Until a few years ago, geographic studies were restricted to the drawing up of thematic maps in which large areas, generally provinces in the case of Spain, were selected as the basic study unit. Yet while this representation has shown itself to be useful for describing spatial patterns in broad terms, it nevertheless proves inadequate if the aim is to conduct an in-depth study into the origin of some specific disease. For this purpose, it becomes necessary to resort to a smaller geographic scale, usually health district or municipal area, which in turn entails dealing with the inherent problem that has come to be called “analysis of small areas”. Recent advances in the discipline known as spatial epidemiology, especially those advances relating to methods of analysis of spatial data, have opened the way to new approaches to mortality analysis which enable these challenges to be successfully met.

In this paper, we apply these methods to the study of municipal distribution of pleural cancer mortality in Spain, an acknowledged indicator of exposure to asbestos and mesothelioma mortality. Most mesotheliomas are due to exposure to asbestos, with 80–85% of cases attributable to occupational exposure. Increased risk has been reported for workers employed in asbestos mines, asbestos plants, the production of anti-gas masks, shipyards, railways, and other occupations involving inhalation of asbestos dust.

Furthermore, there are also reports of mesothelioma development deriving from non-occupational exposure to asbestos. This problem is present in populations living in the proximity of asbestos mines and plants, and family members of workers, who come into household contact with asbestos dust deposited and brought home on work clothes. The presence of asbestos in the structure of buildings is yet another potential risk for the appearance of mesotheliomas, due to the release of fibres in asbestos stripping and demolition tasks.

The municipal populations, broken down by age group (18 groups) and sex, were drawn from the 1991 census and 1996 voters roll. These years correspond to the midpoint points of the two quinquennia that comprise the study period (1989–93 and 1994–98), thereby rendering it easy to ascertain person-years by multiplying the populations by 5.

Standardised mortality ratios (SMR) were calculated as the ratio between observed and expected deaths. For the calculation of expected cases, the overall Spanish mortality rates for the above two 5-year periods were applied to each town’s person-years by age group, sex, and quinquennium.

The calculation of smoothed municipal relative risks (RR) for map plotting purposes was based on fitting spatial Poisson models with two random effects terms that took the following into account: (a) municipal contiguity (spatial term); and (b) municipal heterogeneity. These models come within the so-called conditional autoregressive (CAR) models for drawing up disease maps, initially proposed by Besag and colleagues and subsequently applied in the field of epidemiology. The models were fitted using Bayesian Markov chain Monte Carlo simulation methods with non-informative priors. Posterior distributions of relative risk were obtained using WinBugs. The criterion of contiguity used was adjacency of municipal boundaries. The model fitted is known as the Besag, York, and Mollié (BYM) model and an explicit formulation of the same and the WinBugs code we have used can be consulted in GeoBUGS.

Convergence of the simulations was verified using the BOA (Bayesian output analysis) R program library. Given the great number of parameters of the models, the convergence analysis was performed on a randomly selected sample of 10 towns and cities, taking strata defined by municipal size.

The results of the models were included in a geographic information system to plot maps that depicted standardised mortality ratios, smoothed RR estimates, and the distribution of the posterior probability that RR >1.

RESULTS

From 1989 to 1998, a total of 1647 pleural cancer related deaths were registered in Spain. Cases were registered in only 601 towns and cities. The majority of towns without cases

Abbreviations: RR, relative risk; SMR, standardised mortality ratio
Figure 1  Distribution pattern of the smoothed relative risk (RR) for pleural cancer mortality in Spain, 1989–98.

Figure 2  Distribution pattern of the standardized mortality ratio (left) and the posterior probability of RR being greater than 1 (right). Pleural cancer mortality, Spain, 1989–98.
had fewer than 3500 inhabitants. Using these data, an acceptable computation time, and conventional computers, we were able to compile and ascertain the posterior distribution of relative risk on the basis of a single spatial model that included all of Spain’s 8077 towns and cities and the 47 916 adjacencies existing between them.

Convergence of the estimators was achieved before 100 000 iterations. For the maps shown, a “burn-in” (iterations discarded to ensure convergence) of 300 000 iterations was performed and the posterior distribution was derived with 5000 iterations. Figure 1 depicts the distribution pattern of the smoothed relative risk (RR), and fig 2 depicts the SMR and the posterior probability of the estimated RR being greater than 1.

The SMR map (fig 2) shows the polarisation of the distribution towards its extremes (towns with and without cases), with no specific pattern being clearly discernable. The “noise” present in this map, deriving from the instability of the indicator, is filtered by the smoothing procedure, the result of which is shown in fig 1.

A peculiarity of this smoothed map is that, with a certain degree of accuracy, it “flags” those towns and cities in which some form of exposure to asbestos has occurred. Hence, places such as El Ferrol, Cartagena, Cadiz, Avilés, and Santander, in which shipyards or some other type of asbestos using industry existed for many years, are highlighted.

Barcelona Province displays a remarkable pattern of excess mortality. It is home to the localities with highest risk, particularly those situated in the Vallés District, with Cerdanyola being the town to register the highest RR in Spain. This pattern is found in no other province or region. Possibly, it is the fibre-cement industry that accounts for this increased risk in the Province of Barcelona as well as the pattern observed in the south of the Madrid Region (Getafe). Table 1 shows information on observed and expected deaths in the most representative towns situated in each area in which excess mortality was detected. The map that indicates the distribution of these municipalities, along with their respective probabilities of having excess mortality, is shown in fig 2.

**DISCUSSION**

The results of this study reveal a higher risk of death due to pleural cancer in well defined towns and areas, many of which correspond to municipalities that were once the site of industries where asbestos was used for many years.

The carcinogenic properties of asbestos have been known since the 1930s. Amphiboles in general, and crocidolite in particular, exert the greatest carcinogenic power, something that is apparently attributable to the diameter and structure of the fibres. A low level of exposure is sufficient to cause a tumour, with a minimum latency period of 10 years. Regulation and prohibition of asbestos have been implemented in many developed countries, with Iceland being the first country to ban this substance in 1983. In 1999, the European Union called for the prohibition of all types of asbestos, with express reference to chrysotile, a ban that is to be extended to all EU members by the appointed deadline of 1 January 2005 (Commission Directive 1999/77/EC of 26 July 1999, EU 1999). In Spain, the use of crocidolite was prohibited in 1984: the use and sale of chrysotile was restricted in 1989 and subsequently banned in 2001, following formal adoption of the provisions of the European directive.

Although pleural cancer is extremely infrequent in Spain, during the last 10 years for which mortality data are available, the trend in pleural cancer rates nevertheless indicates an increase in men, rising from 0.40 per 100 000 population in 1980 to 0.78 in 2001 (in absolute terms, there were 61 pleural cancer deaths in men in 1980 versus 173 in 2001). In women, however, no such rising trend is displayed by the rates (0.23 in 1980 and 0.22 in 2001).

With respect to the data used, a limitation to be borne in mind is that the accuracy of certification of pleural tumours in Spain is less than that for other tumour sites. Based on earlier evaluations, we know that part of the diagnoses of mesotheliomas or pleural cancers might possibly be coded as malignant neoplasm of unspecified site. Furthermore, an assessment made in Italy reported 75% concordance between anatopathological diagnosis and death certificate. In the case of pleural tumours, problems in certification would mean that risk was underestimated in some towns and cities, though there is no reason to think that coding procedures might differ between the respective mortality registries entrusted with this task.

In general terms, the regression model seems to function correctly, yielding a pattern that is plausible in the light of earlier provincial maps. In the Provincial Atlas the areas

<table>
<thead>
<tr>
<th>City or town</th>
<th>Province</th>
<th>Observed</th>
<th>Expected</th>
<th>SMR</th>
<th>p value</th>
<th>Smoothed RR</th>
<th>RR credibility interval</th>
<th>p (RR&gt;1)</th>
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<td>Badalona</td>
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<td>2.48</td>
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<td>2.06</td>
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<td>2.14</td>
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<td>1.90</td>
<td>1.05–3.16</td>
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<td>1.63–5.46</td>
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<td>Zaragoza</td>
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</table>

Municipalities having excess mortality and registering 5 or more observed cases were selected for this table. Credibility interval: Bayesian equivalent to confidence interval.
registering highest mortality were Barcelona, Las Palmas, Guipúzcoa, Vizcaya, and Zaragoza among men, and Barcelona, Huesca, Navarre, and Melilla for women. However, in many other cases where very few towns in the province as a whole were affected, as is the case of Murcia, La Coruña, Cádiz, Santander, or even Madrid, the pattern was hidden by the averaging entailed in such large areas being regarded as provinces. Excess pleural cancer mortality in the Province of Barcelona has already been highlighted.18

Observation of unsmoothed and smoothed maps raises the question of the usefulness of these techniques in the case of tumours as rare as pleural cancer, in which the majority of towns and cities have no cases. What the (unsmoothed) SMR map appears to show are towns with and without cases, so that the neighbouring towns hardly seem to be contaminated by the spatial averaging procedure. To a certain extent, the smoothing procedure seems to respect the singularity of highest risk towns. The possibility of false positives being taken into account is reduced by the map that shows the probability of there being excess cases. In parallel with this, there could be a problem of false negatives—that is, small towns that register risk may disappear as a result of the smoothing procedure. This could be the situation of areas of Castile or Extremadura (SMR map). An aspect that warrants more study is the adaptation of these models to situations such as these, where there are large numbers of towns without pleural cancer deaths, or towns with excess cases surrounded by towns and cities without any cases. Other alternative strategies of analysis to be considered in such circumstances could be the use of models with a mixture of distributions that take discontinuities (jumps in the pattern) into account or “zero inflated Poisson” (ZIP) models.25–27

Despite the possible limitations attaching to such techniques due to their recent implementation in the field of epidemiology, the results are clearly able to pinpoint areas where there were industrial facilities in which asbestos was used. What the mortality analysis is only now highlighting are the consequences of using asbestos in this country for many years. It has been estimated that the number of workers exposed to asbestos in 1991 was 60 48826 in Spain and 1.2 million (0.86% of the economically active population) in the European Union. 50% as construction workers. 29 As a result, the pattern detected is the consequence of exposures that took place a number of decades ago. This lag could be shortened if these techniques were applied to cancer incidence data. If surveillance mechanisms, capable of expediting detection of the presence of environmental exposures which posed a possible health risk to workers and the general population, could be established, this would be of vital importance: it would mean that researchers were no longer be confined to spotlighting the consequences of occupational and environmental catastrophes, as is now the case with past exposure to asbestos.

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REFERENCES