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Mortality and morbidity in a population exposed to multiple sources of air pollution: A retrospective cohort study using air dispersion models

Carla Ancona [a,*], Chiara Badaloni [a], Francesca Mataloni [a], Andrea Bolignano [b], Simone Bucci [a], Giulia Cesaroni [a], Roberto Sozzi [b], Marina Davoli [a], Francesco Forastiere [a]

[a] Department of Epidemiology, Lazio Regional Health Service, Via Santa Costanza 53, 00198 Rome, Italy
[b] Lazio Environmental Protection Agency, Via Boncompagni 101, 00187 Rome, Italy

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ABSTRACT

Background and aims: A landfill, an incinerator, and a refinery plant have been operating since the early 1960s in a contaminated site located in the suburb of Rome (Italy). To evaluate their potential health effects, a population-based retrospective cohort study was conducted using dispersion modeling for exposure assessment.

Methods: A fixed cohort was enrolled in the Rome Longitudinal Study in 2001, mortality and hospitalizations were followed-up until 2010. Exposure assessments to the landfill (H_2S), the incinerator (PM_{10}), and the refinery plant (SO_X) were performed for each subject using a Lagrangian dispersion model. Individual and small-area variables were available (including exposures levels to NO_2 from traffic and diesel trucks). Cox regression analysis was performed (hazard ratios, HRs, 95% CI) using linear terms for the exposures (5th–95th percentiles difference). Single and bi-pollutant models were run.

Results: The cohort included 85,559 individuals. The estimated annual average exposures levels were correlated. H_2S from the landfill was associated with cardiovascular hospital admissions in both genders (HR 1.04 95% CI 1.00–1.09 in women); PM_{10} from the incinerator was associated with pancreatic cancer mortality in both genders (HR 1.40 95% CI 1.03–1.90 in men, HR 1.47 95% CI 1.12–1.93 in women) and with breast morbidity in women (HR 1.13 95% CI 1.00–1.27). SO_x from the refinery was associated with laryngeal cancer mortality in women (HR 4.99 95% CI 1.64–15.9) and respiratory hospital admissions (HR 1.13 95% CI 1.01–1.27).

Conclusions: We found an association of the pollution sources with some cancer forms and cardio-respiratory diseases. Although there was a high correlation between the estimated exposures, an indication of specific effects from the different sources emerged.

1. Introduction

In the Malagrotta area, located in the suburb of Rome (Italy), a large landfill for municipal solid waste (MSW), an incinerator of medical wastes, and a petrochemical refinery are situated within just a few kilometers of each other. Limited evidence of increased risk of cancer has been suggested among people living close to incinerators (Porta et al., 2009; Forastiere et al., 2011; WHO, 2007) and several uncertainties limit the interpretation of the available epidemiological studies on landfills (Porta et al., 2009). There is no clear indication that living close to a refinery is associated with cancer incidence or cause-specific mortality (Simonsen et al., 2010). An old study suggested an increase in lung cancer mortality among women living close to major industries (Bhopal et al., 1998), while a more recent study (Cirera et al., 2013) has documented an association with haematological cancers.

Most of the studies conducted in contaminated sites have methodological problems, including the use of health data at the aggregate level, the limited possibility of adjusting for socio-economic status, (Floret et al., 2003; Viel et al., 2008) or the distance from the source used as a proxy for population exposure. In 2011, the European Environmental Agency (EEA) suggested applying dispersion models to provide a better exposure assessment (European Environmental Agency, 2014). Recently, an assessment of air pollution exposure from incinerator emissions was performed in the UK and a review on exposure assessment methods in epidemiological studies of incinerators was published (Ashworth et al., 2013; Cordioli et al., 2013).

* Corresponding author. Fax: +39 06 83 060 374.
E-mail address: c.ancona@deplazio.it (C. Ancona).

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Previous studies conducted in the Malagrotta area detected an excess of stomach cancer among workers at the medical waste incinerator and an increase of lung, bladder, brain cancers and multiple myeloma among petroleum refinery workers (Rapiti et al., 1997; Lo Presti et al., 2001). A study on the resident population did not indicate an excess mortality in people living close to the landfill, except for laryngeal cancer among men (Michelozzi et al., 1998).

This study aimed at evaluating the morbidity and mortality effects of exposures to the three sources of air pollution (landfill, incinerator, and refinery plant) in the cohort of people living in the Malagrotta area. Dispersion models were used for exposure assessment considering urban traffic and individual factors (e.g. educational level, occupation, area-based socioeconomic status) as potentially confounding variables.

2. Methods

2.1. The study plants and the area of investigation

The landfill, one of the largest in Europe (15 ha of surface, 1.46 million t MSW/year), began officially in 1984 receiving unprocessed municipal waste; however, the unofficial use of the landfill dates back at least 10–15 years. The closure of the landfill was announced in 2004 but actually occurred at the end of 2013, after Italy received a notice from the EU Commission for infringement of the Landfill Directive (1999/31/EC). The incinerator for medical waste (stack height 80 m, stack diameter 1.13 m, exit velocity 15.5 m/s, capacity 60 t/day) began its activity in 1996, replacing the old MSW incinerator that had burnt waste from 1964 to 1985 and then closed because of failure to comply with pollution standards as no emissions control measures were operating. The petrochemical refinery (97 ha of surface, 15 stacks ranging from 25 to 72 m in height, stacks diameter ranging from 0.8 to 2.9 m, exit velocity ranging from 1 to 5.9 m/s) has been refining 4.3 million t/year of crude oil since 1964 and is the most important refinery plant in central Italy.

The study area was defined as a 7 km radius from the boundary of the landfill defined using GIS software to allow a proper comparison among subjects with a wide range of contrasting exposure values The petrochemical refinery and the waste incinerator were located by their chimneys coordinates. The World Geodetic System of 1984, with the Universal Transverse Mercator zone 33Nord projection (WGS84_UTM33N) was the reference for the geographical coordinates.

2.2. Exposure assessment

We used a Lagrangian particle model (SPRAY ver.5) to simulate the concentration of air pollutants (ARIANET, 2014). The SPRAY model simulates the transport, dispersion and deposition of pollutants emitted (2005 emission inventories) using the orography, the meteorological data (managed by RAMS 2005 (RAMS, 2014)), the turbulence and the hourly spatial distribution (horizontal and vertical) of the emissions, based on the characteristics of the single source and on the mass fluxes (g/h). The model follows the path of fictitious particles in the atmospheric turbulent flow, and it is able to take into account complex situations, such as the presence of obstacles, breeze cycles, strong meteorological non homogeneities and non-stationary, wind calm conditions.

The domain for estimating pollutants concentrations was a square of $30 \times 30\ km^2$ and the resolution chosen was 500 m (consistent with the meteorological fields). A single concentration value was estimated as the annual average for a square cell of 500 m × 500 m. For each source, a pollutant was selected as the exposure marker: hydrogen sulphide (H_2S) for the landfill, sulphur oxides (SO_X) for the petrochemical refinery, and airborne particulate matter of diameter less than 10 μm (PM_{10}) for the incinerator.

The landfill emissions (H_2S) were generated using Landfill Gas Emissions Model (Landfill Gas Emissions Model, 2014). Using the dates of starting and ending of the operation for each sector of the landfill, the waste capacity and the waste acceptance rate, the emission rates for H_2S were calculated using a first-order decomposition rate equation. The Emission Manager software EMMA was used to approximate the landfill shape as a regular grid with a resolution of 125 m × 125 m and to estimate the hourly emissions of the H_2S emission in each landfill allotment (Calori and Radice, 2004).

We obtained the hourly emission values of SO_X (refinery) and PM_{10} (incinerator) assuming uniform time modulation and using information about the chimney geographic coordinates, its internal diameter, the percentage of release of gases, the temperature and speed of the flue gas. Estimated annual average concentration maps of current H_2S, SO_X, and PM_{10} levels were produced. Although it can be assumed that significant changes occurred in relation to the activity in the area and the specific emissions, i.e. increasing and decreasing of the landfill activity, change in the activity of the incinerator, emission control from the refinery, no emission data from the past were available so to consider time-changes in the exposure variables in the analysis. Therefore, no attempt was made to back extrapolate concentration levels.

2.3. Enrollment of the cohort and follow-up procedures

The Rome Longitudinal Study (RoLS) (a population-based cohort enrolled from the 2001 Italian census) was the source for the study cohort (Cesaroni et al., 2010). The RoLS is part of the National Statistical Program for the years 2011–2014 and was approved by the Italian Data Protection Authority. All residents, living in the study area at the same baseline address for at least 5 years before October 2001, and who did not move during the course of the follow-up, were enrolled. Vital status was assessed using the Rome municipal register during the period October 2001 to December 2010. We considered subjects as lost to follow-up if they died or moved out of the city. Each subject in the cohort was assigned a value of H_2S, SO_X, and PM_{10} corresponding to the estimated map values at their residence.

2.4. Health outcomes

We analyzed natural and cause-specific mortality and hospital admissions. We considered cancer types for which there were some possible hypotheses of an association with environmental factors: stomach, colon and rectum, liver, pancreas, larynx, lung, bladder, kidney, brain, and lymphatic and haematopoietic cancer (see appendix for ICD IX codes) (Porta et al., 2009; Bhopal et al., 1998; Michelozzi et al., 1998; Ranzi et al., 2011; Rushton 2003; Elliott et al., 1996; Bhopal et al., 2009). The underlying cause of death for deceased subjects was retrieved from the regional Registry of Causes of Death, while hospital admissions were obtained from the regional Hospital Information System. For each subject only the principal diagnoses cause of hospitalization were used and the event was defined at the time of the first hospitalization for a specific cause that occurred in the study period.

2.5. Covariates

We considered for each subject age, gender, region of birth (north, center, south, out of Italy) educational level (high: university, medium: high school and low: elementary school),