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RESEARCH ARTICLE

Association between air quality and quality of life

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Abstract Air quality—or its converse, air pollution—is a significant risk factor for human health. Recent studies have reported association between air pollution and human health. There are numerous diseases that may be caused by air pollution such as respiratory infection, lung cancer, cardiovascular disease, chronic obstructive pulmonary disease, and asthma. In this study, the relationship between air quality and quality of life was examined by using canonical correlation analysis. Data of this study was collected from 27 countries. WHO statistics were used as the main source of quality of life data set (*Y* variables set). European Environment Agency statistics and (for outdoor air-PM10) WHO statistics were used as the main source of air quality data set (*X* variables set). It is found that there are significant positive correlation between air quality and quality of life.

Keywords Air quality · Air pollution · Canonical correlation · Environment · Health · Quality of life

Introduction

Air pollution, a major environmental health problem affecting everyone, is the introduction of particulate matter, chemicals, or biological materials into the atmosphere. These materials cause harm or discomfort to humans or other living organisms, or cause damage to the natural or built environment.

Major primary pollutants produced by human activity include; sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide, volatile organic compounds (VOCs), particulate matter (PM), chlorofluorocarbons, and ammonia (NH3) (Mathew 2013).

Air quality—or its converse, air pollution—is a significant risk factor for human health. There are numerous diseases that may be caused by air pollution such as respiratory infection, lung cancer, cardiovascular disease, chronic obstructive pulmonary disease (COPD), and asthma (Pruss-Ustun and Corvalán 2006; Sadalla et al. 2005). About 5 % of the disease burden of lung cancer has been attributed to outdoor air pollution (Cohen et al. 2004; WHO 2002).

Exposures to outdoor air pollution accounted for approximately 2 % of the global cardiopulmonary disease burden (Cohen et al. 2004; WHO 2002). Outdoor PM air pollution is estimated to be responsible for about 3 % of adult cardiopulmonary disease mortality; about 5 % of trachea, bronchus, and lung cancer mortality; and about 1 % of mortality in children from acute respiratory infection in urban areas worldwide (Cohen et al. 2005). COPD is a slowly progressing disease characterized by a gradual loss of lung function (Pruss-Ustun and Corvalán 2006). One of the risk factors for COPD is to exposure air pollution (American Lung Association 2008; Pruss-Ustun and Corvalán 2006). Outdoor air pollution accounted for 3 % of cardiopulmonary mortality (Cohen et al. 2004).

Asthma development and exacerbation can be triggered by a variety of indoor and outdoor environmental exposures to dampness, dust mites, fungal allergens, environmental tobacco smoke, and air pollution (Pruss-Ustun and Corvalán 2006). Outdoor air pollution gets worse for existing asthma. Outdoor pollutants known to trigger asthma attacks include

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ozone, particulate matter, nitrogen dioxide, and sulfur dioxide (American Lung Association 2008; Tatum and Shapiro 2005).

It has been estimated that the number of people exposed to sulfur dioxide in excess of the guidelines established by the World Health Organization (WHO) will rise from an already high number of 650,000 people in 1990, to 14 million in 2020 (Streets et al. 1999).

Research conducted during the last 10 to 20 years confirms that outdoor air pollution contributes to illness and death in adults and children (Brunekreef and Holgate 2002). The association between air pollutants and birth weight was statistically significant for either males or females alone (Bell et al. 2008).

The quality of air also affects population's welfare. Pollution-related diseases have an effect on a person's quality of life. Air pollution has an impact on quality of life as a source of stress. It also has an economic impact in terms of health costs and missed days at work and school (Sadalla et al. 2005).

In this study, the relationship between air quality and quality of life in some countries was examined by canonical correlation analysis method using number cruncher statistical system packaged-software.

Material and Methods

Data

Data of this study was collected from 27 countries (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, Bulgaria, Estonia, Latvia, Lithuania, Romania) by using WHO and European Environment Agency (EEA) statistics.

WHO statistics were used as the main source of quality of life data set (Y variables set); EEA statistics and (for outdoor air-PM10) WHO statistics were used as the main source of air quality data set (X variables set).

Y and X variables sets are defined as follows

- $Y1$ Lung cancer (disability-adjusted life years (DALYs) / 1,000 capita) per year.
- $Y2$ Asthma (DALYs/1,000 capita) per year.
- $Y3$ COPD (DALYs/1,000 capita) per year.
- $Y4$ Respiratory infection (DALYs/1,000 capita) per year.
- $Y5$ Cardiovascular disease (DALYs/1,000 capita) per year.
- $Y6$ Under age 5 mortality rate per 1,000 live births.
- $X1$ NH3 (total emissions of NH3-tons).
- $X2$ Non-methane volatile organic compounds-NMVOC (total emissions of NMVOC-tons).
- $X3$ NOx (total emissions of NOx-tons).
- $X4$ SOx (total emissions of SOx-tons).
- $X5$ PM10 (mean urban PM10 $\mu g/m^3$).

Statistical method

Canonical correlation analysis which is a statistical analysis method to explain the correlation structure between two sets of variables is one of the most general of the multivariate techniques. It is used to investigate the relationship between a linear combination of the set of X variables with a linear combination of a set of Y variables.

Consider two groups of variables (X and Y) such that one has p variables ($X1, X2,\ldots,Xp$), and the other has q variables ($Y1, Y2, \ldots,Yq$). Linear combinations of the original variables can be defined as canonical variates (Wm and Vm) as follows:

$$Wm = am1X1 + am2X2 + \ldots + ampXp \quad (1)$$

$$Vm = bm1Y1 + bm2Y2 + \ldots + bmqYq \quad (2)$$

The correlation between Wm and Vm can be called canonical correlation (Cm). Squared canonical correlation (canonical roots or eigenvalues) represents the amount of variance in one canonical variate accounted for by the other canonical variate (Hair et al. 1998).

Results and discussion

Descriptive statistics (the mean values and standard deviation) of each variable considered in both sets are presented in Table 1.

The Pearson's correlations between variables of quality of life and variables of air quality are shown in Table 2. These correlations show that cardiovascular disease is negatively correlated to asthma and positively correlated to respiratory infection and under age 5 mortality rate. Age under 5 mortality rate is also positively correlated to respiratory infection. COPD is positively correlated to lung cancer. SOx, is positively correlated to NH3, NMVOC and NOx. A paper reported that correlation between other pollutants and sulfur dioxide (SO_2) was also strong (Katsouyanni et al. 1990). In this study, no association with mortality was found for SOx, NH3, NMVOC and NOx. Samet et al., (2000) found that SO_2 causes respiratory problems. It is found in this study that PM10 is positively correlated to respiratory infection and under age 5 mortality rate. Bobak and Leon (1992) correlated infant mortality with air pollution by particulate matter over the years 1986–1988. NMVOC, NH3, and NOX are highly correlated to each other. In this study, no significant association was found between nitrogen dioxide (NO_2) and PM10 but studies have found associations between NO_2 and PM10 (Bakonyi

Table 1 Descriptive statistics section

Type	Variable	Mean	Standard deviation
Y	Lung cancer	1.233333	0.3772369
Y	Asthma	0.6777778	0.2722179
Y	COPD	0.5518519	0.2708539
Y	Respiratory infections	0.5222222	0.3886202
Y	Cardiovascular disease	4.692593	2.354525
Y	Age <5 mortality rate	5.777778	2.913276
X	NH3	150,515	191313.1
X	NMVOC	372,147.8	449,990.6
X	NOx	448,987.4	526,835.2
X	SOx	319,692	402,396.3
X	PM10	31.48148	13.54585

et al. 2004; Mackerron and Mourato 2009; Neidell 2004). Some studies reported association between PM and lung cancer (Biggeri et al. 1996; Choi et al. 1997; Dockery et al. 1993; Pope et al. 1995) and also between NO_2 and lung cancer (Biggeri et al. 1996; Choi et al. 1997; Nafstad et al. 2003). The risk of death from respiratory diseases was estimated to increase by 2.3 % for PM10, 2,3 % for SO2 and 1.1 % for CO for each interquartile range change (Tsai et al. 2003).

Similar to this study, a significant and positive association was found between PM10 concentration and daily mortality caused by respiratory disease (Bakonyi et al. 2004; Sanhueza et al. 2006).

Result of a study show that an increase of 10 mg/m^3 in the mean levels of PM10 and PM2.5 encountered during the 3 previous days was associated with an increase of 3 % (0.8 and 5.3 %) and 5.9 % (2.9 and 9.0 %) in the number of doctor's house calls for upper respiratory diseases and lower respiratory diseases, respectively (Chardon et al. 2007). Other studies also found an overall increase of 4.0 % (95 % confidence interval=1.1–6.9 %) in respiratory emergency hospital admissions associated with an increase of 10 μg/m^3 in PM10 in the single pollutant model (Braga et al. 2007; Chen et al. 2007).

The test statistics for the canonical correlation analysis are presented in Table 3. The canonical correlation between the first (0.858) pair was found to be significant ($p<0.05$) from the likelihood ratio test. The remaining canonical correlation is not statistically significant ($p>0.05$).

By construing the first canonical variate, it is possible to find relationship between quality of life and air quality as rate of 73.64 %. For the first canonical variate, there are significant positive correlations between quality of life and air quality. Similarly, in a study, it was found that up to two thirds of Londoners believe that air quality affects their quality of life (Greater London Authorıty 2005; Mackerron and Mourato 2009). Most studies find a significant positive relationship between environmental quality and life satisfaction (Ferreira et al. 2006; Rehdanz and Maddison 2008; Welsch 2002; Welsch 2003; Welsch 2006; Welsch 2007). All of these studies reported significant negative association between air pollution and life satisfaction.

The first canonical variate suggests that about 28 % of the variation in *Y* variables is explained by the *X* variables and about 12 % of the variation in *X* variables is explained by the *Y* variables.

Standardized canonical coefficients shows variation (kind of standard deviation) in canonical variate in parallel with one standard deviation increase in original variables; in other words, these coefficients represent relative contributions of original variables to the related variate. According to standardized canonical coefficients for the first *X*, *Y* variate equations of *X*1 and *Y*1 canonical variate are as follows:

$$X1 = 0.09x1 + 2.27x2 - 2.79x3 + 0.63x4 + 0.43x5$$
$$Y1 = 0.05y1 - 0.47y2 - 0.16y3 + 0.05y4 - 0.3y5 + 0.92y6$$

Table 2 Correlation section

	Lung cancer	Asthma	COPD	Respiratory infections	Cardiovascular disease	Under age 5 mortality rate	NH3	NMVOC	NOx	SOx	PM10
Lung cancer	1.00										
Asthma	−0.44	1.00									
COPD	0.50	−0.07	1.00								
Respiratory infections	0.005	−0.33	−0.07	1.00							
Cardiovascular disease	0.38	−0.58	0.04	0.69	1.00						
Age <5 mortality rate	0.17	−0.37	0.06	0.76	0.72	1.00					
NH3	0.12	0.07	−0.13	−0.28	−0.27	−0.05	1.00				
NMVOC	0.07	0.02	−0.10	−0.24	−0.22	−0.0045	0.93	1.00			
NOX	0.09	0.12	−0.08	−0.33	−0.27	−0.12	0.92	0.96	1.00		
SOX	0.27	−0.13	−0.11	0.06	0.24	0.28	0.53	0.55	0.64	1.00	
PM10	0.26	−0.46	0.09	0.53	0.45	0.67	0.06	0.12	0.05	0.42	1.00

Table 3 Canonical correlations section

Variate number	Canonical correlation	R^2	F value	Num DF	Den DF	Prob Level	Wilks' Lambda
1	0.858113	0.736358	1.72	30	66	0.033569	0.098724
2	0.605166	0.366226	0.99	20	57	0.489211	0.374460

F value tests whether this canonical correlation and those following are zero

Since the canonical coefficients can be unstable due to small sample size or presence of multicollinearity in the data, the loadings were also considered to provide substantive meaning of each variable for the canonical variate (Akbaş and Takma 2005). To evaluate the important accounts of the significant canonical function, canonical loadings were used in this study. Canonical loadings greater than ±0.30 were considered to be important (Hair et al. 1998). The variable–variate correlations (canonical loadings and canonical cross loadings) of the first canonical variate are presented in Table 4.

Age <5 mortality rate is the most influential variables in forming $Y1$. PM10 is the most influential variables in forming $X1$. Some studies also reported effects of air pollution on infant mortality (Bobak and Leon 1992; Bobak and Leon 1999; Loomis et al. 1999; Penna, and Duchiade 1991) and mortality in children under 5 years of age (Conceicao et al. 2001; Ostro et al. 1999).

It is observed that there are associations between air pollution and daily consultations for asthma and other lower respiratory disease in London. The most significant associations were observed in children and the most important pollutants were found as NO_2, CO, and SO_2 for children and PM10 for adults (Hajat et al. 1999). In another study it is found that NO_2, CO, and PM10 are highly correlated pollutants (Neidell 2004).

As the study found, PM10 can lead to health problems in the exposed population (Braga et al. 2007). Among all air pollutants, particulate matter causes the most significant effects on human health. For this reason, PM10 may be considered to be a reliable indicator of air pollution (Colucci et al. 2006).

Table 4 Variable–variate correlations (canonical loadings and canonical cross loadings)

	$Y1$	$X1$
Lung cancer	0.222412	0.190855
Asthma	−0.662500	−0.568500
COPD	−0.060426	−0.051853
Respiratory infections	0.703485	0.603669
Cardiovascular disease	0.677183	0.581099
Age <5 mortality rate	0.912302	0.782858
NH3	0.011789	0.013738
NMVOC	0.059389	0.069208
NOx	−0.086309	−0.100580
SOx	0.276387	0.322087
PM10	0.715999	0.834388

Two of the variables (asthma and COPD) have negative loadings and four of the variables (age <5 mortality rate, respiratory infections, cardiovascular disease, and lung cancer) have positive loadings on the quality of life set.

One of the variables (NOx) has negative loading and four of the variables (PM10, SOx, NMVOC, NH3) have positive loadings on the air quality set. Canonical cross loadings of variables with variate are almost the same as canonical loadings.

Several studies have found positive correlation between mortality due to respiratory and cardiovascular system and air pollution (Holgate et al. 1999; Katsouyanni et al. 1997; Schwartz 1994; Zmirou et al. 1998). Cardiovascular diseases have been linked with environmental risk such as air pollution (Pope et al. 2008).

In Brazil, increasing air pollution in urban areas has led to a rise in respiratory diseases among children and the elderly and has also been the main cause of hospital admissions (Castro et al. 2007). Significant associations between the increase of respiratory emergency visits and air pollution were observed. The most robust associations were observed with PM10 (Lin et al. 1999).

The study found no association between air pollution and lung cancer. Similarly, Szaniszlo and Ungvary (2001) did not observe increased mortality in ambient air-exposed individuals, as evidenced by a lack of rise in cancer-related disease (Szaniszlo and Ungvary 2001). But most studies found positive correlation between air pollution and cancer. A study reported that urban air pollution increases lung cancer risk (Nyberg et al. 2000). Results of a study provide evidence that air pollution is a moderate risk factor for certain histologic types of lung cancer (Belen et al. 2008).

Conclusion

A primary objective of air quality policies around the world is to protect human health. We conclude that air pollution has an effect on population's quality of life which is one of the main components of the decrease of mortality and disease (Darcin and Darcin 2007). Air pollution is a major environmental risk to health. The results of this study also provide evidence that air pollution is a moderate risk factor for human health and quality of life. Further studies are needed to clarify interaction between air quality and quality of life.

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