PHASE

Public health Adaptation Strategies to extreme weather events

SCIENTIFIC SUMMARY for Public health on the synergy between extreme temperatures, heat waves, air pollution and forest fires

What is known on the synergistic health effects of extreme temperatures, air pollution and forest fires

Background

Every year, high temperatures and heat waves during summer and low temperatures and cold spells in the winter are associated with large increases in mortality. Climate change is expected to result in a further rise in temperature but also in more extreme events (Meehl and Tebaldi 2004, McMichael et al. 2006, IPCC, Climate change 2007). There has been an increasing awareness of the acute health effects of temperature extremes, particularly heat, supported by a growing body of scientific evidence (Zanobetti and Schwartz 2008, Baccini et al. 2008, Analitis et al. 2008, D'Ippoliti et al. 2010). Recent evidence on the effects of hot weather, such as the high mortality experienced during the extreme heat wave that struck Europe in the summer of 2003, have raised public concern (Michelozzi et al. 2005, Le Tetre et al. 2006). Forest fire events have also been reported to have acute health effects and their frequency is expected to increase with climate change. Forest and land destruction especially near urban areas, worsens the quality of life. Furthermore, apart from accidents occurring during the fires there is evidence for an increase in hospital visits for respiratory disease exacerbation and in the frequency of respiratory symptoms. There are also reports for increased non-accidental morality which could be related to increased air pollution and also extreme stress (Analitis et al 2014).

Air pollution is a well-known public health risk factor. In the past 25 years results from many epidemiologic studies gave evidence for a positive association between air pollutants concentrations and total and cause-specific mortality (Schwartz and Dockery 1992, Dockery et al. 1993, Anderson et al. 1996). Large multicity studies in Europe, USA and other part of the world, documented and quantified the adverse effects of air pollution on health (Katsouyanni et al. 1997, Samet et al. 2000, Katsouyanni et al. 2009). Fine particles (PM10, PM2.5), ozone, nitrogen dioxide and sulfur dioxide concentrations even at relatively low levels, have been linked with increases in morbidity and mortality. In the recent

Global Burden of Disease study (Lim et al 2012) air pollution is included among the top ten factors with the largest effects on the global disease burden.

Meteorology and air pollution are associated. Climate change could affect air quality directly but also indirectly by affecting the proportional contribution of sources and via changes in human behavior (Ebi and McGregor 2008). Climate change can affect local to regional air quality directly through changes in chemical reaction rates, boundary layer heights that affect vertical mixing of pollutants, and changes in synoptic airflow patterns that govern pollutant transport. Energy demand could also increase and, as we continue to rely on the combustion of fossil fuels, this could lead to an increase of PM and NOx levels. Additionally, some particles as well as ozone are products of photochemical reactions and increase with higher temperatures at any given precursor emission level. Forest fires on the other hand directly emit greenhouse gases, particles and other gases (including ozone precursors) into the air. The effects of the forest fire events on short concentrations of pollutants which influence populated areas have been studied in some case studies and effects have been reported, but more research is needed on the way these emissions are dispersed in time and space and their contribution to the long term concentrations in the various locations of interest (Bytnerowicz et al 2009).

To better assess the potential impact of current climate change scenarios on human health, it is necessary to understand not only the independent effects of temperature and other meteorological variables (adjusting for confounders, including pollutants), but also to elucidate any synergistic effects between EWE and forest fires on the one hand and air pollution on the other. The focus of our review (Katsouyanni et al, 2014) was the synergy between two exposures, each of which encompasses a variety of components: air pollution on the one hand and EWE and FF on the other. There is scope in considering these synergies, as has been described in more detail above: 1. evidence on interactive effects has already been published and 2. climate change is expected to lead to an increasing frequency of EWE and FF, leading to even larger effects of air pollution on health, if synergy is a reality.

The study of short and longer-term effects requires different information: data on air pollutants concentrations are needed for daily or even shorter time periods in order to study acute effects, which are of particular relevance in relation to EWE and FF due to their inherent episodic nature. Additionally information on the contributions of EWE and FF to long-term concentrations in densely populated locations is needed, since there is ample evidence that long term effects are particularly important for public health. Furthermore, the relative toxicity of particles emitted by FF or originating from chemical processes associated with EWE is of importance for assessing the type and severity of health outcomes.
The information available for research or for health impact assessment on the issues described above is sparse and fragmentary. There is an urgent need to enlarge the evidence base in an organized and planned way, the importance of which is highlighted by climate change related increases expected in EWE and FF.

More specifically for European research the following points are considered as most important:

1. Coordinated research to assess emissions from FF, their dispersion according to prevailing weather patterns and how they affect pollutant concentrations at short time scales, in densely populated urban centers.
2. Quantification of the long term contribution of FF emissions to specific population exposures.
3. Research leading to better understanding of the association of desert dust events, heat waves and cold spells and air pollution concentrations mainly in urban centers (also in other locations).
4. Epidemiological and toxicological studies on the relative toxicity of particles emitted from various sources or influenced by climate driven chemical reactions and how this toxicity may be influenced by the particles' physical and chemical properties.

Subgroups of the population most at risk

Subgroups of the population most vulnerable to the effects of air pollution or heat are relatively well established (Koppe et al. 2004; Lippman 2000). They include: the elderly; those in institutions, such as residential care homes, are at particular risk; young children and asthma sufferers; people suffering from chronic diseases, particularly cardiovascular and respiratory conditions, renal diseases, diabetes and obesity, as well as those taking certain medications; people of lower socioeconomic status and those living in densely populated urban neighborhoods.

The latter group is at greater risk mainly due to living conditions that lead to higher exposures, although people of low socioeconomic status have also lower health status and are more likely to suffer from predisposing diseases. The known vulnerability of people with lower socioeconomic status brings us to an important point regarding the numerous factors that can modulate an individual's exposure to ambient air pollutants and heat. These include living in an urban vs. rural area, living near sources of pollution such as major highways, patterns of indoor and outdoor activities, means of transportation used, ventilation systems and presence of air conditioning in the workplace and at home, protective behaviors in case of high pollution levels or heat, etc.
Differences in exposure due to such factors probably play a role at least as important as biological susceptibility in determining an individual's overall vulnerability to heat and/or pollution. This is especially true for any synergistic component, which could be subdued by a reduction of either of the two exposures such that interaction conditions are no longer met. It seems reasonable to hypothesize that groups most sensitive to synergistic effects might better be characterized by the prevalence of risk factors for high exposure, rather than by the prevalence of predisposing biological or pathological conditions. This will need to be assessed in future studies.

Under conditions of combined heat and pollution, all of these groups will clearly remain more vulnerable than the general population. However, it is difficult to evaluate who might exhibit additional sensitivity to synergistic effects, because such questions have not yet been formally addressed in the literature. There is only very limited evidence pointing to specific groups that might be particularly sensitive.

In the PHASE project, analysis of the synergistic effect of high and low apparent temperature and heat wave days with air pollution by age groups has been applied. The high temperature and heat wave effects are found higher among the elderly as expected, for total, cardiovascular and respiratory mortality. The interaction terms (assessing synergy) indicate synergy between high temperature and high ozone and PM_{10} pollution for the 75+ age group but do not reach the nominal level of statistical significance in most cases. Only the increase in cardiovascular mortality associated with an increase in apparent temperature is statistically significantly higher during days with higher PM_{10} concentrations. The pattern is largely similar during heat-wave days. However, as heat wave days are relatively few the results are not statistically robust, especially concerning respiratory deaths, which also represent a small number (usually less that 10% of the total number of deaths). Finally there appears to be no indication for synergistic effects in any age group during the cold period.

Within PHASE, the effects of forest fires and they synergy with high PM10 levels has been assessed for two representative cities, Athens and Valencia. The main effects on mortality during forest fire days were high and statistically significant in Athens, especially for the >75 years age group. These effects were much more pronounced on days with large (as opposed to medium and small) fires. However, the synergy detected was more evident and only reached statistical significance in days that were characterized by small or medium fires and high PM10 concentrations and not for days with large fires and high PM10 levels.

What the PHASE project has contributed (results from case studies and work carried out in PHASE)

In the framework of the PHASE Project, in WP7, we studied the potential synergy between air pollution and extreme weather events and forest fires and their impact on cause specific mortality. This issue has not been addressed before to such a scope and extent.

The database compiled for the PHASE project includes mortality by cause and age group, meteorological and air pollution daily series from 8 European cities (Athens, Barcelona, Budapest, Helsinki, Paris, Rome, Stockholm and Valencia) within the years 1990-2010.

The mortality data included the daily number of deaths from all natural (ICD-9: 1-799), cardiovascular (ICD-9: 390-459) and respiratory causes (ICD-9: 460-519) by age groups: 0-14, 15-64, 65-74 and >75 years and all ages. Mortality data were obtained from the registries of each participating city.

The air pollution data included gaseous and particulate pollution indicators, and specifically: PM10 (mean 24-hours- TSP in Valencia), O3 (maximum 1 hour, maximum 8-hours moving average), NO2 (maximum 1 hour, mean 24-hours) and SO2 (mean 24-hours). The air pollution series were obtained from the urban monitoring network of each city.

The meteorological data consisted of air temperature, apparent temperature, relative humidity, wind speed and direction and sea level pressure daily series.

The main meteorological exposure used was apparent temperature (AT), which is a combination of air temperature (temp) and dew point (dew) using the formula:

$$AT = -2.653 + 0.994*temp + 0.0153*(dew)^2$$

(Kalkstein and Valimont 1986).

Concerning forest fires, two case studies in Athens, Greece and Valencia, Spain took place, based on the fact that these two cities represent cities with forest fire problems in the south of Europe and data availability. Information on the date that each fire was started and extinguished, the total area burned and the location of the fire was available from 2005 to 2010 in Athens and from 1994 to 2010 in Valencia. Data were provided from the Fire Service for Athens and from the Spanish Ministry of Environment and Agriculture for Valencia.

The analysis was carried out separately in the warm (April to September) and cold (October to March) period of the years 2004 to 2010. Based on previous results and in collaboration with WP4, the temperature-mortality association was considered J-shaped in the warm season and linear in the cold season. Furthermore lags 0-3 and 0-6 were considered for the warm and the cold period, respectively.

Heat waves – air pollution interaction were studied in the summer months (June to August). We used the EUROHEAT project’s definition for heat-waves. Specifically in order for a day to be characterized as a heat-wave day, both maximum apparent temperature and the minimum temperature had to be > 90th percentile of its distribution in a particular city for each month over all years, with duration >= 2 days.

For the first stage (city specific) analyses, a GEE modeling approach was applied. We assumed a Poisson distribution for the outcome variable (daily number of deaths). Furthermore, we assumed that the observations within each season are correlated while observations in different seasons are independent. Based on previous studies a first order correlation structure was specified.

We studied temperature and heat-waves separately. Temperature was entered in the model as a piecewise-linear term with different slopes above and under the turning point in the warm period analysis and as a linear term in the cold one. A dummy variable indicating a heat-wave day was the main exposure variable when heat-episodes were studied. Potential confounders were introduced as covariates were air pollution (lag 0-1), barometric pressure, wind speed, calendar month, day of the week, holiday and time trend. The air pollutants were considered alternatively in each model. For the investigation of interaction between temperature/heat-wave and pollutant effects, an interaction term between temperature/heat-wave and each pollutant separately was introduced in the model and the effect of heat-wave days was estimated during “high” and “low” pollution days. As “low” pollution days we have defined the days at the 25th percentile of the pollutant distribution and as “high” pollutant days those at the 75th percentile.

A second-stage analysis, random effects meta-analysis, was performed to provide a quantitative summary of all individual-city results.

For the forest fires case studies we used Generalized Additive Models (GAM) allowing for overdispersion (quasi-likelihood used). The daily number of total natural and cause-specific deaths by age group was used alternatively as outcome variables. Three dummy variables were included in the model for forest fires: one indicating the days during which a major forest fire was occurring (one which burnt more than 30,000,000 m^2), a second indicating days with medium size forest fires (the ones which burnt between 1,001,000 and 30,000,000 m^2 and a third for days with small fires (that burnt between 10,000 and 1,000,000 m^2). This categorization was based on the distribution of the area burnt. If in a specific day there was more than one fire, the area burnt that day was the sum of all simultaneous fires. Potential confounders were also included in the models: apparent temperature (spline), PM10, wind speed and direction, day of week and time trend.

Main findings

The strong effect of increasing temperatures and heat waves, especially in the older age groups (65-74 years and >=75 years old) are also identified in this analysis. The interaction between high ozone and PM10 concentrations is positive in most age groups and causes of death but does not reach always the nominal level of statistical significance. A significant interaction between temperature and PM10 in total (15-64 age group) and CVD mortality (>75 and all ages) was found. Thus, for example, on days with "low" ozone concentrations (defined as days at the 25^{th} percentile of each city-specific ozone distribution) 1 ^{o}C increase in apparent temperature is associated with 2.5% increase in the total daily number of deaths, whilst on "high" ozone days (defined as days at the 75^{th} percentile of each city-specific ozone distribution) it is associated with 2.8% increase ($P<0.10$); on low PM10 days one ^{o}C increase in apparent temperature is associated with 2.3% increase in the cardiovascular daily number of deaths, whilst on "high" PM10 days it is associated with 2.9% increase ($P<0.05$). The same pattern, but less consistent, is evident with heat wave days, which are generally associated with larger increases in total and cause-specific mortality when ozone and PM10 are also high, compared to when they are low, but the differences do not reach the nominal level of statistical significance.

In the cold season there is no consistent/significant evidence for temperature – air pollution interaction. Also, no consistent interaction was identified for NO_2 and SO_2 effects.

In Athens, large fires have a strong effect on the daily number of deaths during the days of the fire and there is dose-response (ie a consistently higher effect is observed for large fires compared to medium or small). The effects are stronger for respiratory mortality and for the elderly population groups.

There is some evidence for synergy between the occurrence of a forest fire and high particulate pollution levels effects on total and CVD mortality in the younger (<75) age group and for small or medium size fires (rather than large fires). It should be noted that the emissions of gases and particles from FF may or may not affect particle concentrations in nearby areas, as the transportation and dispersion of pollutants depends on the prevailing meteorological conditions (such as wind speed and direction). An explanation of this phenomenon may lie on the fact that the effects of forest fires do not operate only via exposure to particulate matter, but may also reflect the population stress from the extended and prolonged fires and by intense media focus. The latter mechanism is comparatively more important in larger size fires compared to small, leaving ground for the role of increased pollution concentrations to be more easily detected in correspondence to smaller size FF.

There appears to be interaction (or effect modification) between the effect of FF and the occurrence of a heat wave (HW). Thus the effects of FF during HW days are significantly larger compared to non-HW days. Additional adjustment for temperature leads to a decrease of the FF effects, which however remain large and statistically significant (and show dose-response).

The analysis of data from Valencia led to less consistent results: thus none of the effects per age group or cause of death were statistically significant, whilst effects on cardiovascular mortality were more evident in those <75 years of age and those on respiratory mortality more evident in the elderly (>=75 years). Because of the lack of statistical significance, interaction (synergy) was not investigated further.

Implications for Public health (key public health messages)

1. When a meteorological forecast for increased temperature or heat wave is in place, extra measures should be taken to decrease air pollution concentrations, especially by ozone and particulate matter.
2. The role of pollutant emissions during forest fire events are not well understood on a large enough scale for population studies. From our case study analysis, there are indications that the effects of forest fires are stronger when the emitted pollutants are leading to increased particulate matter concentrations.

Preparedness and response tools necessary to define a Prevention Plan

1. A communication campaign to inform the population on the avoidance of high temperature exposures and concurrent high ozone and PM10 exposures will be useful for the protection of public health. The elderly should be particularly addressed.
2. When a meteorological forecast for particularly high temperatures or heat waves is in place, there should be a warning system, including and immediate communication with the air quality decision makers to give them time for interventions to lower air pollution concentrations (especially ozone, and its precursors, and particles).

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