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Benoît Otjacques
Patrik Hitzelberger
Stefan Naumann
Volker Wohlgemuth *Editors*

From Science to Society

New Trends in Environmental Informatics

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Editors
Benoît Otjacques
Environmental Research and Innovation
Luxembourg Institute of Science
and Technology
Esch/Alzette
Luxembourg

Patrik Hitzelberger
Environmental Research and Innovation
Luxembourg Institute of Science
and Technology
Esch/Alzette
Luxembourg

Stefan Naumann
Institut für Softwaresysteme in Wirtschaft,
Umwelt und Verwaltung
Hochschule Trier - Umwelt-Campus
Birkenfeld
Birkenfeld
Germany

Volker Wohlgemuth
Environmental Informatics
University of Applied Sciences
Berlin
Germany

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Contents

Initial Assessment of Air Pollution and Emergency Ambulance Calls in 35 Israeli Cities

Barak Fishbain and Eli Yafe

Abstract Statistical analysis was done for correlations between chronic exposure to ambient air pollution concentrations and emergency ambulance calls in 35 Israeli cities between 2007 and 2012. A second analysis was done between the rate of acute exposure through the rate of extreme events (at least 2 standard errors over the national mean) over the same time period and in the same cities. This study is unique by assessing this association by looking at emergency calls' locations rather than the hospital location. The importance of such study is twofold. First, it facilitates the consideration of environmental conditions in the process of emergency services staffing, allowing for a better utilization of professional personnel and improving overall service. Second, it may shed new light on air pollutants and their correlations to specific medical emergency conditions.

Keywords Air pollution · Environmental health · Medical emergencies · Air pollution exposure

1 Introduction

The health effects of different air pollutants have been well documented (e.g., Beelen et al. 2014; Brauer et al. 2008; Shah et al. 2012; Smith 1987). Carbon Monoxide (CO), originating mostly from anthropogenic activity, typically emissions from transportation (Badr and Probert 1994), was linked with emergency admissions for cerebrovascular diseases (Chan et al. 2006) and myocardial infraction (MI) (Mustafić et al. 2012). Having said that, a comprehensive 6-year

B. Fishbain (✉)
Faculty of Civil and Environmental Engineering,
Technion-Israel Institute of Technology, Haifa, Israel
e-mail: fishbain@technion.ac.il

E. Yafe
Magen David Adom, 60, Yigal - Alon Street, 67062 Tel Aviv, Israel
e-mail: Eliy@mda.org.il

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study done in Edmonton (Canada) (Villeneuve et al. 2012), showed no statistically significant correlation between ambient levels of CO and hospital visits for stroke, i.e., cerebrovascular accidents. Elevated exposure to CO also showed no effect on premature births (Srám et al. 2005).

Nitrogen oxides (NO, NO_2 and collectively NO_x) arise in the atmosphere largely from the bonding of atmospheric nitrogen and oxygen under high temperature conditions (Badr and Probert 1993). NO_2 ambient levels were found to be correlated to emergency room admissions for hypertension (Guo et al. 2010; Szyszkowicz et al. 2012), asthma aggravation (Koenig 1999) and MI (Mustafić et al. 2012). Weak correlations were found between strokes and NO_2 levels (Villeneuve et al. 2012). A lower prevalence of measured high blood pressure was found in the population exposed to elevated NO_x (Sørensen et al. 2012). NO_2 was associated with increased odds for premature birth only when combined with SO_2 and PM_{10} exposure (Srám et al. 2005).

Tropospheric ozone is a secondary pollutant, originating from complex photocatalytic interactions between Volatile Organic Compounds (VOCs), NO_x and other atmospheric constituents (Jenkin and Clemitshaw 2000). While exposure to higher levels of ozone was found to be a risk factor for hypertension (Dong et al. 2013) and cerebrovascular diseases (Chan et al. 2006), other studies concluded it did not play a role in increasing risk for MI (Mustafić et al. 2012) and stroke (Villeneuve et al. 2012).

Particulate matter (PM) is a solid or liquid phase object transported in the air. The most common measurement today for particulate matter is PM_{10}, which assesses the mass concentration of particulates smaller than 10 microns in diameter. In recent years, there has been a shift toward measuring $PM_{2.5}$, which is more relevant physiologically (Janssen et al. 2011; Schwartz et al. 2002). While the contribution of PM pollution to premature births was reported by Srám et al. (2005), a review, conducted in 2010, concluded that there is no convincing evidence PM is indeed associated with pre-term birth (Bosetti et al. 2010). A later study reiterated the notion that $PM_{2.5}$ does contribute to risk of pre-term birth (Kloog et al. 2012). The associations between PM levels and hypertension (Dong et al. 2013; Guo et al. 2009; Szyszkowicz et al. 2012), MI (Mustafić et al. 2012) and cerebrovascular diseases (Chan et al. 2006) were established, while no correlation was found between PM and stroke (Villeneuve et al. 2012).

Sulfur dioxide (SO_2) is produced via the burning of sulfur-containing fuel such as oil and coal (Dickey 2000). The associated risk of exposure to higher levels of SO_2 to all the above diseases was well documented (Dong et al. 2013; Guo et al. 2010; Mustafić et al. 2012; Kaplan et al. 2012; Koenig 1999; Srám et al. 2005; Szyszkowicz et al. 2012; Villeneuve et al. 2012).

Volatile organic compounds (VOCs) are a large group of pollutants, including (among others), aromatic hydrocarbons such as benzene, ethylbenzene, m-xylene, p-xylene, o-xylene and toluene (Wallace 1996). VOCs (in particular benzene) have been shown to be strongly correlated to several adverse health effects (Adgate and Goldstein 2014; He et al. 2015; Kim et al. 2013). In a cross-sectional US study, elevated exposure to benzene, ethylbenzene and M&P-Xylenes (MPX) has been linked with wheezing attacks (Arif and Shah 2007). However, VOCs is a large family of pollutants with different characteristics and health effects, which makes its measurement difficult. Further, as VOCs are not part of the set of criteria pollutants, they are significantly less monitored.

The above discussion presents a solid correlation between air pollution and adverse health effects. While this general notion is true, the literature shows that pinpointing specific pollutant's health impact is most difficult if not illusive task. Previous studies that aimed at inferring the connections between air pollutants' ambient levels and adverse health effects, analyzed hospital admissions. In those studies, the air pollution was measured either in the vicinity of the hospital or the patients' residential address. However, the above analysis strongly suggests that finding the correlations between air-pollution and health effects and quantifying the associated risk is difficult. Some of the criteria pollutants have no known pathways and pathologies for causing some of the observed health impacts. In these cases, it is assumed that the measured pollutants are not the direct cause for the disease, but a surrogate indicator (Villeneuve et al. 2012). As the direct causing substance is unknown, the association between the real cause and the surrogate indicator is also unknown, making the correlation assessment even more difficult. Another reason for the weak correlations between hospital admissions and air-pollution is that most of the studies considered air pollution at the hospital or at the patients' home address. The pollution levels at these locations do not necessarily represent the true level where the actual emergency took place. To this end, this study assesses the air-quality at the location of *emergency calls* (rather than the hospitals' location or patients' home address). By evaluating emergency calls, rather than hospital admissions, only extreme situations are considered as in these cases not only medical treatment was needed, the situation was critical and Advance Life Support (ALS) medical team was called to the scene and thus the health impact was prominent.

2 Materials and Methods

2.1 Data

The air quality data consisted of half-hourly ambient air measurements that were acquired by standard air-quality monitoring (AQM) stations in Israel for the time period between 2007 and 2012. These measurements included Benzene, Carbon Monoxide (CO), Ethyl Benzene (E.Benz), M&P Xylene (MPX), Nitrogen Dioxide (NO_2), Nitrogen Monoxide (NO), Nitrogen Oxides (NO_x), O.Xylene (O.X), Ozone (O_3), Particulate Matter under 10 microns in diameter (PM_{10}), Particulate Matter under 2.5 microns in diameter ($PM_{2.5}$), Sulfur Dioxide (SO_2) and Toluene. Each monitoring station measured a different set of pollutants and thus the amount of data available on each of them was different. The air pollution data went through a process of quality control in which data that was incorrect (such as negative values) was removed (Yuval and Broday 2013).

Data acquired from two distinct types of AQM stations were used in this study: environmental- and traffic-oriented stations. The former is typically located on rooftops and towers, designed to measure ambient pollution levels. The latter type is designed to measure transportation related pollution. The inlets of these stations are located in proximity to traffic routes (i.e., lower heights than the inlets of the environmental stations) and typically they measure only pollutants that are known to be related to traffic, such as PM, nitrogen oxides and carbon monoxide. While the inclusion of the two station types into one environmental dataset allows to regard larger dynamic range of nitrogen oxides and carbon monoxides levels, as inherently transportation stations measure higher values of these pollutants, it might bias the results, as traffic stations are not available in all cities.

Yearly city-level categorized emergency ambulance calls were recorded by Magen David Adom (MDA), the Israeli branch of the red cross organization and the national medical emergency service, which serves more than 95% of all ambulance calls in Israel. The categories were set by MDA medical staff on site. The categories included in this study are: parturient (giving birth), hypertension (high blood pressure), breathing difficulties, cerebrovascular accident, CVA, (i.e., stroke) and myocardial infarction (heart attack). It is important to note that the health data was not corrected for the socioeconomic nor any other demographic parameter of the different cities. Thus, the initial findings of this study should be considered as general guidelines for a future, thorough, epidemiological studies.

These two databases had an overlap of 35 cities, accounting for more than half the population of Israel totaling 3,921,900 people in 2007 to 4,043,454 in 2012. This population had a record of 817,639 categorized emergencies during the 5-year time period. Some of these cities had more than one monitoring station. For cities in which more than one station measured a particular pollutant, the mean measurement of all stations in the city was used for the data-point. A data-point is any combination of city and year. That is, for each city, there were 5 data-points (2007, 2008, 2009, 2010, 2011 and 2012), treated distinctly. Examples of data-points are Tel-Aviv 2008, Hadera 2007, Tel-Aviv 2007, Jerusalem 2011, etc.

2.2 Methods

A separate analysis was done for acute and chronic exposure. Chronic exposure was assessed by correlating the mean yearly concentration with emergency calls for each combination of pollutant and emergency type. Acute exposure was assessed by defining a half-hourly measurement that was over 2 standard deviations higher than the national mean as extreme. The rate of extreme measurements for each city in each year was tested as an explaining variable to the number of ambulance calls of each type.

The same correlation tests were conducted for both types of exposure. A multiple linear regression model was made for each combination of pollutant and emergency, when adding the existence of a hospital in the city as a second explaining variable. From this analysis the sign of the pollutant slope was extracted, together with a p-value of the t-test for weather that slope is significantly non-zero.

For further analysis, the data was sliced by pollution levels above or below the median, so that each data-point was marked as "high", "low" or "data not available" with regards to each pollutant. The two groups ("high" and "low") were compared using Analysis of Variance (ANOVA) in order to determine the statistical significance of the difference between their means, taking into account the possibly stratifying parameter of having a hospital present in the city. For the same partitioning, an odds ratio was calculated where the group above the mean were considered "exposed" whilst the group below the mean was considered "not exposed". The odds ratio was calculated using the Cochran-Mantel-Haenszel Estimate, when the presence of a hospital was considered as stratifying variable.

In addition, the same calculations of ANOVA and odds ratio were applied for comparing the top and bottom 25% of exposure to each pollutant (both acute and chronic, separately).

A correlation was considered statistically significant if the p-value computed from the F ratio that was produced by the ANOVA test, or the t-value from the t-test, was smaller than 0.05.

3 Results and Discussion

Tables 1 and 2 detail the correlations between the aforementioned pollutants' chronic and acute exposure respectively for which at least one of the three p-values (t-test for linear regression, ANOVA for top vs. bottom 50% and ANOVA for top vs. bottom 25%) were lower than 0.05. Abbreviations: N.S.—Not Significant, OR—Odds Ratio, N—number of data-points with both a measurement for this pollutant and ambulance data, slope and sign of linear regression correlation (+/−).

The correlations observed for **Parturient** emergency cases show negative correlations to all three nitrogen oxide parameters (NO, NO_2 and NO_x), when comparing above and below the median for both acute and chronic exposure. The volatile organic compound toluene showed a statistically significant negative correlation. On the other hand, carbon monoxide displayed a negative correlation only for acute exposure. $PM_{2.5}$ was positively correlated with parturient emergencies when considering chronic exposure. Acute ozone exposure was the only type of correlation that was statistically significant in all three tests (positive correlation for linear, median and 25%).

It is not clear that parturient emergency calls are directly related to pre-term birth or other adverse effects on the baby. Additional confounding factors should be tested in further research. If we assume parturient ambulance calls are a good indicator of pre-term birth, then there is some agreement and some disagreement

Table 1 Health impact of chronic exposure

Health case	Pollutant	N	Chronic					
			Linear		Top versus bottom 50%		Top versus bottom 25%	
			P-value	Slope	P-value	OR	P-Value	OR
Parturient emergencies	CO	75	N.S.		N.S.		N.S.	
	NO_2	173	N.S.		8.05E-03	0.77	N.S.	
	NO	173	N.S.		8.87E-03	0.77	N.S.	
	NO_x	173	N.S.		7.80E-04	0.59	N.S.	
	O_3	125	N.S.		N.S.		N.S.	
	$PM_{2.5}$	82	4.22E-02	+	1.99E-03	1.7	N.S.	N.S.
	Toluene	22	6.06E-03	–	8.37E-03	0.41	N.S.	
Hypertension emergencies	NO_2	146	8.60E-03	–	2.42E-02	0.76	N.S.	N.S.
	NO_x	146	1.75E-02	–	4.96E-02	0.88	N.S.	N.S.
	O_3	105	N.S.		2.34E-02	0.76	N.S.	
Breathing emergencies	Benzene	21	5.10E-04	+	5.00E-02	1.44	8.61E-04	1.7
	CO	75	N.S.		N.S.		N.S.	
	O_3	125	N.S.		2.34E-02	0.76	N.S.	N.S.
Cerebrovascular	Benzene	21	N.S.		N.S.		N.S.	
	CO	75	6.28E-03	–	6.71E-03	0.8	8.00E-03	0.63
	NO_2	125	2.67E-02	–	4.99E-02	0.83	N.S.	N.S.
	$PM_{2.5}$	90	7.82E-04	+	N.S.		6.93E-04	1.02
Heart attacks	NO_2	173	6.39E-03	–	4.48E-03	0.84	4.12E-02	0.77
	PM_{10}	90	N.S.		N.S.		N.S.	

with the data produced here and previous research. Nitrogen oxides and Carbon Monoxide have not been previously linked with pre-term birth by themselves. In this project, a negative correlation emerged. The literature is inconsistent regarding the relationship between PM and pre-term birth. Some claim there is no significant correlation and some claim a positive correlation. In this study, a positive correlation was observed, yet only for $PM_{2.5}$. Previous studies on the relationship between pre-term birth and organic air pollutants were not found. In this project, exposure to toluene was inversely correlated to parturient emergencies.

Hypertension was negatively correlated with chronic exposure to NO_2 and NO_x. Ozone was negatively correlated in one test only with hypertension (median test for chronic exposure). Acute expose for none of the pollutants correlated with hypertension. Except for the Danish cohort (Sørensen et al. 2012), all reviewed literature showed positive links between air pollutants (including NO_2) and hypertension. It should be noted that the Danish cohort was the only study that examined NO_x rather than NO_2. In the analysis presented here, some nitrogen oxides measurements (NO_2 and NO_x) had a negative correlation with high blood pressure. This fits with the Danish cohort (Sørensen et al. 2012). The negative

Table 2 Health impact of acute exposure

Health case	Pollutant	N	Acute					
			Linear		Top versus bottom 50%		Top versus bottom 25%	
			P-value	Slope	P-value	OR	P-Value	OR
Parturient emergencies	CO	75	N.S.		1.14E-02	0.62	N.S.	N.S.
	NO_2	173	N.S.		6.11E-03	0.64	N.S.	N.S.
	NO	173	N.S.		4.54E-03	0.69	N.S.	N.S.
	NO_x	173	N.S.		9.91E-04	0.6	N.S.	N.S.
	O_3	125	2.20E-02	+	8.15E-03	2.31	5.35E-03	2.87
	$PM_{2.5}$	82	N.S.		N.S.		N.S.	N.S.
	Toluene	22	1.78E-02	–	4.03E-02	0.42	N.S.	
Hypertension emergencies	NO_2	146	N.S.		N.S.		N.S.	N.S.
	NO_x	146	N.S.		N.S.		N.S.	
	O_3	105	N.S.		N.S.		N.S.	
Breathing emergencies	Benzene	21	5.87E-03	+	2.19E-03	1.71	4.97E-03	1.7
	CO	75	N.S.		6.62E-03	1.03	N.S.	N.S.
	O_3	125	3.85E-02	–	N.S.		3.10E-02	0.71
Cerebrovascular	Benzene	21	N.S.		2.97E-02	1.37	N.S.	
	CO	75	N.S.		N.S.		N.S.	
	NO_2	125	N.S.		N.S.		N.S.	N.S.
	$PM_{2.5}$	90	N.S.		N.S.		N.S.	N.S.
Heart attacks	NO_2	173	N.S.		N.S.		N.S.	
	PM_{10}	90	N.S.		3.35E-02	0.81	N.S.	

correlation observed here between O_3 and hypertension does not fit previous findings (Dong et al. 2013).

Breathing emergencies were positively correlated in all six statistical tests with benzene. It was also positively correlated with acute exposure to carbon monoxide in one test. A negative correlation was calculated for ozone in three tests out of the six.

One of the strongest correlations found in this study was between benzene (both chronic and acute) and ambulance calls originating from breathing difficulties. This fits well with the previous observations made by Arif and Shah (2007). Ozone showed a negative correlation to breathing-related ambulance calls. A possible explanation for this is O_3 being a secondary pollutant thus having a lower presence in areas with high levels of primary air pollutants. CO was significantly correlated with these emergencies only for acute exposure.

Populations with a higher than the median rate of acute benzene exposure had a statistically significant greater incidence of **cerebrovascular accidents** (CVA). Chronic carbon monoxide showed a negative correlation to stroke in all 3 tests, while no significant correlation was found with acute exposure. NO_2 showed a negative correlation in two of the chronic tests. $PM_{2.5}$ showed a positive correlation in two of the chronic tests. The aforementioned acute-only negative effect of carbon monoxide is interesting especially when considering CVA. Cerebrovascular accidents were significantly less common in populations exposed to elevated chronic CO levels. No such result was found in previous studies. However, a positive link was found in Taipei (Chan et al. 2006). A possible explanation for this may be found in recent medical studies, which found a therapeutic effect for controlled CO release into the body of CVA patients (Bauer et al. 2012). NO_2 also showed negative correlations to CVA, in contradiction to the Taipei study. However, according to Villeneuve et al. (2012), positive correlation to NO_2 may be due to a different traffic-related pollutant that was not measured in Edmonton (i.e., NO2 was served as a surrogate indicator). This could fit with the observed positive correlation with acute Benzene exposure. The positive correlation found for chronic $PM_{2.5}$ and CVA agrees with the Taipei study (Chan et al. 2006) and not with the Edmonton study (which found no significant correlation to PM) (Szyszkowicz et al. 2012).

Myocardial infarctions were more common amongst populations with low exposure to NO_2. A negative correlation was also found for acute PM_{10} exposure. In contradiction to previous data (Mustafić et al. 2012), nitrogen dioxide and PM_{10} displayed a negative correlation with heat attacks. PM_{10}, as discussed previously, is less of an indicator for physiological effect relatively to $PM_{2.5}$, which could explain this discrepancy. With NO_2 the disagreement may be due to a confounding factor not thought of.

4 Conclusions

This study presented an initial evaluation of the correlations and linkage between medical emergency calls and air pollution acute and chronic exposure. The study's findings show that exposure to extreme concentrations of carbon monoxide was correlated with an increased risk for breath-related emergencies, while average ambient concentrations were correlated with a decreased risk of stroke. Both chronic and acute exposure to volatile organic compounds such as benzene were correlated with several types of emergencies, specifically breathing difficulties and cerebrovascular accidents. Acute $PM_{2.5}$ was correlated with an increased rate of childbirth emergency calls.

The study should not be interpreted as giving definitive odds ratios of adverse health effects as a result of exposure to air pollution. The methods used were far too naive for that. With that, this study offers new insight and facilitates the inclusion of air-quality data in medical emergency teams staffing. The research also presents another angle on the difficult analysis of the association between air quality and health. Hence, the new findings presented here should be the basis for a direction of further, more rigorous, research in this field.

Volatile organic compounds (in particular benzene) have been shown to be strongly correlated to several adverse health effects while being the least monitored pollutants. In order to really understand the detriment to public health possibly caused by them, they must be better monitored. It is highly unlikely for any substantial discovery to be made with the current level of VOC data gathering.

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