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Proximity to mining industry and cancer mortality

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HIGHLIGHTS

Increased risk of cancer mortality among populations in the vicinity of mines.
We found that underground coal mining was related to digestive cancers and thyroid cancer.
We found that lung cancer was associated with open-air coal mining.
We used information from the European Pollutant Release and Transfer Register.
Integrated nested Laplace approximations (INLA) was used as Bayesian inference tool.

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ABSTRACT

Mining installations are releasing toxic substances into the environment which could pose a health problem to populations in their vicinity. We sought to investigate whether there might be excess cancer-related mortality in populations residing in towns lying in the vicinity of Spanish mining industries governed by the Integrated Pollution Prevention and Control Directive, and the European Pollutant Release and Transfer Register Regulation, according to the type of extraction method used. An ecologic study was designed to examine municipal mortality due to 32 types of cancer, across the period 1997 through 2006. Population exposure to pollution was estimated on the basis of distance from town of residence to pollution source. Poisson regression models, using the Bayesian conditional autoregressive model proposed by Besag, York and Molliè and Integrated Nested Laplace Approximations for Bayesian inference, were used: to analyze risk of dying from cancer in a 5-kilometer zone around mining installations; effect of type of industrial activity; and to conduct individual analyses within a 50-kilometer radius of each installation. Excess mortality (relative risk, 95% credible interval) of colorectal cancer (1.097, 1.041–1.157), lung cancer (1.066, 1.009–1.126) specifically related with proximity to opencast coal mining, bladder cancer (1.106, 1.016–1.203) and leukemia (1.093, 1.003–1.191) related with other opencast mining installations, was detected among the overall population in the vicinity of mining installations. Other tumors also associated in the stratified analysis by type of mine, were: thyroid, gallbladder and liver cancers (underground coal installations); brain cancer (opencast coal mining); stomach cancer (coal and other opencast mining installations); and myeloma (underground mining installations). The results suggested an association between risk of dying due to digestive, respiratory, hematologic and thyroid cancers and proximity to Spanish mining industries. These associations were dependent on the type of mine.

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Abbreviations: PAHs, Polycyclic aromatic hydrocarbons; IARC, International Agency for Research on Cancer; IPPC, Integrated Pollution Prevention and Control; EPER, European Pollutant Emission Register; E-PRTR, European Pollutant Release and Transfer Register; INE, *Instituto Nacional de Estadística* (National Statistics Institute); MARM, *Ministerio de Medio Ambiente y Medio Rural y Marino* (Ministry for the Environment and Rural & Marine Habitats); SMRs, Standardized Mortality Ratios; INLA, Integrated Nested Laplace Approximations; RR, Relative risks; CIs, Credible intervals; O_i, Observed deaths; E_i, Expected deaths; $Expos_i$, Variable of exposure; Soc_i, Standardized sociodemographic indicators; ill, Percentage of illiteracy; unem, Percentage of unemployed; far, Percentage of farmers; ps, Population size; pph, Average persons per household; inc, Mean income as a measure of income level.

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1. Introduction

Mining operations could be releasing toxic substances which may pose a health problem to populations. Not only are mine workers directly affected by their work environment (Gonzalez and Agudo, 1999; Donoghue, 2004; Attfield and Kuempel, 2008), but also toxic substances released may be transported from the mine site and affect local communities and the environment (Garcia-Sanchez et al., 2010; Wu et al., 2011; Gonzalez-Montana et al., 2011; Huertas et al., 2012). These toxic substances emitted from mining facilities include a wide range of toxic substances, such as dioxins, cyanide, mercury, arsenic, lead, cadmium, antimony, polycyclic aromatic hydrocarbons (PAHs) and numerous others, some of them recognized as human carcinogens by the IARC (International Agency for Research on Cancer) (1987).

Spain is a leading global producer of mineral resources in the European Union, with stress on the production of ornamental rocks and minerals (Ministerio de Ciencia e Innovación, 2012). However, the Spanish mining sector displays a general downward trend in terms of both the amount of saleable material and the number of facilities and work sites. More specifically, there has been a gradual reduction in the extraction of energy products such as coal, and a stabilization in metal ore mining (copper, nickel, tin and tungsten). In this context, certain minerals and ornamental rocks, such as celestite, feldspar, gypsum, slate, marble or granite, are becoming more relevant in the sector (Ministerio de Ciencia e Innovación, 2012). The principal coal mines are located in the northern region, specifically in the provinces of Asturias and Leon. The main iron ore deposits are also found in the north, particularly in the provinces of Santander and Vizcaya, while the south (Autonomous Region of Andalusia) is known for metal ore mining, with over half the country's production. The highest values of production in Spain are registered by the Autonomous Regions of Castille-Leon (coal, anthracite, slate, glauberite and tungsten) and Catalonia (oil, ornamental rocks and potash) (Ministerio de Ciencia e Innovación, 2009).

There is some evidence of excess risk of some cancers in the proximity of different types of mining facilities (Dondon et al., 2005; Hendryx et al., 2008; Wang et al., 2011). Dondon et al. (2005) described significant excess mortality due to lung, pharynx and digestive system cancers in the communes surrounding an ore mine in Salsigne, France. They suggested that this excess of cancer deaths is probably explained by arsenic environmental contamination typical from this kind of mining facilities. Hendryx et al. (2008) showed that residence in coal mining areas of Appalachia (USA) is a contributing factor to lung cancer, pointing that the results may be stronger for exposure to surface mining operations relative to underground mining because of greater exposure to airborne particulates from surface mining operations. Wang et al. (2011) also described significant excess mortality due to stomach cancer and other types, such as esophageal cancer in communities surrounding the ore mine of Dabaoshan in China. Moreover, Lopez-Abente et al. (2012) found no excess risk of pleural cancer in the proximity of mining facilities.

With respect to pollution sources, the European Commission directives passed in 2002 afforded a new means of studying the consequences of industrial pollution: the Integrated Pollution Prevention and Control (IPPC), governed both by Directive 96/61/CE and by Act 16/2002, which incorporates this Directive into the Spanish legal system, lays down that, to be able to operate, industries covered by the regulation must obtain the so-called Integrated Environmental Permit. Information gathered as a consequence of the application of these statutory provisions constitutes an inventory of geo-located industries with environmental impact in Spain and across Europe. This same enactment implemented the European Pollutant Emission Register (EPER), now updated in the form of the new European Pollutant Release and Transfer Register (E-PRTR), which incorporates additional information on releases. This new register makes it compulsory to declare all emissions that exceed the designated thresholds. IPPC and E-PRTR records thus constitute a public inventory of industries, created by the European Commission, which is a valuable resource for monitoring industrial pollution and, by extension, renders it possible for the association between residential proximity to such pollutant installations and risk of cancer mortality to be studied. Moreover, E-PRTR records contain information about the activities in which the installations are involved, e.g., in the case of the mining industry, there is a description of the ore-extraction method (opencast or underground) as well as the industrial sub-activity of each installation recorded. A description of this database has already been published elsewhere (Garcia-Perez et al., 2007).

In this context, due to the availability of information on several categories of mines in the IPPC + E-PRTR database, the fact that previous studies focused on only a few tumors and specific types of mines (i.e., coal or metal ore), and the different statistical approaches adopted for analyzing the association between residential proximity to pollutant installations and cancer, the aims of this study were: (1) to assess possible excess mortality due to 32 types of cancer among populations residing in the vicinity of Spanish mining installations governed by the IPPC Directive and E-PRTR Regulation; (2) to study this risk in the context of different types of mines by reference to their respective E-PRTR categories; and, (3) to perform analyses for the population, both overall and by sex, in order to assess possible differences vis-à-vis some mining installations which might or might not point to occupational exposures.

2. Materials and methods

2.1. Data

We designed an ecologic study to examine 32 causes of cancer mortality at a municipal level (8,098 Spanish towns), across the period 1997–2006. Separate analyses were performed for the population, both overall and by sex.

Observed municipal mortality data were drawn from the records of the National Statistics Institute (*Instituto Nacional de Estadística — INE*) for the study period, and corresponded to deaths due to 32 types of malignant neoplasm (Table 1 Supplementary material (SM)). Expected cases were calculated by taking the specific rates for Spain as a whole, broken down by age group (18 groups, 0–4, 5–9,…,85 and over), sex, and five-year period (1997–2001, 2002–2006), and multiplying these by the person-years for each town, broken down by the same strata. For calculation of person-years, the two five-year periods were considered, with data corresponding to 1999 and 2004 taken as the estimator of the population at the midpoint of the study period. Population data were likewise drawn from INE records.

Population exposure to industrial pollution was estimated by reference to the distance from the town centroid (municipality) to the industrial facility. Municipal centroids used for analysis are not polygonal centroids. They are situated in the center of the most populous zone where the town hall and the main church tend to be located.

We used data on industries governed by the IPPC and facilities pertaining to industrial activities not subject to the IPPC Act 16/2002 but included in the E-PRTR (IPPC + E-PRTR), provided by the Spanish Ministry for the Environment and Rural & Marine Habitats (*Ministerio de Medio Ambiente y Medio Rural y Marino*). We selected the 120 mining installations that corresponded to facilities coded as “3a” (underground mining and related operations) or “3b” (opencast mining and quarrying) in the E-PRTR category from the Mineral Industry PRTR Industrial Activity group (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:033:0001:0017:EN:PDF), which, according to Spain's National Classifications of Economic Activities (*Clasificación Nacional de Actividades Económicas — CNAE*) governed by Royal Decree 472/2007 (see Table 2 SM). The geographic coordinates of their position recorded in the IPPC + E-PRTR database were validated, by meticulously reviewing industrial locations using the following: Google Earth, with aerial images and the Street View application; the Spanish Farm Plot Geographic Information System (SIGPAC) (Ministerio de Medio Ambiente y Medio Rural y Marino (MARM), 2012), which includes orthophotos of the entire surface of Spanish territory, along with topographic maps showing the names of the industries, industrial estates, roads, buildings and streets; the Google Maps server (Google Inc., 2012), which allows for a search of addresses and companies, and offers high-quality aerial photographs; the Yellow Pages web page (Yell Publicidad SAU, 2011), which allows for a search of addresses and companies; Internet aerial photographs; and the web pages of the industries themselves, to ensure that location of the industrial facility was exactly where it should be. We also used the information yielded by a previous validation analysis of some of these geographic coordinates (Garcia-Perez et al., 2008). 25% of the mining facilities coordinates have been corrected at a distance of 1640 m or more from the original location in the IPPC + E-PRTR data base.

Sociodemographic variables were obtained from the 1991 Spanish Census and chosen for their availability at a municipal level and potential explanatory ability vis-à-vis the geographic mortality patterns (Lopez-Abente et al., 2006b), including percentage of illiteracy (ill), percentage of unemployed (unem), percentage of farmers (far), population size (ps), average persons per household (pph), and mean income as a measure of income level (inc) (Ayuso-Orejana et al., 1993).

2.2. Statistical analysis

In a first phase, we conducted exploratory "near vs. far" analyses to estimate the relative risks (RRs) of towns situated at 5 km from mining industries. A critical question in study design is the choice of radius surrounding industrial installation. Our choice of 5 km as the threshold distance coincides with that used by other authors (Karavus et al., 2002; Garcia-Perez et al., 2009, 2010) as is justified because in these type of studies, if some increase risks were to be found, it would most likely be in areas lying closest to the pollutant source. Moreover, we conducted this exploratory "near vs. far" analysis at 15 different distances (from 1 to 15 km) from mining industries showing that 5 km is a good choice, in terms of being able to best discriminate the risk and furnish a number of observed deaths which would have enough statistical power (Figs. 1–4 of the Supplementary material). The "exposure" variable was coded as a "dummy", with three levels, namely: 1) exposed group ("near"), consisting of towns having their municipal centroid at ≤5 km from any mining installation; 2) intermediate group, consisting of towns at ≤5 km from any industrial installation other than mining facilities; and, 3) unexposed group ("far"), consisting of towns having no IPPC-registered industry within 5 km of their municipal centroid (reference level).

In a second phase, we conducted a second analysis, stratifying the risk by type of industrial activity. For the purpose, we created a new variable with the levels shown below, according to the mining method employed, which, in turn, depended on the characteristics of the mineral deposits to be exploited and the similarity of their pollutant emission patterns recorded in the IPPC + E-PRTR dataset. The exposure variable was coded as a "dummy", with 9 levels (see Mining groups in Table 3 SM): 1) group 1, i.e., towns lying at≤"chosen distance" from a single mining group category-1 installation (underground extraction of anthracite, bituminous coal and lignite); 2) group 2, i.e., towns lying at ≤"chosen distance" from a single mining group category-2 installation (underground extraction of metallic or non-metallic minerals); 3) group 3, i.e., towns lying at ≤"chosen distance" from a single mining group category-3 installation (underground extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other); 4) group 4, i.e., towns lying at ≤"chosen distance" from a single mining group category-4 installation (opencast extraction of anthracite, bituminous coal and lignite); 5) group 5, i.e., towns lying at ≤"chosen distance" from a single mining group category-2 installation (opencast extraction of metallic or non-metallic minerals); 6) group 6, i.e., towns lying at ≤"chosen distance" from a single mining group category-6 installation (opencast extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other); 7) group 7, i.e., towns lying at ≤"chosen distance" from more than one E-PRTR category-3a or -3b mining installation (multiple pollution sources); 8) intermediate group, i.e. towns lying at ≤"chosen distance" from any industry other than mining; and 9) unexposed mining group, i.e., towns having no mining IPPC + E-PRTR-registered industry within a radius of the "chosen distance" from the centroid (reference level).

Finally, in view of the fact that the characteristics of the respective mining installations could vary (type and volume of emissions, level of production), installations were analyzed individually, with the analysis being confined to an area of 50 km surrounding each installation, so as to have a local comparison group. The regression coefficient of the exposure term in the models gave us the logarithm of the ratio between the respective standardized mortality ratios (SMRs) for the exposed and reference zones, which we called "RR".

RRs and their 95% credible intervals (95% CIs) were estimated for all the analyses on the basis of Poisson regression models, using a Bayesian conditional autoregressive model proposed by Besag, York and Molliè (BYM) (Besag et al., 1991), with explanatory variables. Observed deaths (O_i) were the dependent variable and expected deaths (E_i) were the offset. All estimates for the above variable of exposure ($Expos_i$) were adjusted for the standardized sociodemographic indicators (Soc_i), outlined above.

In the BYM Bayesian autoregressive model, the random effects terms include two components, namely: a spatial term containing municipal contiguities (b_i); and the municipal heterogeneity term (h_i). The variable of exposure and potential confounding covariates were fixed-effects terms in the models:

$$\mathrm{Oi}\sim\mathrm{Poisson}(\mu_i = E_i\ \lambda_i)$$

$$\log(\lambda_i) = \alpha Expos_i + \textstyle\sum_j \beta_j Soc_i + h_i + b_i \rightarrow \log(\mu_i) = \log(E_i) + \alpha Expos_i + \textstyle\sum_j \beta_j Soc_{ij} + h_i + b_i$$

$$i = 1\ldots 8098$$

$$j = 1\ldots 6$$

$$Soc_{ij} = ill_i + unem_i + far_i + ps_i + pph_i + inc_i$$

$$\begin{aligned} &h_i \sim Normal(\theta, \tau\mathrm{h}) \\ &b_i \sim \mathrm{Car.Normal}(\eta_\mathrm{i}, \tau\mathrm{b}) \\ &\tau\ h \sim \mathrm{Gamma}(\alpha, \beta) \\ &\tau\ b \sim \mathrm{Gamma}(\gamma, \delta) \end{aligned}$$

Integrated Nested Laplace Approximations (INLAs) (Rue et al., 2009) were used as a tool for Bayesian inference. To this end, we used R-INLA (Rue et al., 2012) with the option of Gaussian estimation of the parameters, a package available in the R environment (R Development Core Team, 2010). A total of 8098 towns were included, and the spatial data on municipal contiguities were obtained by processing the official INE maps. No account was taken during cancer induction periods because the mines have been in operation for many years (Taking into account that the minimum induction periods for the solid tumors are usually 10 years (United Nations Scientific Committee on the Effects of Atomic Radiation, 2006), the 81% of facilities stated their activity before 1992, 10 years before the central year of the study period).

Many functions included in "splancs", "sp", "maptools" and "spdep" R packages, free downloaded from http://cran.r-project.org/, were used for reading, visualizing, and analyzing spatial data.

3. Results

Fig. 1 depicts the geographic distribution of the 120 mining industries studied by the mining group (see Table 3 SM). While the majority of installations in groups 1, 2, 3 and 4 were located in the northwest of the country, those in groups 5 and 6 tended to spread over parts of central, northeastern and southern Spain. The mining groups with the highest number of facilities were numbers 1 (underground extraction of anthracite, hula and lignite) and 6 (opencast extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other), with 35 and 59 installations, respectively. Mining group 2 (underground extraction of metallic or non-metallic minerals) registered the lowest number of installations (2).

The RRs and their 95% CIs of dying from cancer in towns lying close to mining industries (using the 15 different distances analyzed) are shown in Figs. 1–4 of the Supplementary material. We chose 5 km as the "best distance" in terms of being able to best discriminate the risk and furnish a number of observed deaths that would have enough statistical power.

Table 1 shows the RRs and 95% CIs of dying from cancers that registered statistically significant results in towns situated at a distance of 5 km or less from mining installations, estimated using spatial regression models: there were statistically significant RRs of dying due to colorectal cancer (both sexes), lung cancer (men), bladder cancer (men), and leukemia (both sexes) in the proximity of mining installations. The highest RR corresponded to the association with bladder cancer (RR (95% CI) for men = 1.129 (1.030–1.237)), for which the numbers of observed and expected deaths were 822 and 746.71, respectively.

Table 2 shows the RRs of dying from cancers with significant results and a total number of observed deaths ≥5, in towns situated at a distance of 5 km or less from mining installations, by type of mining group. This stratified analysis served to highlight significant results that were masked in the analysis shown in Table 1. Hence: in mining group 1 (underground extraction of anthracite, bituminous coal and lignite), there were significant RRs for colorectal (men), gallbladder (men) and thyroid gland (men and women) cancers; in mining group 2 (underground extraction of metallic or non metallic minerals), there were no towns in the "exposed" area; in mining group 3 (underground extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other), there were significant RRs for colorectal cancer (men), bladder cancer (men) and myeloma (men); in mining group 4 (opencast extraction of anthracite, bituminous coal and lignite), there were significant RRs for colorectal (women), liver (men), lung (men) and brain cancer (men); in mining group 5 (opencast extraction of metallic or non-metallic minerals), there were significant RRs for stomach cancer (women) and leukemia (men); in mining group 6 (opencast extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other), there were significant RRs for colorectal cancer (both sexes) and leukemia (women). The statistically significantly highest excess risk was concentrated among men in the vicinity of mining group 3 installations, in relation with myeloma (RR (95% CI) = 2.26 (1.26–4.04)), with 12 and 5.5 observed and expected deaths, respectively.

Lastly, Table 4 SM shows the RRs of mortality for areas (≤5 km) surrounding individual mining industries within a 50-kilometer circle drawn around each installation. Data are shown for installations having a statistically significant excess risk in the "near vs. far" analysis and a total number of observed deaths ≥5.

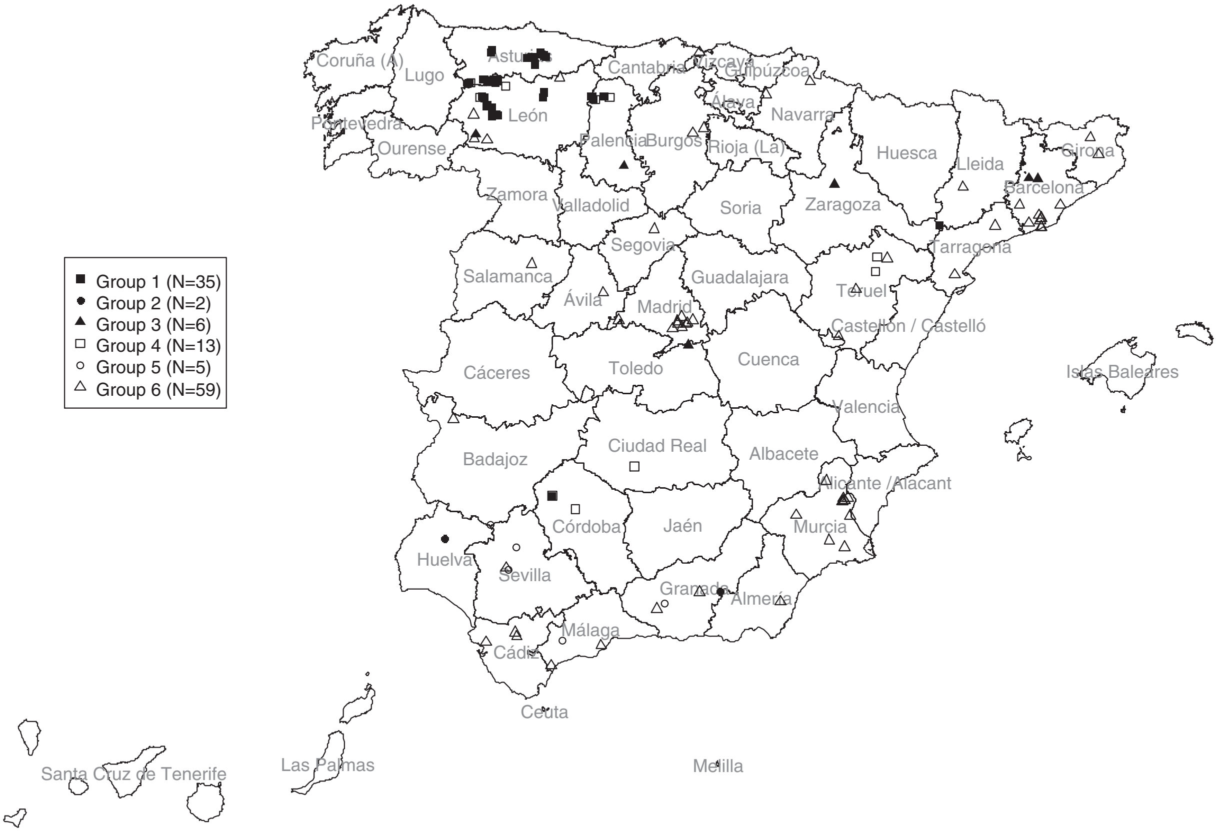

Fig. 1. Geographic distribution of Spanish mining industries. Mining groups: 1 = underground extraction of anthracite, bituminous coal and lignite; 2 = underground extraction of metallic or non metallic minerals; 3 = underground extraction of ornamental rocks, sand, clay, chemistry products, fertilizers or other; 4 = open-pit extraction of anthracite, bituminous coal and lignite; 5 = open-pit extraction of metallic or non metallic minerals; 6 = open-pit extraction of ornamental rocks, sand, clay, chemistry products, fertilizers or other.

Table 1
Relative risk (RR) and 95% credible intervals (95% CI) of dying from those cancers with statistically significant increment risk in towns situated at a distance of less than 5 km from mining installations, estimated using spatial regression models.

tumor	Sex	Number of towns[a]	Obs[b]	Exp[c]	RR	95% CI	
Colorectal	Both	126	2817	2634.1	1.10	1.04	1.16
	Men	126	1626	1506.1	1.10	1.03	1.17
	Women	126	1191	1128.0	1.09	1.02	1.17
Lung	Both	126	4334	4077.7	1.07	1.01	1.13
	Men	126	3904	3615.3	1.08	1.02	1.14
	Women	126	430	462.4	0.97	0.86	1.09
Bladder	Both	126	977	897.7	1.11	1.02	1.20
	Men	126	822	746.7	1.13	1.03	1.24
	Women	126	155	151.0	1.02	0.86	1.22
Leukemia	Both	126	712	646.2	1.09	1.00	1.19
	Men	126	398	366.9	1.12	1.00	1.25
	Women	126	314	279.3	1.12	0.99	1.27

[a] Number of towns = number of towns included in the analysis.
[b] Obs = observed deaths.
[c] Exp = expected deaths.

4. Discussion

This study is one of the first to use publicly accessible, E-PRTR and IPPC information to explore the effects of the mining sector on cancer mortality among neighboring populations. Summarizing all the results, our study indicates an excess risk of cancer mortality across the sexes among persons living in the vicinity of certain types of mining installations. The main results, based on the association analysis that included all the mining facilities, showed an excess of colorectal, lung and bladder cancer- and leukemia-related mortality among men and women living in the vicinity of mining installations. When stratified by mining group, the results indicated, moreover, that these associations were related with certain specific types of mining facilities, and also pointed to some new associations with gallbladder, thyroid, bladder, liver, brain and stomach cancers, and with myeloma.

Another aspect to be borne in mind is that in some specific installations or groups of installations, excess risks solely affected men, a finding that may be indicative of a possible source of occupational exposure (for example, lung and bladder cancer).

Our results show significant excess mortality due to cancers of the digestive system, related with all the mining groups analyzed. There was evidence of risk of colorectal, gallbladder and bladder cancers among men living near underground mining facilities, pointing to a possible occupational exposure. Indeed, there are some papers which confirm this association between digestive cancers and occupational mining exposures (Lopez-Abente et al., 2006a; Rushton et al., 2010). According to these authors, mining exposure could include some potential carcinogens, such as asbestos, diesel engine exhaust, nickel, PAHs and lead, among others. A more detailed examination reveals that there was an association between proximity to mining group 1 facilities and colorectal or gallbladder cancer mortality among men working in underground extraction of anthracite and bituminous coal mines (individual analyses, Table 4 SM). As will be seen, moreover, the association between mining group 3 (underground extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other) and bladder cancer focused (individual analyses, Table 4 SM) on potash mines, a finding in line with previous reports (Kogevinas et al., 2003; Lopez-Abente et al., 2006a). Lopez-Abente et al. described that high concentrations of arsenic have been detected in the Cardener and Llobregat Rivers (Catalonia, Spain), concentrations that have clearly increased due to the influence of the sodium and potash mining activity of the region. The miners of these installations could be directly exposed to these high concentrations and may explain the spatial pattern of bladder cancer in men in Catalonia region (Spain). Moreover, Kogevinas et al. showed that the highest risk found between occupation and industries was salt mining (OR = 4.41), pointing that mining is one of the major occupations currently contributing to occupational bladder cancer in European men.

With regard to proximity to opencast mining groups, there was evidence of risk of colorectal and stomach cancers in men and women alike, pointing to a potential environmental exposure. Specifically, colorectal cancer appeared in association with proximity to anthracite, bituminous coal and lignite mines (mining group 4) and ornamental rock mines (mining group 6). On the other hand, stomach cancer in women was associated with proximity to installations extracting metallic or non-metallic minerals (mining group 5). In the individual analysis, this association was not detected due to the low number of observed cases. In men, a relationship was in evidence between proximity to group 4 installations (opencast extraction of anthracite, bituminous coal and lignite) and primary liver cancer, an association already documented in relation to mercury mines (Gomez et al., 2007).

The possible exposure pathway in which most of the metalloid and heavy metals released from mining facilities into the water, reached individuals is the trophic chain. In that way, Wang et al. (2011) showed that the concentration of heavy metals in environmental samples from the vicinity a multi-metal sulfide mine in Guangdong Province, China, was higher than in a reference area.

The associations described above are supported by previous studies, namely: Wang et al. (2011) showed that stomach cancer mortality rates were significantly higher in the environs of a multi-metal sulfide mine; Su et al. (2006) showed that cumulative mortality from stomach cancer was significantly higher among iron-mine workers who were exposed to dust than among those who were not so exposed; and Weinberg et al. (1985) showed that coal mining could be a risk factor for stomach cancer among females married to miners.

Another noteworthy result is the significant excess lung cancer mortality related with proximity to mining group 4 installations (opencast anthracite, bituminous coal and lignite mines). These types of mining industries emit a wide range of carcinogenic pollutants to air (discussed above) and have been linked to this particular cancer (Smith, 1959; Hendryx et al., 2008, 2010).

A further interesting result is the excess thyroid-related mortality seen in the vicinity of mining group 1 installations. Although there was not enough statistical power for this to be detected in the individual analysis, the mining-group analysis showed it as affecting both men and women pointing to a potential environmental exposure. The best-evidenced etiologic factor implicated in thyroid cancer is ionizing radiation. In 1978, McBride et al. (1978) examined the uranium and thorium content of fly ash from coal-fired power plants in Tennessee and Alabama (USA): they estimated radiation exposure around the coal plants and compared it with exposure levels around boiling-water reactor and pressurized-water nuclear power plants. The estimated radiation doses ingested by people living near the coal plants were equal to or higher than doses for people living around the nuclear facilities. This fact may go to support the idea of a possible association between coal mines and thyroid cancer. In addition, on studying municipal mortality due to thyroid cancer in Spain, Lope et al. (2006) found a clear pattern of excess thyroid cancer mortality in the north of Spain, where most of the country's coal mines are located, indicating that environmental factors might provide possible etiologic hypotheses to be borne in mind in future geographic studies.

With regard to hematologic cancers, excess myeloma-related mortality was observed in the vicinity of mining group 3 (underground extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other) in men, and leukemia-related mortality in the vicinity of mining groups 5 (opencast extraction of metallic or non metallic minerals) in men and 6 (opencast extraction of ornamental rocks, sand, clay, chemical products, fertilizers or other) in women. The most relevant etiologic factors implicated in these cancers are ionizing radiation and benzene (Herrinton et al., 1996; Boice and Lubin, 1997;

Table 2
Relative risk (RR) of dying from those cancers with statistically significant increment risk in towns situated at a distance of less than 5 km using spatial regression models by mining group (1 = underground extraction of anthracite, bituminous coal and lignite; 2 = underground extraction of metallic or non metallic minerals; 3 = underground extraction of ornamental rocks, sand, clay, chemistry products, fertilizers or other; 4 = open-pit extraction of anthracite, bituminous coal and lignite; 5 = open-pit extraction of metallic or non metallic minerals; 6 = open-pit extraction of ornamental rocks, sand, clay, chemistry products, fertilizers or other). Statistically significant increment risks are in bold.

Tumor	Group	Both						Men						Women					
		RR	95% CI[a]		N[b]	Obs[c]	Exp[d]	RR	95% CI[a]		N[b]	Obs[c]	Exp[d]	RR	95% CI[a]		N[b]	Obs[c]	Exp[d]
Stomach	1	1.16	0.94	1.43	13	365	298.2	1.15	0.91	1.44	13	229	179.1	1.13	0.88	1.46	13	136	119.1
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	0.99	0.70	1.41	10	46	42.3	1.01	0.66	1.54	10	28	26.3	1.04	0.63	1.73	10	18	16.0
	4	1.13	0.83	1.53	12	105	97.6	1.13	0.80	1.59	12	66	60.5	1.13	0.76	1.67	12	39	37.2
	5	1.51	0.95	2.38	6	24	19.4	1.28	0.71	2.31	6	13	12.4	**1.97**	**1.05**	**3.70**	**6**	**11**	**7.0**
	6	1.08	0.97	1.20	81	744	797.4	1.07	0.95	1.21	81	478	507.4	1.06	0.91	1.22	81	266	290.0
Colorectal	1	**1.27**	**1.12**	**1.44**	**13**	**740**	**605.7**	**1.31**	**1.13**	**1.52**	**13**	**452**	**331.8**	1.15	0.98	1.35	13	288	273.9
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	1.22	0.97	1.54	10	98	86.5	**1.36**	**1.03**	**1.81**	**10**	**61**	**49.4**	1.06	0.75	1.50	10	37	37.1
	4	**1.26**	**1.04**	**1.51**	**12**	**217**	**197.8**	1.16	0.92	1.46	12	118	112.2	**1.29**	**1.02**	**1.64**	**12**	**99**	**85.5**
	5	0.72	0.47	1.11	6	23	38.6	0.79	0.46	1.36	6	14	22.6	0.64	0.33	1.24	6	9	16.0
	6	**1.09**	**1.02**	**1.16**	**81**	**1623**	**1590.7**	**1.08**	**1.00**	**1.18**	**81**	**924**	**926.2**	**1.09**	**1.00**	**1.19**	**81**	**699**	**664.5**
Liver	1	1.12	0.83	1.51	13	167	122.3	1.18	0.87	1.61	13	132	86.5	1.15	0.71	1.86	13	35	35.8
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	1.12	0.64	1.93	10	18	17.1	1.03	0.54	1.94	10	12	12.4	1.36	0.56	3.29	10	6	4.7
	4	1.51	0.99	2.30	12	54	40.1	**1.69**	**1.09**	**2.63**	**12**	**42**	**29.0**	1.21	0.59	2.52	12	12	11.1
	5	0.50	0.16	1.62	6	3	8.2	0.24	0.03	1.75	6	1	6.1	1.16	0.28	4.93	6	2	2.1
	6	0.94	0.81	1.11	81	313	330.5	0.94	0.79	1.11	81	225	247.2	0.98	0.76	1.28	81	88	83.3
Gallbladder	1	1.09	0.79	1.52	13	54	69.7	**1.53**	**1.00**	**2.35**	**13**	**29**	**23.0**	0.81	0.52	1.26	13	25	46.7
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	1.02	0.52	2.01	10	9	9.7	0.96	0.30	3.02	10	3	3.4	1.01	0.44	2.31	10	6	6.3
	4	1.12	0.72	1.76	12	25	22.2	1.49	0.78	2.85	12	11	7.8	0.94	0.53	1.68	12	14	14.4
	5	1.27	0.59	2.74	6	7	4.2	0.67	0.09	4.79	6	1	1.5	1.61	0.70	3.69	6	6	2.7
	6	1.06	0.90	1.25	81	185	171.2	1.11	0.85	1.45	81	66	62.7	1.05	0.86	1.29	81	119	108.5
Lung	1	1.09	0.95	1.26	13	977	880.8	1.13	0.96	1.31	13	884	776.4	0.79	0.60	1.04	13	93	104.4
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	1.16	0.92	1.47	10	123	125.3	1.20	0.93	1.53	10	113	111.5	0.84	0.44	1.62	10	10	13.8
	4	**1.22**	**1.01**	**1.49**	**12**	**348**	**295.3**	**1.29**	**1.05**	**1.59**	**12**	**331**	**261.9**	0.57	0.33	0.97	12	17	33.4
	5	1.07	0.80	1.44	6	62	62.1	1.11	0.82	1.51	6	58	55.4	0.71	0.26	1.93	6	4	6.7
	6	1.05	0.98	1.12	81	2640	2546.6	1.06	0.98	1.14	81	2358	2261.9	0.99	0.85	1.14	81	282	284.7
Bladder	1	1.04	0.85	1.28	13	208	204.9	1.10	0.88	1.37	13	174	167.2	0.84	0.58	1.21	13	34	37.8
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	**1.86**	**1.36**	**2.54**	**10**	**54**	**30.5**	**1.92**	**1.37**	**2.70**	**10**	**45**	**25.2**	1.78	0.91	3.47	10	9	5.2
	4	0.96	0.71	1.32	12	63	68.2	1.02	0.73	1.43	12	55	56.5	0.69	0.34	1.40	12	8	11.7
	5	0.92	0.50	1.70	6	11	13.2	1.10	0.59	2.04	6	11	11.1	0.00	0.00	5.E+07	6	0	2.1
	6	1.10	0.99	1.22	81	598	541.7	1.10	0.98	1.23	81	498	454.5	1.15	0.93	1.43	81	100	87.2
Brain	1	0.96	0.76	1.21	13	101	107.4	0.93	0.69	1.24	13	55	58.0	1.00	0.72	1.38	13	46	49.4
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	0.84	0.47	1.51	10	12	14.6	0.86	0.41	1.83	10	7	8.1	0.82	0.34	1.99	10	5	6.5
	4	1.37	0.98	1.90	12	45	36.1	**1.75**	**1.19**	**2.57**	**12**	**32**	**20.0**	0.86	0.49	1.52	12	13	16.1
	5	1.26	0.65	2.47	6	9	8.0	1.43	0.63	3.23	6	6	4.7	0.97	0.31	3.05	6	3	3.4
	6	0.99	0.87	1.12	81	317	331.9	0.96	0.82	1.13	81	179	191.8	1.02	0.85	1.22	81	138	140.1
Thyroid gland	1	**1.77**	**1.15**	**2.71**	**13**	**29**	**13.9**	**2.05**	**1.01**	**4.13**	**13**	**9**	**4.4**	**1.70**	**1.02**	**2.84**	**13**	**20**	**9.5**
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	0.00	0.00	5.E+07	10	0	1.9	0.01	0.00	8.E+08	10	0	0.6	0.01	0.00	1.E+08	10	0	1.3
	4	0.50	0.12	2.05	12	2	4.4	1.45	0.35	5.93	12	2	1.5	0.00	0.00	2.E+07	12	0	2.9
	5	2.67	0.65	10.90	6	2	0.9	3.46	0.48	25.06	6	1	0.3	2.01	0.28	14.54	6	1	0.6
	6	1.00	0.70	1.44	81	34	35.5	1.14	0.65	1.98	81	14	12.9	0.90	0.57	1.43	81	20	22.6
Myeloma	1	1.07	0.83	1.37	13	83	77.8	1.22	0.88	1.70	13	42	37.3	0.96	0.69	1.36	13	41	40.5
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	1.58	0.97	2.58	10	17	10.9	**2.26**	**1.26**	**4.04**	**10**	**12**	**5.5**	0.92	0.38	2.23	10	5	5.4
	4	1.22	0.83	1.78	12	31	25.1	1.59	0.99	2.55	12	20	12.5	0.85	0.46	1.56	12	11	12.6
	5	0.41	0.10	1.65	6	2	4.9	0.00	0.00	3.E+07	6	0	2.5	0.83	0.21	3.33	6	2	2.3
	6	0.94	0.80	1.09	81	192	197.9	1.00	0.81	1.23	81	103	102.4	0.89	0.71	1.11	81	89	95.6
Leukemia	1	1.10	0.91	1.33	13	154	141.7	1.17	0.92	1.48	13	86	77.0	1.05	0.80	1.37	13	68	64.7
	2	–	–	–	0	0	0.0	–	–	–	0	0	0.0	–	–	–	0	0	0.0
	3	0.74	0.44	1.23	10	15	20.1	1.08	0.61	1.91	10	12	11.4	0.33	0.11	1.02	10	3	8.7
	4	1.15	0.86	1.55	12	54	47.2	1.24	0.86	1.79	12	32	26.6	1.07	0.69	1.66	12	22	20.7
	5	**1.69**	**1.02**	**2.79**	**6**	**16**	**9.7**	**2.20**	**1.23**	**3.92**	**6**	**12**	**5.7**	1.02	0.38	2.74	6	4	4.1
	6	1.10	0.99	1.22	81	447	400.0	1.05	0.91	1.20	81	241	231.1	**1.18**	**1.02**	**1.37**	**81**	**206**	**168.9**

[a] 95% CI = 95% credible interval of the RR.
[b] N = number of towns in the "exposure" area.
[c] Obs = number of observed deaths in the "exposure" area.
[d] Exp = number of expected deaths in the "exposure" area.

Siemiatycki et al., 2004; Linet et al., 2006). Although these factors cannot be clearly related with the mining groups described, the individual analysis detected some associations between leukemia-related mortality and mining group 1 installations (underground extraction of anthracite, bituminous coal and lignite), which were more closely related with exposure to ionizing radiation. Even so, our results could be pointing in the same direction as those of Strom et al. (1994), who found an excess of these cancers in a mining community and identified combustion waste as an etiologic cause.

Lastly excess brain-cancer-related mortality was found in the vicinity of mining group 4 installations in men. Once again, ionizing radiation is one of the best-evidenced etiologic factors implicated in this cancer. As mentioned previously, coal mines could be linked to both workers and nearby towns being affected by this exposure (McBride et al., 1978).

Lopez-Abente et al. (2012), using the same statistical methodology and IPPC data base of facilities, found no excess risk of pleural cancer in the proximity (<2 km) of mining facilities. This lack of association is in accordance with our results.

Finally, though the results from the individual analysis served to highlight few new significant results in relation with esophageal, breast, uterine, ovarian, testicular and prostate cancers, they generally pointed in the same direction as did the results stratified by the mining group.

The mining groups created in this study were intended to pool installations having similar characteristics, in terms of the factors to be taken into account when trying to comprehend the environmental impact of any given mining enterprise. These were: (1) the type of mining method used, which, in turn, depends on the characteristics of the mineral deposit to be exploited. There are two main methods, each closely related to impacts of differing degrees on nature and society. These are (a) underground mining, and (b) opencast mining; and, (2) the characteristics of the minerals to be extracted and their intended use, since this will dictate the treatment they receive when they are being mined and processed. Minerals can broadly be divided into: non-metallic (such as those used to make construction materials), which require little physical treatment, e.g., crushing and grinding, and no chemical treatment at all; and, metallic, which require a high level of processing as well as the application of many chemical reagents, all of which generates great amounts of waste (Ministerio de Ciencia e Innovación, 2012).

Within this framework, the main environmental effects of mining installations (Kesler, 1994; Ripley et al., 1996; Marcus, 1997) could include the following. First, (a) air pollution: air can be polluted by solid impurities that can reach the lungs, such as dust (with silica, asbestos, beryllium, fluorite, nickel, quartz, mercury, vermilion, titanium dioxide, manganese oxides, uranium compounds and tin minerals) and toxic or inert fuels produced or employed at different times during the mining process. Possible additions to this are residual gasses or vapors containing cyanide, mercury and sulfur dioxide, released by incomplete combustion processes, ponds or lagoons with stagnant, polluted water and/or decomposing organic material. Second, (b) perturbation of surface water: the waste produced in the exploitation area may cause the sedimentary layers of the region's rivers to grow. Dams and oxidation ponds, badly built, maintained or used, can lead to the contamination of surface waters by spillage of liquid waste. Equally damaging and likely are inadequate usage, storage and/or transport of different consumables, such as fuels, lubricants and chemical reagents. It is also worth mentioning that the material extracted from underground mines may contain high concentrations of chlorides and sulfates. This should be a primary concern in the case of salt dumps in damp climates, where rainfall accumulates dissolved salts. Third, (c) perturbation of phreatic or groundwater: groundwater can be contaminated by used oils, reagents and mineral salts leached by rainwater from the waste piles of solid post-treatment residuals. Likewise, spillage or leakage from tailings dams, or polluted water that escapes during the extraction process, may reach the phreatic layers. Finally, if local groundwater is used to supply the significant needs of an opencast mining operation, the water table may drop significantly. Underground mining can also pollute groundwater. Mine waters are an important source of contamination, as the solutions used for in situ leaching and refrigerants escape during the work of pitting. Surface water from the dumps and other sources can also leach into groundwater and impair their quality. Fourth, (d) other: mining activities have resulted in the formation of dumps in the vicinity of mines, which may contain metal residues hazardous to health.

Owing to the nature and definition of the data used, there were several study limitations, one of which was the use of mortality rather than incidence. The lack of information on non-lethal cancer cases may have served to bias the analysis. In the absence of a population-based incidence registry covering the entire country, we used mortality data. In Spain, however, tumors with lower survival rates are well represented using death certificates, according to Perez-Gomez et al. (2006).

Another limitation was that distance to the pollution source was used as a proxy of exposure, by assuming an isotropic model. This could introduce a problem of misclassification, since real exposure is critically dependent on other variables, such as prevailing winds or geographic landforms. Previous studies within the same project have discussed this topic in depth (Garcia-Perez et al., 2009; Ramis et al., 2009, 2011). Nevertheless, we should like to make a point that the problems of using isotropic instead of anisotropic distances would, in any event, affect the analysis, by restricting the ability to find positive results and shifting the results towards the null hypothesis, rather than furnishing spurious results. There are other methodologies for exposure evaluation based on dispersion modeling or the use of pollutants concentrations in media (Nieuwenhuijsen et al., 2006). However, since we have no relevant information for these models like meteorological data or validated air pollution emissions, we decided to use the distance as a measure of exposure.

A further possible bias lies in the use of centroids as coordinates for pinpointing the entire population of a town, when, in reality, the population may be fairly widely dispersed. We also assumed that subjects' registered place of residence determined exposure, which implies that the whole municipal population was exposed to the same type and amount of pollutant substances. Nevertheless, the use of small areas as units reduces the risks of ecologic bias and misclassification stemming from these assumptions (Richardson et al., 2004), and these problems would be posed in all cases, limiting the capacity to find positive results but in no way invalidating the associations found. Moreover, the centroids used in the analysis are not “polygonal centroids”. They are situated in the center of the most populous zone where the town hall and the main church tend to be located. This fact could be reducing the risks of ecological bias and misclassification.

A critical decision in the definition of the exposure variable was the maximum distance of 5 km. We repeated the analysis for several distances (ranging from 1 through 15 km), as a way of deciding on the best distance for detecting risks and having enough statistical power.

One aspect addressed in the analyses is the problem of multiple comparisons or multiple testing (to find associations that are falsely positive by random chance). We estimated that for $=0.05$, random chance would account for 2.4 positive associations (number of comparisons × percentage of statistically significant $RR>1$ expected under the null hypothesis, i.e., 2.5%) for the analyses by tumor in Table 2, numbers which are lower than those of the associations observed.

Another point to be borne in mind is that some installations, for which statistically significant RRs are observed, might be situated in areas with other industries releasing pollution into the environment, a problem when it comes to interpreting the results. Nevertheless mining installations are usually situated far from other facilities, and including towns exposed to other mining IPPC + E-PRTR installations as the “intermediate group” in the statistical analyses go some way to solving this problem.

Finally, E-PRTR register is a useful tool for epidemiological research. However, some information not validated could be included in the register helping researchers to improve the quality of their work; e.g. starting date of activity, production volume, number of installations or number of workers.

5. Conclusions

The results suggest a possible increased risk of cancer mortality among populations residing in the vicinity of mining installations. Specifically, digestive cancers and thyroid cancer tend to be related with underground coal mining affecting men and women, a finding that may be indicative of a possible source of environmental exposure; and lung cancer with opencast coal mining only in men pointing an occupational exposure. In order to confirm these results, it would be of great interest to analyze cancer incidence, which was not included in this study, and assess the possibility of using better exposure markers for studying what is happening in the environs of each specific installation. Despite all the limitations mentioned in the manuscript, the design of the present study could be a useful tool for studying point-source environmental pollution and cancer.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2012.07.019.

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