What Does the Inflow of Patients into the Rambam Medical Center in Haifa Tells Us about Outdoor Temperatures and Air Pollution?

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The present study investigates the relationship between atmospheric conditions in the Haifa Bay area and the number of daily visits to the emergency department (ED) of the Rambam medical center in Haifa. In the analysis, average daily PM10 concentrations, measured by the local air monitoring stations, were mutually compared with the number of patients arriving to the emergency department of the medical center and controlled for the mean ambient daily temperatures, humidity and several other potential confounders. The analysis reveals a strong positive association between ambient daily temperatures and PM10 concentrations, and the number of patients arriving at the same day to the Rambam medical center, controlled for autoregressive effects, day of the week and season of the year. Yet, the association between meteorological conditions and the daily number of ED visits emerged with different strength across different age groups.

Keywords: Climate change; air pollution; hospital emergency department admissions; age groups

According to recent studies, the risk of heat and air pollution related morbidity and mortality increases among the elderly, children, people with pre-existing cardiovascular and respiratory diseases and among the urban poor (McMichael et al., 2004; Confalonieri et al., 2007). Although these studies found the greatest impact of heat on mortality among the elderly (75+ year old), in a recent study carried out

in several European cities (Baccini et al., 2009), heat-attributable deaths were also detected among younger adults.

In addition to direct effects on morbidity and mortality, the frequency and intensity of extreme temperatures also have indirect effects on health (Costello et al., 2009). One of them is the impact of heat extremes on urban air pollution, which tends to increase during heat waves, thus aggravating pre-existing respiratory and cardiovascular diseases (Markandya and Chiabai, 2009).

The impacts of urban air pollution on the public health have been extensively investigated in numerous studies, carried out both in Israel and abroad (see *inter alia*, Dockery et al, 1989,1993; Gauderman et al, 2000, 2004, 2007; Paz et al., 2009; Portnov et al, 2007, 2009; Dubnov et al, 2007). Recent epidemiologic studies provided extensive empirical evidence about the association between air pollution episodes, characterized by high levels of particulate air pollution and daily mortality (Ware et al., 1981; Dockery and Pope, 1994; Holgate et al., 1999; Chen et al., 2004).

The health effects of airborne particulates (such as PM_{10} and $PM_{2.5}$) on population health are widely discussed in the literature (see *e.g.* Dokery et al, 1989, 1994; Annesi-Maesano et al., 2007). While patho-physiological mechanisms of their influence remain to be elucidated, numerous experimental models confirm that PM (and other oxidant pollutants) are associated with the observed pathologies. In particular, oxidative stress and inflammatory responses in the respiratory system, along with consecutive systemic inflammatory responses, have been described in several studies (see inter alia Schlesinger et al., 2006).

In some regions, dust storms are a significant source of air pollution by particulate matters (PM). Thus, while Harrison et al., (1997) and Harrison and Yin (2000) found strong similarities between airborne PM, sampled in cities in developed and developing countries, they also pointed out that, in several less developed countries, the situation is different due to wind-blown coarse dust, reflecting local geology and surface conditions. As these studies revealed, the concentration of these pollutants is dependent on climate as the processes which suspend them into the atmosphere tend to be favored by dry surfaces and strong winds.

Several empirical studies focused on health impacts of dust storms. Thus, for instance, Chen et al., (2004), analyzed the effects of Asian dust storms on daily mortality in Taipei (Taiwan). As they found, the strongest dust storms increased the risk of respiratory diseases by 7.66% in one day after the event, by 4.92% for total deaths two days following the dust storms and by 2.59% for cardiovascular diseases in two days following the dust storms.

In recent years, the linkage between environmental change and dust storms has become a research focus. As found, dust influx is increasing as a result of soil degradation and desertification processes, in parallel with changes in wind direction and intensity (Portnov and Paz, 2008). However, large increases in the frequency of dust and sand storms over the past three years are more logically explained by changes in

weather and climate than desertification because the land area affected by desertification changes relatively little over a few years (Zhang et al., 2003). According to Prospero and Lamb (2003), who analyzed the climate change implications of dust transport from Africa to the Caribbean, the great sensitivity of dust emissions to climate, and future changes in the climate could result in large emissions from African and other arid regions in the future.

The Mediterranean Basin is characterized by a substantial warming tendency, especially during the summer season, with a clear increase in the occurrence of extremely high temperature events (Giorgi and Lionello, 2008). In the 21st century, the Mediterranean Basin is expected to be one of the most prominent and vulnerable climate change "hot spots". According to these trends, the increasing heat wave intensity and length might pose severe health problems (Paz et al., 2010).

According to Ganor and Mamane (1982), every year, tens of millions of tons of Sahara natural dust reach the eastern Mediterranean coast, located at the distance of some 2000 km from the Sahara desert. The probability for a dust episode to occur in the region increases from autumn to winter. Then, it remains steady during most of the winter, rises to its peak in April, and then decreases sharply towards summer (Ganor, 1994). In another recent paper, Ganor et al., (2010) observed 966 dust days in the eastern Mediterranean during 1958-2006. As they found, the total incidence of dust days in the region increased during past decades with an average rate of additional 2.7 dust-storm days per decade.

Although several empirical studies investigated the links between atmospheric conditions and population morbidity, there is still lack of knowledge about the linkage between the above climatic trends (i.e., temperature increase and dust storm frequency rise) and their possible impacts on human health. Moreover, this linkage has to be analyzed in depth in the eastern Mediterranean Basin, characterized by significant temperature increases, frequent dust storms and rapidly growing population.

RESEARCH METHODOLOGY

Study Area

The present analysis covers the City of Haifa and its north-eastern suburb of Kiryat Haim (see Figure 1). Haifa (265,000 residents as of 2008) is the third largest city in Israel, after Jerusalem and Tel Aviv. Since the early 1930's, the city and its suburbs have developed into Israel's primary industrial region (Portnov et al., 2008; Paz et al., 2009). The area hosts the country's largest oil refineries (with the total production capacity of 8 million tons of oil per year), a major oil-fired power plant (about 430 megawatt), as well as several smaller petrochemical and agrochemical facilities (Portnov et al., 2008). The location of large industrial complexes in the area, its complex hilly topography, and unique sea-land meteorology result in distinctive

spatial patterns of air pollution (Yuval et al., 2005). There are several health care facilities located in the city proper. Among them is the Rambam Medical Center, located in the northern part of the city (see Figure 1). Since its establishment in 1938, this center is the largest public health care facility in the Northern part of Israel.
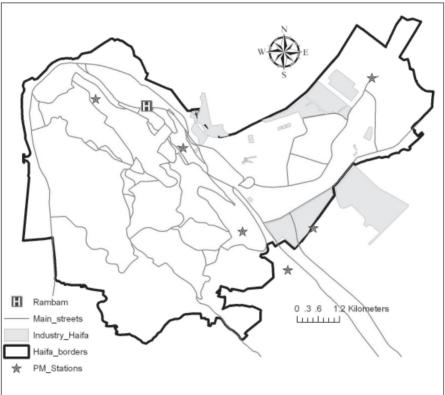
Figure 1: Map of the study area in metropolitan Haifa

Note: The air quality monitoring station, located south of the Haifa municipal boundary, in the town of Kiryat Tivon, is not shown on the map

Data Sources

The data for the present analysis were obtained from the following two main sources:

- The numbers of daily emergency department (ED) visits and disease diagnoses (approx. 730 daily observations over the period of January, 2005 to December, 2006) were obtained from the Rambam Medical Center;
- The daily mean PM_{10} air pollution levels and meteorological data (mean daily

temperatures and relative humidity) were obtained from seven air quality monitoring stations located in the study area (see Figure 1) which continuously monitor half-an-hour mean concentrations of PM_{10}, as well as outdoor temperatures and humidity.

Dependent Variables

Four dependent variables were analyzed: a) the total number of the patients arriving on a given day to the *general* emergency department (ED) of the medical center and b) the daily numbers of visitors by three separate age groups of patients - children below 18, adults (18-64) and the elderly (65+), to control for possible age-related effects.[1]

Explanatory Variables

The following variables were used to explain the inflow of patients into the ED of the medical center:
- **PM:** Mean daily PM_{10} concentrations (ppm), obtained by averaging daily records of 7 air quality monitoring stations (AQMS) located in the study area;
- **HSI:** Heat Stress Index, calculated using a non-linear combination of mean daily temperatures and relative humidity[2] (see Appendix 1), obtained by averaging records of individual AQMS;
- Binary variables for **summer** (June through August) and **winter** (December through February), to control for possible seasonality;
- Dichotomous variables for **Saturdays** and **Sundays**, as opposed to other days of the week (Saturday is weekend in Israel, during which many people do not travel on religious grounds, whereas Sunday is the first working day of the week, which corresponds to Monday in western countries, during which a high medical center turnover is commonly recorded).

We also included in the analysis a dichotomous variable - **2LW**, - for the 2006 Second Lebanon War (July 12th through August 14th, 2006), during which the northern part of the country came to a temporary standstill, and one-day lags of heat stress and PM_{10} (HSI_1 and PM10_1, respectively), to account for a potential lag between changes in environmental conditions and ED turnover.

Statistical Analysis

First, we started with a general analysis of the total numbers of ED visits. As their distribution appeared to be reasonably close to normal (see Table 1), autoregressive integrated moving-average (ARIMA) models were used to investigate the link between heat stress, PM_{10} measurements and the number of ER visits, controlled for days of the week, seasons of the year and auto-regressive components.[3]

In calibrating the ARIMA models, the numbers of autoregressive orders, time-se-

ries stationarity, and moving-average orders were analyzed. In the following discussion only the best performing model specifications (ARIMA [7,1,2]) are reported. The ARIMA analysis was performed in the SPSS17.0™.[4]

Table 1: Descriptive statistics of the research variables

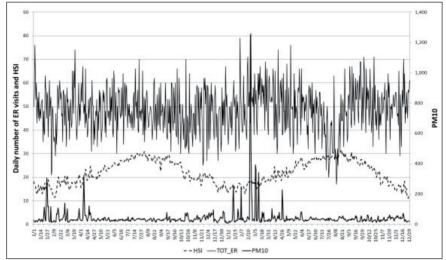| Parameter	All ED visits	Daily ED visits by age group		
		<18	18-64	65+
Mean	48.45	8.63	23.55	16.26
Std. Deviation	9.85	3.39	6.13	4.88
Minimum	17	0	7	2
Maximum	81	23	46	34
No of days under analysis	730	730	730	730
Test distributions:				
KS (normal)*	1.047	2.756	1.633	1.820
Asymp. Sig. (2-tailed)	0.223	<0.001	0.010	0.003
KS (Uniform)*	6.127	9.712	7.976	7.363
Asymp. Sig. (2-tailed)	<0.001	<0.001	<0.001	<0.001
KS (Poisson)	2.350	1.056	1.538	1.563
Asymp. Sig. (2-tailed)*	<0.001	0.215	0.018	0.015

*Kolmogorov-Smirnov test

RESULTS

General Trends

As Figure 2 shows, the number of daily ED visits appears to fluctuate in the range of 30-60 visits per day. There are more ED visits in summer, July through August, when heat stress reaches its peaks of about 30-32°C, while there are less visits in the fall (September through November), when HSI drops to more comfortable levels of 18-20°C. A substantial decline in the number of ER visits is also observed in July-August 2006 (i.e., during the 2006 Second Lebanon war), when the average daily numbers dropped to 35~ visits per day from its average numbers of 50 visits per day one month earlier. Characteristically, several "splashes" in the PM_{10} concentrations, observed throughout the study period (e.g., in January 2004, April 2004, February-March 2006 and in April 2006), *do not* appear to correspond to any substantial rise in the numbers of ED visits. However, a more thorough investigation, controlled for potential confounders, is needed to verify this observation.

Figure 2: Mean daily HSIs (middle line); concentrations of PM_{10} (bottom line) vs. numbers of ER visits in 2005-2006 (upper line) - a time sequence plot.

ARIMA Models

In addition to ER visits' autoregressive lags and disturbances (AR1-AR2, AR7 and MA1-MA2), which correlate, rather unsurprisingly, with the numbers of ER visits in a given day, the Saturday, Sunday, 2LW, PM_{10} and HSI variables show a strong association with the daily ED turnover ($P<0.05$; see Table 2). On the overall, as expected, the numbers of ED patients drop on Saturday, when many people refrain from travelling on religious grounds, and increase on Sunday, the first working day of the week ($P<0.01$). There also appear to be significantly less ED visits during the Second Lebanon war (2LW: b=-13.475; $P<0.001$), when many residents of the area refrained from travelling altogether, unless absolutely necessary, due to rocket attacks and proximity of the study area to the Lebanese border.

Notably, higher PM_{10} concentrations and heat stress appear to increase the ER turnover on the same day (PM_{10}: b=0.013; t=2.152; p<0.05; HSI: b=0.525; t=1.823; p<0.1; see Table 2). However, the effect of these climatic variables is not uniform across individual age groups. Thus, the number of children brought to the medical center appears to increase substantially in line with rising PM_{10} levels (b=0.009; t=4.346; $P<0.001$), while being less "responsive" to outdoor heat stress (b=0.150; t=1.332; $P>0.1$).

In contrast, the numbers of ED visits by the elderly (65+) appear to be more strongly related to the heat stress (HSI: b=0.288; t=1.865; $P<0.1$), than to PM_{10} air pollution levels (b=0.002; t=0.548; $P>0.1$). Possible reasons for this interesting regularity will be discussed in the following section.

Table 2: Factors affecting the number of ER visits by all population and separate age groups (Method – Autoregressive integrated moving average model - ARIMA [7,1,2])

Variables	All ED visits		<18		18-64		65+	
	B^a	t^b	B^a	t^b	B^a	t^b	B^a	t^b
A. Regression Coefficients								
Summer	-2.074	-1.444	-0.183	-0.352	-1.087	-1.238	-0.461	-0.773
Winter	0.498	0.355	0.083	0.165	-0.133	-0.154	0.021	0.037
Saturday	-8.542	-8.667***	-0.483	-1.444	-3.042	-4.580***	-4.266	-9.210***
Sunday	8.953	9.080***	0.788	2.353**	5.570	8.380***	2.237	4.827***
2LW	-13.475	-6.065***	-3.557	-4.346***	-3.932	-2.964***	-5.842	-6.278***
PM_{10}	0.013	2.152**	0.009	4.063***	0.002	0.584	0.002	0.548
PM10_1	-0.002	-0.295	-0.005	-2.052**	0.001	0.128	0.003	0.931
HSI	0.527	1.823*	0.150	1.332	0.091	0.455	0.288	1.865*
HSI_1	-0.261	-0.900	-0.207	-1.831*	0.179	0.895	-0.352	-2.276**
B. Non-Seasonal Lags								
AR1	-0.339	-1.816*	0.344	0.815	-0.390	-1.760**	-0.792	-2.445**
AR2	0.049	1.106	0.080	1.667	-0.014	-0.297	0.029	0.584
AR3	0.085	2.045**	0.030	0.539	-0.069	-1.524	0.104	2.088**
AR4	0.015	0.347	-0.025	-0.554	0.012	0.264	0.026	0.447
AR5	0.046	1.125	0.022	0.536	0.036	0.824	-0.062	-1.211
AR6	-0.004	-0.104	-0.033	-0.815	0.018	0.419	-0.029	-0.586
AR7	0.155	3.668***	0.044	1.135	0.134	3.262***	0.019	0.432
MA1	0.553	2.983***	1.261	2.989***	0.510	2.306**	0.180	0.557
MA2	0.419	2.328**	-0.268	-0.649	0.447	2.112**	0.794	2.503**
Constant	0.002	0.254	0.002	1.131	0.000	-0.015	0.001	0.365
Series length	730		730		730		730	
RSS	50821		7972		24667		15653	
Log-Likelihood	-2541		-1862		-2258		-2086	
AIC^d	5120		3763		4554		4210	

[a] Unstandardized regression coefficient; [b] t-statistic; [c] residual standard error of the estimate; [d] Akaike's Information Criterion.
*** Indicates a 0.01 two-tailed significance level; ** indicates a 0.05 two-tailed significance level; * indicates a 0.10 two-tailed significance level.

Using the regression coefficients reported in Table 2, we can estimate changes in ED admissions attributed to HSI and PM_{10} changes. Thus, an increase in PM con-

centrations from their daily average of 50 ppm to the absolute maximum, observed in the study area (about 950 ppm), is likely to augment, *ceteris paribus,* the number of daily ED admission in the 0-18 age group by about 50%, from 7 (long term daily average) to 11, or by 0.8 additional admissions per each 100 ppm increase in the ambient PM_{10} volumes. Concurrently, a 50% increase in the heat stress, from its daily average of 18°C to its absolute maximum of 32°C, observed in the study area in 2004-2006, is likely to bring another 4 patients per day in the 65+ age group, which corresponds to an increase by about 25% from its average of 16 patients per day in that age group (see Table 1).

CONCLUSIONS AND DISCUSSION

In the present study we investigated the link between daily changes in atmospheric conditions and the influx of patients of different age groups into the Rambam medical center in Haifa, which is the largest public health facility in the study area. The analysis of daily time series was performed using advanced statistical tools (ARIMA). The analysis revealed a strong association between the daily numbers of ED admissions and outdoor atmospheric conditions, measured by heat stress and PM_{10} air pollution. Importantly, the relationship emerged statistically strong after controlling for auto-regression lags (that is, the numbers of medical center admission during previous days and their variability) and several potential confounders, including day of the week and season of the year. The question posited in the title of the paper, *What does the inflow of patients into the Rambam medical center in Haifa tells us about outdoor temperatures and air pollution?*, can thus be answered as follows: *the daily influx of patients into this medical facility appears to be a robust indicator of outdoor air pollution and heat stress fluctuations.* In particular, according to our estimates, an increase in PM_{10} concentrations from their daily average of 50 ppm to the absolute maximum observed in the study area of 950 ppm, is likely to raise, *ceteris paribus,* the number of daily ED admission in the 0-18 age group by about 50%. Concurrently, a 50% increase in the heat stress (HSI), from its daily average of 18°C to its absolute maximum observed in the study area during 2004-2006 (32°C), is likely to increase the inflow of patients in the 65+ age group by about 25%.

The above mentioned differential impacts of HSI and PM_{10} fluctuations on different age groups (that is, a stronger effect of PM_{10} on children than on the rest of population, and a stronger effect of HIS rises on the elderly than on the rest of the study cohort) is an interesting finding of this study. Although these differential effects and their underlying causes warrant further investigation, some general explanations can nevertheless be offered.

Children are found to be at particular risk of air pollution exposure, due to their unique anatomical, physiological, and behavioral characteristics. Thus, the number of children's alveoli tends to increase tenfold from birth to the age of four and their lung tissue develops with greater permeability of the epithelium layer than it does in

adults. In addition, both the lung surface area and air intake per kilogram of lung tissue are 50% greater for children than for adults. Lastly, children tend to spend more time outdoors and perform outdoor activities with greater lung ventilation rates than adults (Dubnov et al., 2011).

Several studies of the effect of air pollution focused on the exacerbation of existing respiratory diseases in children, respiratory symptoms, and short, usually reversible, effects of air pollution on children's pulmonary function (PF), especially linked to ozone (O_3). Large-scale longitudinal studies, initiated in the early 1990's, such as the Children's Health Study, added several other air pollutants to the list of environmental factors that are likely to affect the development of children's pulmonary function: particulate matters (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and elemental carbon (C) (*ibid.*). In light of these findings, our results, linking medical center admissions of children to outdoor PM_{10} pollution events, are fully explainable. Concurrently, the effect of heat extremes on respiratory and cardiovascular morbidity among the elderly and people with weakened immune system is also widely reported in the literature (cf. *inter alia* Markandya and Chiabai, 2009). The main contribution of the present study to the existing body of literature is, in our view, that the *same extreme atmospheric conditions may generate different health responses from different population groups.*

Lastly, the economic implications of the results of the present study should be mentioned. As in other developed countries, medical care in Israel, especially associated with hospitalization, is very costly and places a considerable burden on the public budget. In light of this trend, the significant increase of extreme weather events together with the fact that severe atmospheric conditions, such as heat waves and air pollution events, may force more people to seek medical attention may justify more attention to disease prevention, by e.g., improving the quality of construction (insulation, cross-ventilation, cooling, etc.) and reducing air pollution, etc. These measures may be, altogether, a better use of public funds, while improving population health in general, especially among vulnerable population groups.

NOTES

1. The numbers do not include car-related injuries and cancer patients arriving for treatment.
2. Calculation of the Heat Stress Index (HSI): Heat Stress Index (HIS) is "apparent temperature" that reflects the combination of actual ambient temperatures and relative humidity (Steadman, 1979) and is calculated as follows:
    $$HSI = 0.567 \times Ta + 0.393 \times e + 3.94 \qquad [1]$$
    where: Ta= Dry bulb temperature (°C), and e= Water vapor pressure (hPa) [humidity], calculated using the following equation:
    $$e = rh\,/100 \times 6.105 \times \exp\,[17.27 \times Ta\,/\,(237.7 + Ta\,)] \qquad [2]$$

where: rh= Relative Humidity [%]
3. Autoregressive Integrated Moving Average model (ARIMA) is a statistical technique for the analysis of sequential observations, especially suited for Gaussian data, which makes it possible to include, in addition to autoregressive components, predictor variables to the model (Box et al, 1994).
4. Poisson regressions are commonly used in epidemiological studies for analyzing the associations between daily counts of events and environmental events (see inter alia Kuhn et al, 1994; Tobias et al, 2001). Several empirical studies have found that ARIMA models and Poisson regressions provide very similar results (Long 1997; Thompson et al, 2009). Although the Poisson approach is suited for count data, the preliminary investigation indicated that the distribution patterns of our data (especially for all population; see Table 1) were fairly close to normality, thus justifying the use of ARIMA models.

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