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Original Research

Investigating the Relationship between Air Pollutants and Meteorology: A Canonical Correlation Analysis

Abdulmuhsin S. Shihab*

Mosul University, Environmental Research Centre, Mosul, IRAQ

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Abstract

In order to characterize the most important meteorological parameters that determine air pollutants' behavior, canonical correlation analysis was conducted. Meteorological parameters include temperature, rainfall, relative humidity, wind speed and wind direction. On the other hand, air pollutants include O_3, NO, NO_2, SO_2, CO, CH_4, non-methane hydrocarbons (NMHC) and PM_{10}. The study was conducted in Mosul city, northern Iraq. The data were collected using a fixed monitoring station and ultrasonic weather station placed on the side of a separate main heavy traffic road. The first two canonical functions extracted by the analysis explained more than 95% of the variance in air pollutants. The first canonical function shows high canonical correlation coefficient between its pair canonical variates (0.849, $p<0.001$), versus 0.445 ($p<0.001$) between the pair variates of the second function. The results of the canonical correlation analysis highlighted that temperature was the major contributor in the explanatory capacity of meteorological parameters compared with the other parameters. On the other hand, ozone had a major contribution to the explanatory capacity of air pollutants compared with the other pollutants. The major conclusion is the ability of canonical correlation analysis to reduce the input parameters mainly to temperature and ozone in this study.

Keywords: canonical correlation analysis, air pollutants, meteorological parameters, canonical variate, canonical loading, temperature, ozone

Introduction

Air pollution has gained a great concern due to its adverse health impacts [1, 2]. Urban areas suffer from air pollution due to human activities especially consuming fuel in transportation and industrialization, as well as particulate matter transported by wind. Air pollutants are emitted away from the source to the atmosphere and can exist in it from hours to several days according to meteorological parameters, which is governed them [3].

Meteorological parameters may be a saving agent from pollutants by dispersing them or it may be a bad agent by seizing them. The concentration of air pollutants depends not only on the pollution source emissions, but meteorological factors intensively influence the variations in pollutants concentrations

*e-mail: mss_qzz@uomosul.edu.iq

[4, 5]. The source of emission may be controlled when the levels of pollutants are exceeded, while meteorological conditions cannot be controlled [6, 7]. Furthermore, most of the variations in daily air quality can be interpreted by the meteorological conditions [8]. Meteorological parameters like temperature also aid in the chemical reactions of pollutants [9]. Therefore, it is necessary to study the relationships between air pollutants and meteorological parameters. It will designate the meteorological parameters which is more effective on air quality variation, in addition to detect the pollutants that more influenced by meteorology. This will help in the monitoring process of air pollutants.

Numerous studies had been conducted on the relationship between a single selected air pollutant and meteorological factors. Some researchers used multiple regression to analyze the effect of meteorological parameters on air pollutants. Turk and Kavraz [10] investigated the relationship between air pollutants (particulate matter and SO_2) and meteorological parameters (temperature, wind speed and humidity) in Trabzon city, Turkey. They found a reverse relationship with a coefficient of determination from 88-97%. Hadei et al. [11] used statistical models to investigate the relationship between concentration of each air pollutant as response and meteorological factors as predictor variables in their study in Tehran/ Iran. They concluded that meteorological factors affect air pollutants concentration in general. Moreover, Hou and Xu [12] in Beijing/ China constructing a complex nonlinear model to study the relationship between air pollutants individually and meteorological parameters. The results highlighted that temperature, relative humidity and visibility are the most contributors to $PM_{2.5}$ concentration.

Furthermore, correlation matrix or bivariate correlation was used by most of the researchers to study the relationships between air pollutants and meteorological parameters individually. Zyromski et al. [13] created a correlation matrix to study the bivariate relationships between air pollutants and selected meteorological factors in Poland. They found that wind speed had the main effect on the concentration of air pollutants among other meteorological parameters. Habeebullah et al. [14] also used correlation coefficient to investigate the interaction between air pollutants and meteorological parameters in Makkah/ Saudi Arabia. They concluded that meteorological factors contribute to the levels of air pollutants in addition to the amount of pollutants emitted. The results of correlation analysis conducted by Ansari and Ehrampoushb [15] in their study in Tehran/Iran, showed a weak positive correlation between PM2.5 versus average monthly temperature and average monthly humidity. Kermani et al. [16] in Karaj/Iran and Kermani et al. [17] in Isfahan/Iran, found that temperature, relative humidity and air pressure were positively correlated with $PM_{2.5}$ concentration using correlation matrix, in their studies in Karaj and Isfahan, Iran. On the other hand, the rate of cloud cover, dew point and ultraviolet were negatively correlated with $PM_{2.5}$.

The survey of air pollutants and meteorological parameters, as two groups, always includes large amount of data collected by monitoring stations. An efficient tool is required to treat these two groups of variables and to find the overall correlation between them. Canonical correlation analysis (CCA) appears the most suitable tool to study the relationship between two sets of variables, one set as a dependent and the other independent. It is a technique built on determining two linear combinations, one for each set of variables, and then maximizing the correlation coefficient between them as a whole [18]. CCA allows further understanding of the relationship between air pollutants and meteorological parameters than multiple regression of one dependent variable. CCA has been applied successfully in many fields like water quality, veterinary medicine, hospitality and tourism and agriculture. Additionally, it had been used to analyze relationships between air quality and meteorology in a limited way [19, 20].

The aims of this research are: (a) to determine the interrelationship between 8 air pollutants and 5 meteorological parameters; (b) to find which air pollutants underg the highest variation along the year; (c) to find which meteorological parameters is are the most contributors to this variation.

Materials and Methods

Study Area

Mosul city was selected for the current study as the largest population in northern Iraq. It lies on the two sides of Tigris river with an area of 180 km^2 and a population of 2,443,861 [21]. It has a semi-arid climate and extremely hot, extended, dry summer, mild spring and autumn and moderately wet cool winter [22]. The prevailing wind direction is NW with 17.2% calm conditions. In addition, the dominant wind speed ranged between more than 0 to 2 km/hr [23].

The monitoring station is located in the garden of the public library, near a traffic light intersection and on the northern side of a main separated road with heavy traffic volume as it is fed from two bridges: Al-Hurrya bridge from the South-west and Sanhareb bridge from the North-west. The monitoring station is surrounded by many buildings: public library at the north, Iraqi engineers union from the west and Courthouse of the city at the east (Fig. 1). In addition, a housing area is located north of the monitoring station.

Data Collection

The concentrations of air pollutants were collected by a fixed monitoring station type Horiba (German

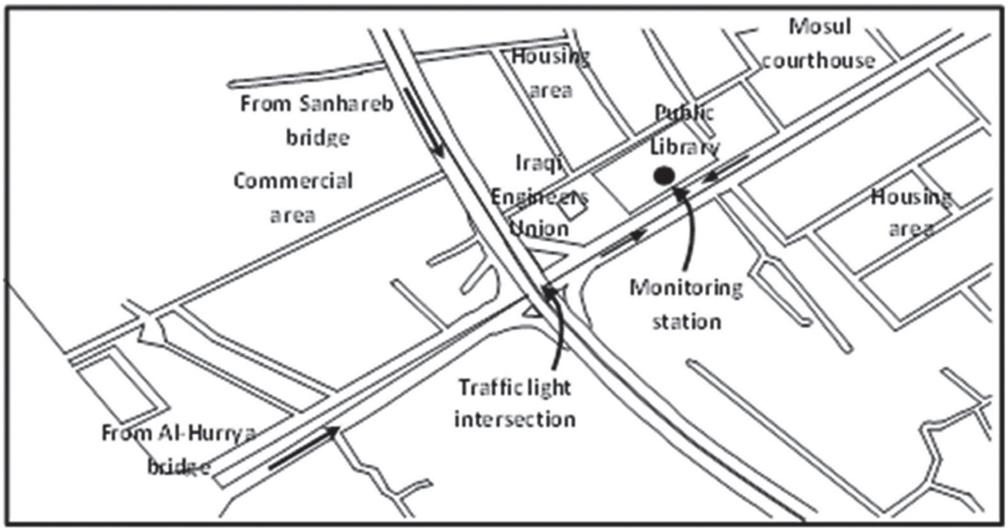

Fig. 1. Location of the study site with monitoring station.

made). The parameters measured by the station included: O_3, NO, NO_2, SO_2, CO, CH_4, non-methane hydrocarbons (NMHC) and PM_{10}. An automatic calibration of the devices in the station are conducted using span gases and zero gas. The measurements were conducted every three minutes and then the average of 30 minutes was calculated. The meteorological parameters were measured by ultrasonic weather station type WS-600 fixed in the site. The data collected include: temperature, rainfall, relative humidity, wind speed and wind direction. This station belongs to Ninevah Environment Directorate. The surveillance operation was lasted from Feb 2013 till Jan 2014.

Statistical Analysis

Canonical Correlation Analysis

It is a technique used to find a linear relationship between two sets of data, with multiple variables [24]. One of the sets is considered predictor and the other set response. Canonical correlation analysis recognizes pairs of patterns in linear combination (named canonical variates) and creates sets of transformed variables by projecting the original data onto these patterns.

Each pair of canonical variates formed together a canonical function (Fig. 2). Furthermore, in the canonical function, the correlation between the two variates represents the canonical correlation analysis. The first pair has the biggest correlation among the following pairs. The following pairs are uncorrelated with each previous pair [25].

The raw data need to be standardized as air quality parameters and meteorological parameters have different magnitudes and scales of measurements according to Z-scale by using Equation (1), [26, 27]:

$$Z_{ij} = (X_{ij} - \mu)/\sigma \tag{1}$$

Where Z_{ij} is the standard score of jth value of the measured variable i; μ is the variable mean value and σ is the standard deviation. This standardization will give equal weights to variables in the statistical analysis. Besides, this process will normalize the variance of the distribution [28].

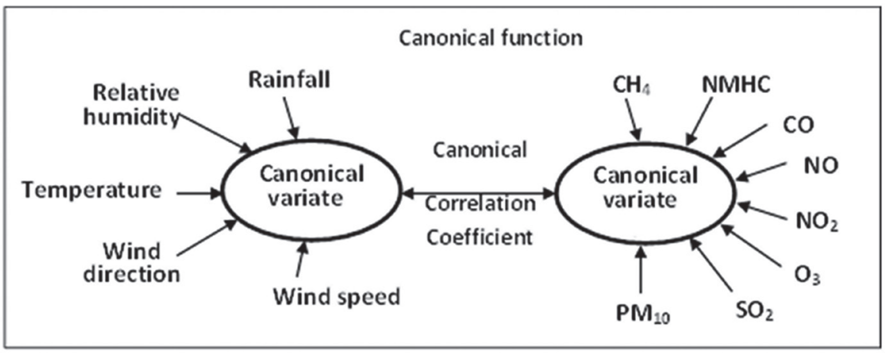

Fig. 2. The components of canonical function.

The linear combinations extracted by canonical correlation analysis can be expressed as in Equation (2) for predictor and Equation (3) for response:

$$M\text{-}P_i = a_1X_1 + a_2X_2 + a_3X_3 + ... + a_mX_m \quad (2)$$

$$A\text{-}P_i = b_1Y_1 + b_2Y_2 + b_3Y_3 + ... + b_nY_n \quad (3)$$

$X_1, X_2, \ldots X_m$ represent meteorological parameters
$Y_1, Y_2, \ldots Y_n$ represent air pollutants
$a_1, a_2, \ldots a_m$ represent canonical coefficients (weights) for predictor
$b_1, b_2, \ldots b_n$ represent canonical coefficients (weights) for response
m = number of meteorological parameters
n = number of air pollutants
M-Pi = canonical variate for meteorological parameters
A-Pi = canonical variate for air pollutants

The standardized coefficients of weights can be used to found which variables are unnecessary in interpreting the canonical variables [29]. These coefficients specify the relative status of meteorological parameters in air pollutants variation.

Results and Discussion

Spearman correlation among air pollutants and meteorological parameters were analyzed (Table 1). All air pollutants were significantly correlated among themselves except O_3 with CH_4. Most of these correlations were positive. The correlation between CO and NO has the highest positive value of 0.866, which agreed with the findings of Kim et al. [30]. The correlations among meteorological parameters signifying weak although they are significant, except for temperature versus relative humidity, which shows inverse relationship with high correlation value of -0.914. These results is in agreement with the findings of Yoshida et al. [31]. The bivariate correlation between air pollution elements and meteorological parameters revealed positively and negatively significant relationships, in addition to view non-significant ones. Most of these correlations were weak, although they are significant except for O_3 with temperature (0.802) and with relative humidity (-0.756), which means that O_3 increases with temperature and decreases with relative humidity. These relationships of O_3 agreed with the results of Dovile [32], Nazif et al. [33] and Ilic et al. [34].

To obtain more obvious picture for the relationship between air pollutants and meteorological parameters and to reduce the dimensionality of input variables, canonical correlation analysis was applied between air pollutants as a data set and meteorological parameters as another data set.

Two canonical functions were selected as they explain more than 95% of the variance in air pollutants. These functions are statistically significant at $p<0.001$ (Table 2). Large samples have the tendency to show statistical significance in all cases, although the practical significance is not pointed [35].

Linear combinations resulted for meteorological parameters as predictor are denoted M-P1 and M-P2, whereas the linear combinations corresponding to air pollutants as response are denoted A-P1 and A-P2. The first canonical variate pair has a high correlation of 0.849 between M-P1 and A-P1 (Table 2). Additionally, M-P1 explains 87.21% of the variance in A-P1. The most effective variable in the predictor data set M-P1 is temperature with a canonical coefficient of 0.744 and to a lesser extent relative humidity with inverse coefficient of -0.279. This means that one standard deviation increase in temperature leads to 0.744 standard deviation increase in the score of M-P1 when all other units are held constant. On the other hand, rainfall, wind direction and wind speed have weak effect on this variate as their coefficients values near zero. The response data set A-P1 is mainly influenced by O_3 with a canonical coefficient of 0.852. This means that one standard deviation increase in O_3 leads to 0.916 standard deviation increase in the score of A-P1 when all other units are held constant. The other air pollutants show low canonical coefficients of less than 0.3.

This canonical function (M-P1, A-P1) shows that mainly temperature and to lesser extent relative humidity influence the ozone concentrations. Photochemical reactions is stimulated by high temperatures and increase the rate of ozone production [36, 37]. On the other hand, relative humidity inversely affect ozone formation and higher ozone concentration occurred at low relative humidity [38-40]. NO as a precursor of ozone is negatively loaded on this variate. It is inversely correlated with ozone (Table 1) which agreed with the results of Mahidin et al. [41]. The canonical coefficients of this variate show that higher temperature and lower relative humidity lead to low concentrations of NO. They are inversely correlated as shown in Table 1. These results agreed with the findings of Kayes et al. [42].

The second canonical function has a significant correlation between M-P2 and A-P2 of about half that of the first function with 0.445 (Table 2). The amount of A-P2 variance explained by M-P2 is 8.36%. Wind direction is the most leading variable in M-P2 with a canonical coefficient of -1.059. In contrast, CO and SO_2 have large coefficients of 0.910 and 0.849 respectively on A-P2. This canonical function (M-P2, A-P2) demonstrates the effect of wind direction on the concentration of CO and SO_2. To the North of the monitoring site, there is a residential area, while to the South there is a roadway followed by a residential area which may explain the effective wind direction. The Eastern or the North-Eastern or the South-Eastern winds contribute to in carrying of air pollutants CO and SO_2 emitted from vehicles to the air quality monitoring station sited at the side of main two sided road of heavy traffic volume. The wind may transport

Table 1. Spearman correlation matrix among air pollutants and meteorological parameters (R – Rainfall, H – Relative humidity, T – Temperature, Dir – Wind direction, Sp – Wind speed).

	CH_4	NMHC	CO	NO	NO_2	O_3	SO_4	PM_{10}	R	H	T	Dir
NMHC	-.109***											
CO	.200***	.661***										
NO	.142***	.567***	.866***									
NO_2	.329***	.454***	.692***	.678***								
O_3	-.005	-.556***	-.674***	-.768***	-.263***							
SO_4	.291***	.318***	.621***	.660***	.790***	-.277***						
PM_{10}	.300***	.275***	.231***	.197***	.369***	-.087*	.325***					
R	.006	.109***	.164***	.175***	.080***	-.187***	.009	-.115***				
H	-.047*	.274***	.416***	.475***	-.060**	-.756***	-.019	-.185***	.241***			
T	.046*	-.269***	-.451***	-.544***	.025	.802***	-.060**	.155***	-.197***	-.914***		
Dir	-.105***	-.260***	-.490***	-.468***	-.449***	.186***	-.528***	-.161***	-.049*	-.095***	.100***	
Sp	-.208***	-.183***	-.190***	-.179***	-.212***	.203***	-.129***	-.131***	.077***	-.119***	.172***	-.089***

* Significant at $p \leq 0.05$, ** Significant at $p<0.01$, *** Significant at $p \leq 0.001$

Table 2. Canonical correlation analysis results including coefficients of variates (weights), correlations between two sets variables (r), eigen values, variance percentage and their probabilities (p).

Canonical Function	M-P1, A-P1	M-P2, A-P2
Statistical parameters		
Canonical correlation (r)	0.849	0.445
Eigen value	2.578	0.247
% Variance	87.21%	8.36%
p-value	<0.001	<0.001
Meteorological parameters		
Rainfall	-0.014	-0.098
Relative humidity	-0.279	-0.369
Temperature	0.744	-0.334
Wind direction	-0.028	-1.059
Wind speed	-0.038	0.438
Air pollutants		
CH_4	0.018	-0.399
NMHC	0.162	-0.348
CO	-0.139	0.910
NO	-0.295	-0.335
NO_2	0.253	-0.243
O_3	0.852	0.336
SO_2	0.184	0.849
PM_{10}	0.146	-0.031

pollutants and deteriorate air quality or it may work as a dilution factor or refresh air quality. Furthermore, wind path is determined by the topography of the area or the distribution of civil facilities in the urban area, therefore, wind direction is important. Many studies had emphasize wind direction effect on air quality [33, 42, 43].

The canonical analysis of air pollutants and meteorological factors in Mosul city has highlighted the periods in the year of high temperature and high concentrations of ozone on the first canonical function. Furthermore, the Eastern wind and high concentration of CO and SO_2 are highlighted in the second canonical function for the studied station in Mosul city.

Fig. 3 shows a significant direct relationship between the score of the variates M-P1 as a predictor and the score of the variate A-P1 as a correspondent with a correlation coefficient of 0.849. When the score of the meteorological parameters (M-P1) increased by one standard deviation, air pollutants score (A-P1) increased by 0.8498 standard deviation. It is clear from

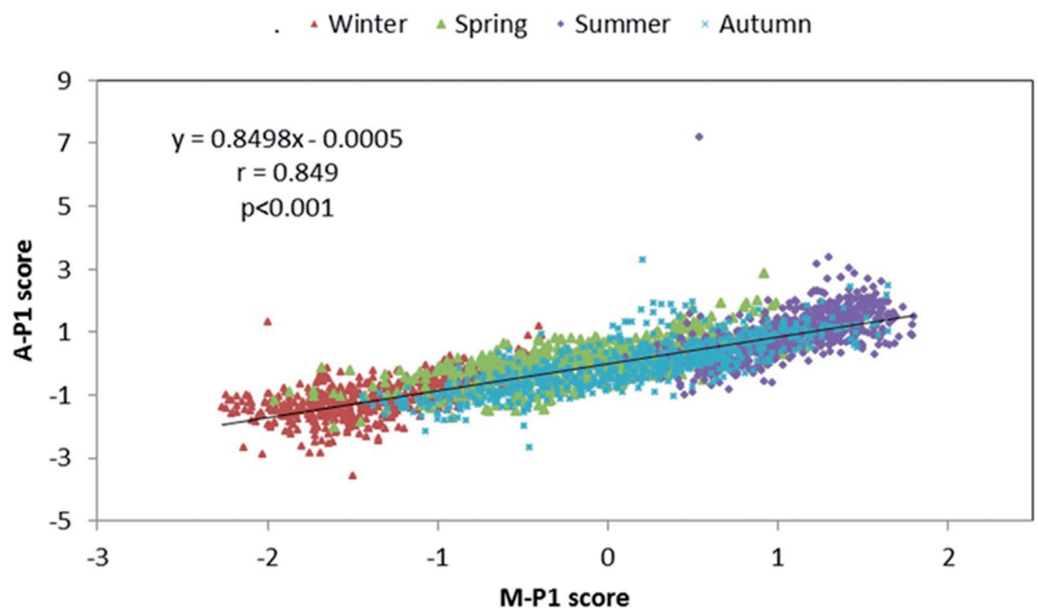

Fig. 3. Relationship between meteorological variate M-P1 and air pollutants variate A-P1 according to season.

Fig. 3 that temperature increase with season has risen M-P1 score as it is positively correlated with this variate (Table 2), which in turn increases ozone concentration. The score of A-P1 is positively correlated with ozone (Table 2), and it will increase with ozone increase.

For canonical function 2, significant positive correlation is noticed between the scores of variate M-P2 and variate A-P2 with a correlation coefficient of 0.445 (Fig. 4). One standard deviation increase in M-P2 causes an increase in A-P2 score by 0.446 standard deviation. The figure shows a scattered points as wind direction and speed exhibits irregular variation along the year.

Canonical loadings specify the relationship between the variables and their canonical variate, whereas canonical cross loadings specify the relationship with the opposite canonical variate. The loadings of canonical variate M-P1 shows that temperature is the most influential parameter in forming the shape of the variate M-P1 with a correlation coefficient of 0.989 followed by relative humidity with inverse correlation of -0.938 (Table 3). The other meteorological parameters have very weak correlations (near zero) with this variate. On the other hand, ozone is most influential in the second canonical variate pair A-P1 with a direct canonical correlation value of 0.916. NO is correlated

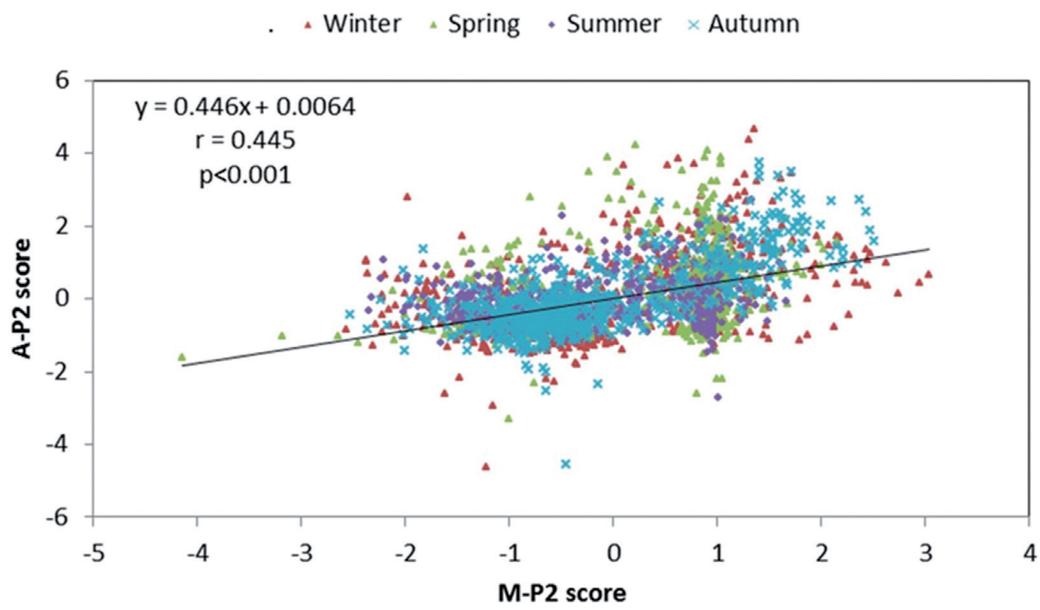

Fig. 4. Relationship between meteorological variate M-P2 and air pollutants variate A-P2 according to season

Table 3. The results of correlations between the studied parameters and its canonical variates (canonical loadings).

Variates / Parameters	M-P1	M-P2
Rainfall	-0.159	-0.111
Relative humidity	-0.938	-0.012
Temperature	0.989	-0.038
Wind direction	0.020	-0.898
Wind speed	-0.024	0.046
Variates	A-P1	A-P2
CH_4	0.164	-0.199
NMHC	-0.365	0.007
CO	-0.520	0.565
NO	-0.615	0.392
NO_2	0.063	0.378
O_3	0.916	-0.071
SO_2	-0.096	0.777
PM10	0.159	0.122

Table 4. The results of correlations between the studied parameters and the opposite set of variates (canonical cross loading).

Canonical variates	A-P1	A-P2
Parameters		
Rainfall	-0.135	-0.050
Relative humidity	-0.796	-0.005
Temperature	0.840	-0.017
Wind direction	0.017	-0.400
Wind speed	-0.020	0.021
Variates	M-P1	M-P2
CH_4	0.139	-0.089
NMHC	-0.310	0.003
CO	-0.442	0.251
NO	-0.522	0.175
NO_2	0.053	0.168
O_3	0.778	-0.031
SO_2	-0.082	0.346
PM10	0.135	0.054

with this variate inversely at a value of -0.615, which is lower than that of ozone by about 33%. Furthermore, this variate justifies the contrast between the secondary pollutant (O_3) and the primary pollutant (NO).

Canonical loadings of meteorological parameters in variate M-P2 indicate that wind direction is the main parameter establishing this variate with a correlation value of -0.898, which means that this variate is represented by the North-East to South-East winds. The other meteorological parameters have very low negative correlation with this variate. In contrast, SO_2 and CO are directly correlated with the response variate A-P2 at a values of 0.777 and 0.565 respectively. Also, NO and NO_2 is correlated directly with this variate in a lesser level of 0.392 and 0.378 respectively. This variate structure is formed from the exhausts pollutants SO_2, CO, NO and NO_2 transported by the wind towards the sides of the road.

Canonical cross loadings of the variates M-P1 and A-P1 revealed a related manner like that of canonical loading, in which high temperature and low relative humidity constitute the main cause of ozone increase and NO decrease (Table 4). The second canonical function shows weak canonical cross loading and differ from that of canonical loading.

Conclusions

Canonical correlation analysis is an efficient tool to find the relationship between two sets of data and draw the main parameters which reflect this relationship, which cannot obtained with the ordinary correlation. According to the interpretation of canonical weights obtained from the canonical correlation analysis of meteorological parameters and air pollutants of Mosul city, it was found that temperature has the great impact on air pollution image in Mosul city, whose effect appeared on ozone gas in air pollutants data set. Furthermore, to a lesser extent, the second function of canonical correlation analysis pointed out the effect of wind direction on air pollutants through transporting SO_2 and CO emitted from vehicles to roadsides. Canonical loadings support this concept, while canonical cross loading support only the concept of temperature and ozone. The major conclusion is the ability of canonical correlation analysis to reduce the input parameters mainly to temperature and ozone or to reduce the dimensionality of input variables. This conclusion provides valuable information to the strategy of air quality monitoring in the study region. It has highlighted the pollutant which need to be monitored more than the others by decreasing its interval of measurements. It is worthy to conduct this study on each region to include the results in the strategies of air quality monitoring.

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Conflict of Interest

The author declares no conflict of interest.

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