 1.957 + (.487) Tmean + (-.258) Tmax + -.214) Tmin + (-.058) WSmean + (.009) WSmax + (.001) WDmax + (.078) RHmean + (-.019) RHmax + (-.056) RHmin + (-1.759) Rain + (-.047) Dew + (.005) sunshine	.636 (significant at 0.01)	= 2.497 + (-1.476) Rain + (-.048) WSmean + (.001) WDmax + (-.008) RHmax	.518 (significant at 0.01)
Autumn	= 13.477 + (-.102) Tmean + (-.031) Tmax + (-.249) Tmin + (-.371) WSmean + (.029) WSmax + (.006) WDmax + (.003) RHmean + (-.043) RHmax + (-.059) RHmin + (.030) Rain + (.370) Dew + (.034) sunshine	.707 (significant at 0.01)	= 6.309 + (-.112) Tmin + (-.346) WSmean + (.006) WDmax	.641 (significant at 0.01)
Winter	= 9.147 + (-.565) Tmean + (.288) Tmax + (.020) Tmin + (-.141) WSmean + (.001) WSmax + (.001) WDmax + (-.051) RHmean + (-.019) RHmax + (.010) RHmin + (.009) Rain + (.249) Dew + (.011) sunshine	.729 (significant at 0.01)	= 4.057+ (-.060) Tmin + (-.138) WSmean	.665 (significant at 0.01)

Note: Tmean=Temperature (mean) , Tmax =Temperature (max), Tmin=Temperature (min), WSmean = Wind speed (mean), WSmax =Wind speed (max), WDmax =Wind direction (max), RHmean = Ratio of Humidity (mean), RHmax =Ratio of Humidity (max), RHmin= Ratio of Humidity (min), Dew =Dew point, sunshine= Sunshine Hours.

Table 4. *CO amount (ppm) using two methods of enter and stepwise for different seasonal condition.*

Conclusions

In the current research air quality analyses for tehran, capital of iran, are conducted for co. Tehran is one of the most polluted cities in iran. Hence a need was felt to carry out an ambient air quality analysis in this city. Results show there is significant relationship between co and some meteorological parameters. Based on these relations, different multiple linear and nonlinear regression equations for co for annual and seasonal conditions were prepared. Results show among different prediction models, stepwise model is the best option. Also different variations in concentration during day, months and seasons were observed. It is assumed some of the amounts for concentration of co especially during morning and night times of cold months are more than the primary standards showing unhealthy condition.

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