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Status of PM_{10} as an air pollutant and prediction using meteorological indexes in Shiraz, Iran

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Abstract. In the present study research air quality analyses for PM_{10}, were conducted in Shiraz, a city in the south of Iran. The measurements were taken from 2011 through 2012 in two different locations to prepare average data in the city. The averages concentrations were calculated for every 24 hours, each month and each season. Results showed that the highest concentration of PM_{10} occurs generally in the night while the least concentration was found at the afternoon. Monthly concentrations of PM_{10} showed highest value in August, while least value was found in January. The seasonal concentrations showed the least amounts in autumn while the highest amounts in summer. 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, evaporation, dew point and rainfall were considered as independent variables. The relationships between concentration of pollutant and meteorological parameters were expressed by multiple linear regression equations for both annual and seasonal conditions SPSS software. RMSE test showed that among different prediction models, stepwise model is the best option.

Keywords: PM_{10}; air pollution; meteorological parameters; regression model

1. 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, Fleischer *et al.* 2014, Majidnezhad 2014). 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).

Particulate Matters (PM) is one of the seven Conventional (criteria) pollutants (including SO_2, CO, 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 (Wang *et al.* 2015, Asghari and Nematzadeh 2016, Khader *et al.* 2016). Concentration on these pollutants, especially in cities, has been regulated by Clean Air Act since 1970 (Cunningham and Cunningham 2002). Particulate pollutants may be classified according to their nature and size as

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follows: smoke, mist, spray, fumes, soot and dust which is main part of PM. Dust is composed of fine solid particulates and their size range from 1 to 100 micron.

The presence of pollutants in the atmosphere, causes a lot of problems, thus the study of pollutant's behavior is necessary. Health effects of PM_{10} depend upon size. Some of main problems are such as: their toxicity, lung damages (like silicosis, black lung disease), mutagenic and carcinogenic, Irritation (eye, nose and throat) and heart damage (Lung not as efficient, heart must work harder to get oxygen).

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 PM 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 $\leq$ 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 showed that 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.

Wang *et al.* (2015) studied on air quality in Chongqing, the largest mountainous city in China. From 2002 to 2012, statistical analysis of SO_2, PM_{10} and NO_2 concentrations is conducted. The analysis of Pearson correlation indicated that concentrations of SO_2, PM_{10} and NO_2 were positively correlated with atmospheric pressure, but negatively with temperature and wind speed. The analysis of Multi-Pollutant Index (MPI) showed that air quality in Chongqing was serious.

The climatology of tropospheric ozone at Irene was investigated using SHADOZ network data to assess the correlation between the observed seasonal ozone enhancement and meteorological factors (Mulumba *et al.* 2015). A multiple linear regression model was used to provide seasonal correlation between ozone and temperature and relative humidity. All seasons display strong regression coefficients between ozone and temperature. Similar trends are also observed for relative humidity and ozone concentrations in autumn, spring and summer.

Statistical modeling of ozone in Shiraz and PM_{10} in Tehran were studied by Masoudi *et al.* (2016a, b). According to the results obtained through multiple linear regression analysis, for seasonal and annual conditions there were significant relationships between ozone and PM_{10} levels and the meteorological factors in both cities.

The presents study exhibits diurnal, monthly and seasonal variations of concentration of PM_{10} and also a statistical model that is able to predict amount of PM_{10}. This is based on multiple linear regression techniques. Multiple Regression estimates the coefficients of the linear equations, involving one or more independent variables that best predict the value of the dependent variable (PM_{10} 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).

2. Materials and methods

2.1 Study area

The research area, Shiraz is the biggest city in the southern part of Iran (Fig. 1) located around 29° 30' N and 52° 30' E and the elevation is about 1500 m above the mean sea level. Annual precipitation of Shiraz is about 330 mm. It has semi-arid climate and residential population was 1,500,000 in 2010. There are lots of cars driven in city and also many factories and industrials around it. So, Shiraz is one of the most polluted cities in Iran and needs to carry out an ambient air quality analysis in this city.

2.2 Methodology

Two available sampling stations in the city called, Setad and Darvazah-Kazarun, belong to

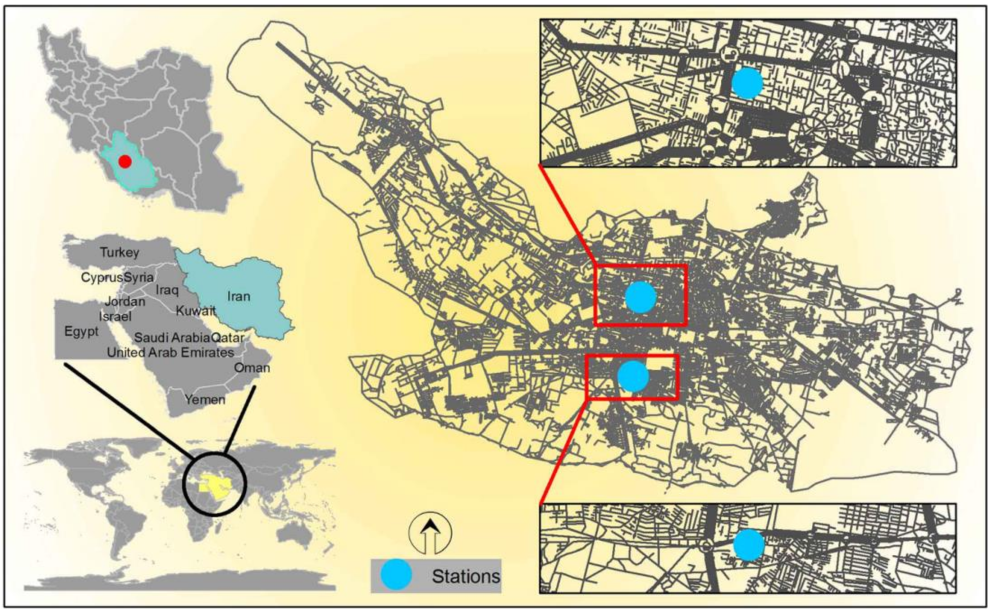


Fig.1 The study area of Shiraz, Iran and location of the air quality monitoring stations

Environmental Organization of Iran were selected to represent different traffic loads and activities.

The sampling has been performed every 30 minutes daily for each pollutant during all months of 2011 and 2012. Among the measured data in the two stations carbon monoxide was chosen. Then the averages were calculated for every hour, monthly and seasonally for the three stations by Excel. Finally averages of data at two stations were used to show air pollution situation as diurnal, monthly and seasonal graphs of concentration of carbon monoxide in the city.

studying correlation of carbon monoxide and metrological parameters of synoptic station of city was the next step. The metrological parameters studied include: temperature (min, max & mean), ratio of humidity (min, max), precipitation, sunshine hours, wind direction (max), wind speed (max & mean) and evaporation.

In the next step, daily average data at two stations in 2012 for was considered as dependent variable in statistical analysis while daily data of meteorological parameters during this year were selected as independent variables in SPSS programme and the multiple regression equations showed that the concentration of carbon monoxide depends on the kind of meteorological parameters and also give an idea about the levels of these relations. The relationship between the dependent variables and each independent variable has been considered for linear technique. 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 carbon monoxide was determined using two multiple regression modeling procedures of ‘enter method’ and ‘stepwise method’. 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.

3. Results and discussion

In Figs. 2, 3 and 4, the diurnal, monthly and seasonal variations of concentration in PM_{10} have been presented. As shown in Fig. 2 the high concentration of PM_{10} occurs in the night while the least concentration occurs in the afternoon. Monthly concentration of PM_{10} showed the highest

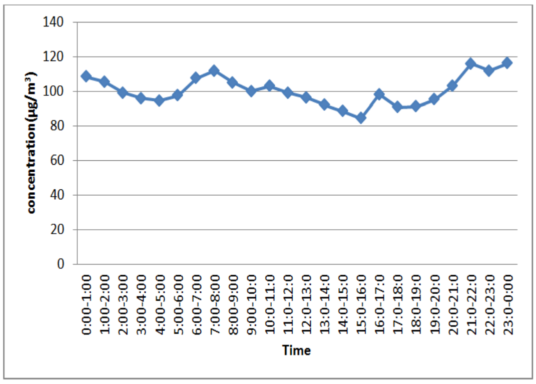


Fig. 2 Diurnal variation of PM_{10} concentration in Shiraz (2011-2012)

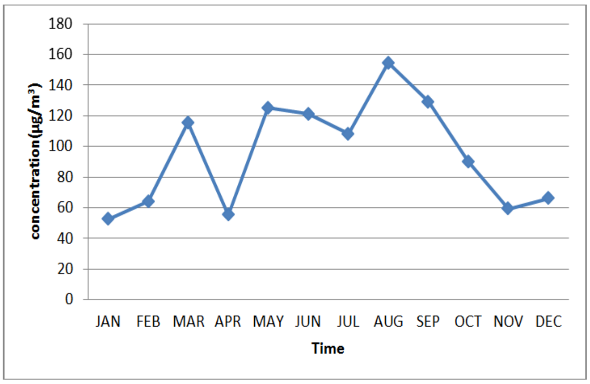


Fig. 3 Monthly variation of PM_{10} concentration in Shiraz (2011-2012)

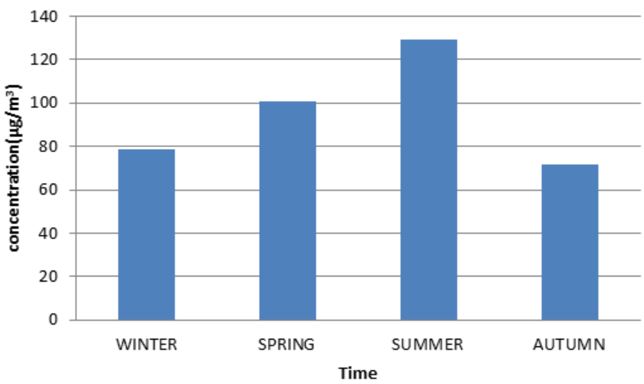


Fig. 4 Seasonal variation of PM_{10} concentration in Shiraz (2011-2012)

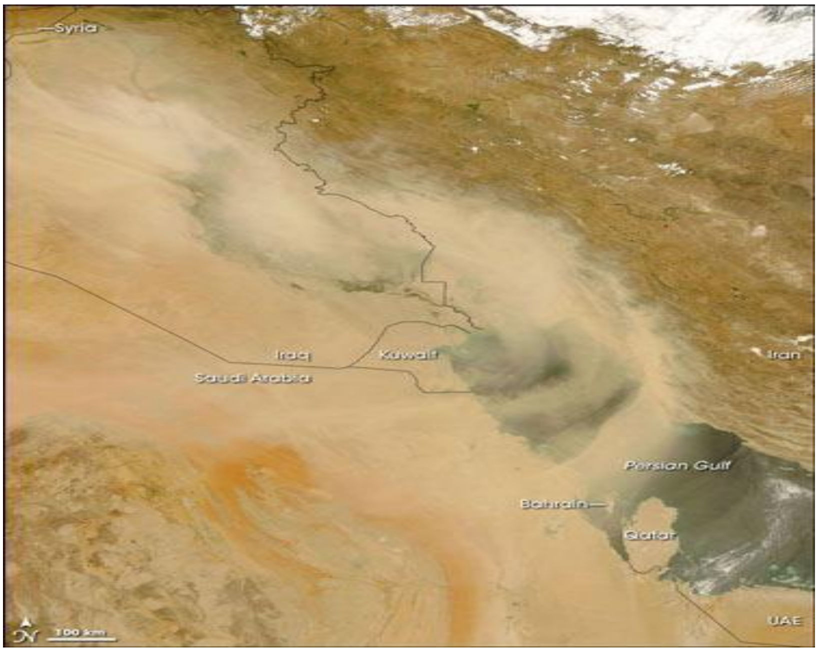
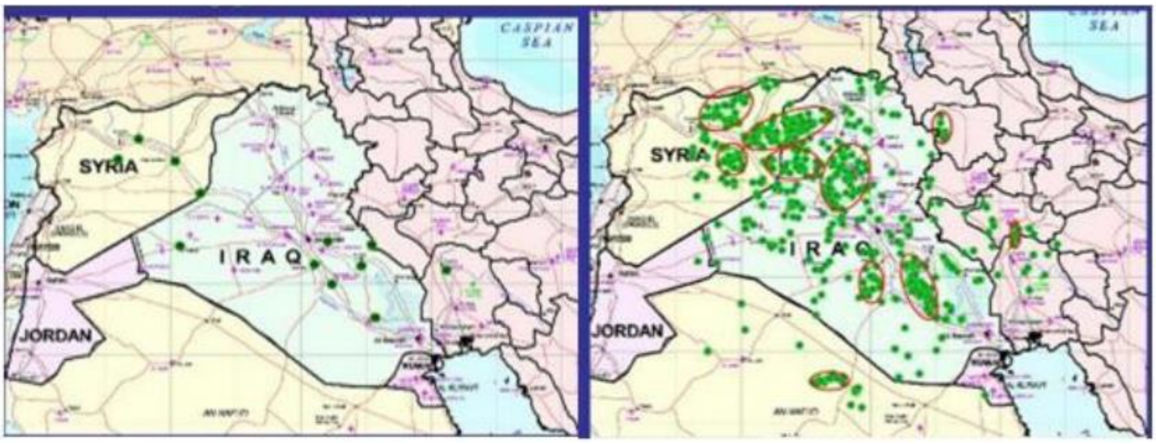


Fig. 5 Satellite image shows origin and source of most of the dust pollution carried by wind in Iran is in dry land of western neighbors especially in Iraq country



(a) 1987 (b) 2008

Fig. 6 Two maps from the western neighbors of Iran showing the number of critical points for detachment of soil particles in wind erosion process have been increased especially in Iraq country during recent years

values in August and the least in January (Fig. 3). Seasonal concentration of PM_{10} showed the highest values in summer and the least in autumn (Fig. 4). These results are almost in good agreement with results obtained in other cities like Tehran (Behzadi and Sakhaei 2014), Esfahan (Gerami 2014) and Ahvaz (Asadifard 2013).

Precipitation is very low and evaporation is very high during these times especially in the end of spring and beginning of summer, therefore soil is very dry allowing for wind erosion and carrying soil suspended particles to long distances. Origin and source of most of the particle matters during this period is in dry lands of western neighbors especially in some critical zones of Iraq country (Fig. 5).

Unfortunately, all graphs showed that the concentrations of PM_{10} are upper than Primary Standards of PM_{10} (50 µg/m^3) recommended by National Ambient Air Quality Standards (NAAQS) of USA and Iran, respectively. High amounts of PM_{10} are observed more during recent years in western and southern parts of Iran as it said above the main source of this pollution is arid lands of Iraq. Especially after wars of USA with this country the number of critical zones for detachment of soil particles in wind erosion process have been increased because of mismanagements and forgetfulness of doing remedial measures and conservation against wind erosion (Fig. 6). Currently Ahvaz, a big city in the south western part of Iran, is introduced as the worst polluted city of the world according to a survey by the World Health Organization in 2011 because of high concentration of dust during year (Guinness World Records 2013). Increasing of PM causes different impacts and problems like occurring and increasing of related illness to this pollution such as cancer and lung damages during recent years which have been recorded by Health offices of region.

Table 1 shows the relationships between PM_{10} and other air pollutants. For example the concentration of PM_{10} shows negative correlation with NO_X and NO_2 while it shows positive correlation with O_3 and SO_2.

These results are not the same as results regarding PM_{10} assessment in other Iranian cities like Tehran (Behzadi and Sakhaei 2014) and Ahvaz (Asadifard 2014) but they are in good agreement with 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 in annual condition are highly significant, indicating a significant relation between the different variables.

Table 1 Correlation between air pollutants and PM_{10}

	CO	NO_2	O_3	NO_X	SO_2
Pearson Correlation	.012	-.241**	.162*	-.220**	.228**
Sig. (2-tailed)	.855	.000	.016	.001	.001
N	221	221	221	221	221

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

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1230386.019	11	111853.274	6.683	.000**
Residual	5757502.268	344	16736.925		
Total	6987888.287	355			

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), Evaporation, Dependent Variable: PM_{10}

Table 2 Continued Analysis of variance, (b)

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1183183.705	3	394394.568	23.916	.000**
Residual	5804704.582	352	16490.638		
Total	6987888.287	355			

Predictors: (Constant), Sunshine Hours, Ratio of Humidity (min), Ratio of Humidity (max), Wind direction (max), Dependent Variable: PM_{10}

Table 3 Coefficients of PM_{10} pollution model and regression lines for both enter (a) and stepwise (b) methods for annual condition, Coefficients (a)

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	136.263	97.538		1.397	.163
Temperature (min)	1.972	3.834	.108	.514	.607
Temperature (max)	.106	3.844	.007	.027	.978
Temperature (mean)	-.661	4.030	-.042	-.164	.870
Ratio of Humidity (min)	.621	1.179	.069	.526	.599
Ratio of Humidity (max)	-1.596	.766	-.243	-2.083	.038*
Rain	-.988	1.930	-.033	-.512	.609
Sunshine Hours	-.880	3.870	-.018	-.227	.820
Evaporation	4.339	5.042	.131	.861	.390
Wind speed (max)	8.543	4.829	.133	1.769	.078
Wind direction (max)	.096	.082	.061	1.169	.243
Wind speed (mean)	-4.698	9.971	-.037	-.471	.638

Table 3 Continued, Coefficients (b)

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	149.235	48.177		3.098	.002
Ratio of Humidity (max)	-1.451	.501	-.221	-2.893	.004**
Wind speed (max)	8.141	3.194	.127	2.549	.011*
Temperature (min)	3.030	1.394	.166	2.174	.030*

Dependent Variable: PM_{10}

In Table 3, the coefficients of PM_{10} 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 PM_{10} 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

PM_{10} amount (µg/m^3) using 'enter method' for annual condition = 136.263+ (1.972) Temperature$_{(min)}$ + (.106) Temperature$_{(max)}$ + (-.661) Temperature$_{(mean)}$ + (.621) Ratio of humidity$_{(min)}$ + (-1.596) Ratio of Humidity$_{(max)}$ + (-.988) Rain + (-.880) Sunshine Hours + (.096) Wind direction$_{(max)}$ + (8.543) Wind speed$_{(max)}$ + (-4.698) Wind speed$_{(mean)}$ + (4.339) Evaporation R= 0.420 (significant at 0.01)

PM_{10} amount (µg/m^3) using 'stepwise method' for annual condition = 149.235+ (8.141) Wind speed$_{(max)}$ + (-1.451) Ratio of Humidity$_{(max)}$ + (3.030) Temperature$_{(min)}$ R=0 .411 (significant at 0.01)

Results of linear regression model show that ratio of humidity (max) has reverse effect on concentration of PM_{10}. So that, when this parameter increases, the concentration of PM_{10} decreases. While, when temperature$_{(min)}$ and wind speed increase the concentration of PM_{10} significantly increases (Table 3b). Other meteorological parameters show different effects on PM_{10} amounts although these results are not significant. For example Sunshine hours and rainfall have reverse effect on concentration of PM_{10} (Table 3a). These results are almost in good agreement with other results regarding PM_{10} measurements in other Iranian cities like Tehran (Behzadi and Sakhaei 2014) and Esfahan (Gerami 2014) and Ahvaz (Asadifard 2013) and other regions (Sánchez-Ccoyllo and Andrade 2002, Elminir 2005, Li *et al.* 2014).

Actually some of these events happen in real condition. Increasing in rainfall and ratio of humidity usually decrease most of air pollutant (Asrari *et al.* 2007). But with increasing Wind speed, we expect dust amounts to be increased. The effect of increasing wind speed and temperature (max and min) and decreasing humidity and rainfall can be seen during the warm months that increase wind erosion in the west of region that permit detachment of soil particles from soil which have been transported as suspended particles by wind.

The values and significance of R (multiple correlation coefficient) in both equations show capability of them in predicting PM_{10} amount. The amount of Adjusted R^2 in both equations is almost 0.167 showing that different parameters can calculate almost 16% variability PM_{10}. This result indicates for predicting most of air pollutants like PM_{10}, we should take into consideration natural and anthropogenic sources of their production such as consumption of fossil fuel and wind erosion process. On the other hand, R in enter method (0.420) is almost equal to stepwise method (0.411), showing no difference. Therefore, second equation based on stepwise method can be used to predict PM_{10} 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 PM_{10} in the city.

Beta in Table 3 shows those independent variables (meteorological parameters) which have more effect on dependent variable PM_{10}. The beta in the both Table 3 shows a highly significant effect of some variables like ratio of humidity$_{(max)}$ and temperature$_{(max)}$ compared to other meteorological parameters for measuring the PM_{10} which is close to the results of Asadifard (2013), Gerami (2014), Behzadi and Sakhaei (2014) and Masoudi *et al.* (2014). Parameter Sig (P-value) from Table 3 shows amount of relation between PM_{10} and meteorological parameters. For example, Table 3a shows that wind direction has higher effect on PM_{10} than wind speed.

On the other hand, in Table 4 the linear regression equations of PM_{10} amount are presented for both enter and stepwise methods in different seasonal condition. Almost all of the models except summer model of stepwise are significant. Stepwise methods show those meteorological

Table 4 PM_{10} amount (µg/m[3]) using two methods of enter and stepwise for different seasonal condition

Season	Enter method	R	Stepwise method	R
Winter	=153.236+ (.696) Tmin + (3.842) Tmax + (-.784) RHmin + (-.461) RHmax + (-.845) R + -(8.116) SH +(6.931) E + (1.869) WSmax +(-.114) WDmax + (-2.599) WSmean	.638 (significant at 0.01)	= 110.944+ (6.657) Tmax + (-6.188) SH + (-1.084) RHmax	.299 (significant at 0.05)
Spring	=344.140 + (6.181)Tmin + (1.024) Tmax + (-3.205) Tmean+(-2.769) RHmin + (-.769) RHmax+(-31.510) R + (-26.190) SH +(4.359) E + (17.669) WSmax +(-.155) WDmax + (.135) WSmean	0.481 (significant at 0.05)	= 99.171+ (9.848) Tmin + (-18.669) SH + (17.115) WSmax	.451 (significant at 0.05)
Summer	= -177.632+ (-15.873) Tmin+ (16.415) Tmax + (-7.836) RHmin + (2.645) RHmax + (-4.247) SH + (2.101) E + (4.384) WSmax + (.044) WDmax + (-4.208) WSmean	.220 (significant at 0.05)	Not prepared by software showing no significance relationship	
Autumn	= 148.001+ (-1.261) Tmin+ (3.159) Tmax + (-.089) RHmin + (-.858) RHmax + (.225) R +(-2.679) SH + (.795) E + (-1.961) WSmax + (-.035) WDmax + (-4.120) WSmean	.831 (significant at 0.01)	= 122.378 + (-.818) RHmax + (2.288)Tmax +(-6.810) WSmean	.813 (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), SH= Sunshine Hours, R=Rainfall, E=Evaporation

parameters which are most important during these seasons for estimating the pollution. Among the models, autumn models have the highest R while the R of summer models shows the least. R in all of seasonal models except summer models and stepwise of winter 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 differ some what with other results regarding PM_{10} assessment in other Iranian cities of Tehran (Behzadi and Sakhaei 2014) and Esfahan (Gerami 2014) and Ahvaz (Asadifard 2013).

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. Predicted amounts using the different annual models for 30 days during 2011 are calculated and compared with observed data during those days using RMSE Eq. (1)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Oobs - Opre)^2}{n}} \tag{1}$$

O_{obs}: observed PM_{10} value, O_{pre}: predicted PM_{10} value using model

The values of RMSE in both linear models of enter (88.12) and stepwise (85.93) show capability of stepwise model in predicting PM_{10} amount compared to enter model. This result which is the same as the results of Asadifard (2013), Gerami (2014), Behzadi and Sakhaei (2014) and Masoudi *et al.* (2014) indicates for predicting most of air pollutants like PM_{10}, we may take into consideration only linear models of stepwise which need less data and also its calculation is easier than enter model.

4. Conclusions

Particulate Matters (PM) is one of the seven Conventional (criteria) pollutants (including SO2, CO, particulates, hydrocarbons, nitrogen oxides, O3 and lead). In the current research, air quality analyses for Shiraz, were conducted for PM_{10}. Shiraz is one of the polluted cities in Iran. Hence a need was felt to carry out an ambient air quality analysis in the city. Results showed there were significant relationships between PM_{10} and some meteorological parameters. Based on these relations, different multiple linear regression equations for PM_{10} for annual and seasonal conditions were prepared. Results showed that among different prediction models, stepwise model was the best option. Also, different variations in concentration during day, months, and seasons were observed. So, in regarding to polluted situation in study area, Researches must be done. Also, 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. Therefore, as far as possible, some strategies like reduction in the number of imported vehicles and the proportion of distance traveled by vehicles etc can be applied to implement the pollution reduction.

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