Geographic Dimensions of a Health Network Dedicated to Occupational and Work Related Diseases
Marie Delaunay, Vincent Godard, Mélina Le Barbier, Annabelle Gilg Soit Ilg, Cédric Aubert, Anne Maitre, Damien Barbeau, Vincent Bonneterre

To cite this version:
Marie Delaunay, Vincent Godard, Mélina Le Barbier, Annabelle Gilg Soit Ilg, Cédric Aubert, et al.. Geographic Dimensions of a Health Network Dedicated to Occupational and Work Related Diseases. International Journal of Health Geographics, BioMed Central, 2016, 15, pp.34. 10.1186/s12942-016-0063-7. hal-01471477
Geographic dimensions of a health network dedicated to occupational and work related diseases

Marie Delaunay¹,²,³, Vincent Godard²,³, Méлина Le Barbier⁴, Annabelle Gilg Soit Ilg⁵, Cédric Aubert¹,⁶, Anne Maître¹,⁷, Damien Barbeau¹,⁷ and Vincent Bonneterre¹,⁶*

Abstract

Background: Although introduced nearly 40 years ago, Geographic Information Systems (GISs) have never been used to study Occupational Health information regarding the different types, scale or sources of data. The geographic distribution of occupational diseases and underlying work activities were always analyzed independently. Our aim was to consider the French Network of Occupational Disease (OD) clinics, namely the "French National OD Surveillance and Prevention Network" (rnv3p) as a spatial object in order to describe its catchment.

Methods: We mapped rnv3p observations at the workplace level. We initially analyzed rnv3p capture with reference to its own data, then to the underlying workforce (INSEE “Employment Areas”), and finally compared its capture of one emblematic occupational disease (mesothelioma) to an external dataset provided by a surveillance system thought to be exhaustive (PNSM).

Results: While the whole country is covered by the network, the density of observations decreases with increase in the distance from the 31 OD clinics (located within the main French cities). Taking into account the underlying workforce, we show that the probability to capture and investigation of OD (assessed by rates of OD per 10,000 workers) also presents large discrepancies between OD clinics. This capture rate might also show differences according to the disease, as exemplified by mesothelioma.

Conclusion: The geographic approach to this network, enhanced by the possibilities provided by the GIS tool, allow a better understanding of the coverage of this network at a national level, as well as the visualization of capture rates for all OD clinics. Highlighting geographic and thematic shading zones bring new perspectives to the analysis of occupational health data, and should improve occupational health vigilance and surveillance.

Keywords: Occupational health, Occupational diseases, Surveillance network, Stakeholders, Geographic Information System, Spatial analysis, France

Background

The Occupational Health (OH) field is complex because it combines many different types of data (activity sector, occupations, risk exposures, diseases), available at different levels (municipalities, activity territories, employment areas, regions, etc.) and from different partners (insurers, stakeholders, monitoring systems). These multiple sources of data, formalized or not, have always been analysed independently, ignoring in particular the associated geographic dimension (zones of activity).

Even though OH is spatially determined, linked to the location of particular sectors of activity, only a few papers have addressed it. Although the use of the Geographic Information System (GIS) was discussed in studies describing the spatial distribution of some activity sectors and work related problems [1–4], very few papers have followed [5].
Very recently a “proof of concept” paper [6] showed that the use of GIS was a useful way to integrate, analyse and present OH data, from a national to a local level (macro approach), but also within a single workplace (micro approach). This article discussed how these methods and the maps derived from them could be useful for clinicians, epidemiologists, prevention stakeholders, and surveillance authorities. For a better assessment of the importance of occupational diseases within a specific territory, it is necessary to take into account the underlying active worker population (“denominator”) and its distribution according to activity sectors. As an example the authors started to map the active population in one specific sector of activity of concern (workplaces and the number of salaried workers in each). To give perspective, further steps identified were to generalize this approach to the whole active population, and to use denominator figures to calculate and map complementary information such as the expected number of occupational diseases, and indicators comparing observed cases and expected number of cases. When a data source is not expected to be exhaustive in its capture (preventing the calculation of incidence rates) such indicators could still be very useful to: (1) describe the catchment area of health providers specializing in the diagnosis and care of occupational diseases, (2) highlight preferential referral zones and surrounding zones, (3) compare the capture rate from several data sources. For this purpose, the denominator information needed to be refined. The units previously used were most often administrative divisions, but these were not the most accurate ones for this new purpose. In France, data regarding economic activities are given using a specific entity known as the employment area (EA). This entity was created in 1983 by the French National Institute of Statistics and Economic Studies (INSEE), and last updated in 2010 [7]. This subdivision had to be considered when comparing data regarding workers (“denominator”) and their health (“numerator” of occupational diseases).

In France, all 31 Occupational Disease Clinics (OD Clinics) are located in university hospitals and are part of the French National Occupational Diseases Surveillance and Prevention Network (rnv3p) [8] whose main objectives are to describe work situations at risk for specific occupational diseases (OD) and work-related diseases (WRD) (which are not embedded in a list entitling rights for compensation), and to seek new and emerging risks [9]. For more simplicity, WRD and OD are summarised in the “OD” concept in this paper. Analyses of rnv3p network data have been mostly done either on cumulated studies (looking for new rare diseases) [10], or taking the time dimension into account [11]. Apart from the map of the OD Clinics (Fig. 1), and the recent previously cited article [6], no analysis has been done to represent and understand the spatial aspect of rnv3p observations and of the related variables (patients addresses, workplace addresses, and the referring physician’s address).

The aim of the present study was to consider the French National Occupational Diseases Surveillance and Prevention Network as a spatial object and to describe its catchment (preferential catchment areas, surrounding zones). To achieve this, we defined three stages. The first was to describe the rnv3p network and the data it collected. The second was to analyse the rnv3p data with reference to the underlying workforce (denominator) in the employment areas. The third stage was to analyse rnv3p catchment of a well-known occupational disease (mesothelioma), in reference a data source thought to be exhaustive.

**Methods**

The whole study process is described in Fig. 2, detailing the three data sources, the periods, geographic scales and subsets considered, and the methods used to answer the 3 objectives.

In order to meet our first objective (an approximate description of rnv3p catchment), we studied the rnv3p observations for the 2001–2012 period at the level of each workplace considered as “responsible” for at least one case of an occupational disease, and then localized it according to municipality. OD Clinics collect four main categories of data, presented in four different tables: “Patient” (anonymized identification codes, age, sex, and address), “Workplace” (anonymized identification code, activity sector, and address), “Consultation” (date of consultation, referring physician and their address, etc.) and “Problem” (disease, exposures and their degree of imputability with respect to the disease, occupation, work station, etc.). For information, the workplace is rated as “responsible” of the disease, if the level of attributability assessed by the OD specialist physician is high, taking into account the type of disease, patient’s past medical history, patient’s history of occupational exposures (nature, duration), estimated levels of exposures, the chronology of the appearance of the disease, and previous medical knowledge. These tables are summarized in a single table of “Observations”, available nationally, without any possibility of direct identification of the patient or their workplace. Nevertheless, this table, which is usually used for data analysis, includes patient and workplace codes. We choose to localize the observations at the address of the workplace rather than to the patient’s address, as this was of greater interest in terms of surveillance and subsequent prevention. To match the address of the workplace to the observation, we had to consecutively link the different tables. Firstly, “Observations” and “Patients” were merged in order to extract the
workplace identity codes. Secondly, “Observations” and “Workplace” were merged to find the addresses of the workplaces (postal code and city). When the observation was enriched with location information, we used a corresponding table [12] that matched the postal code and city with the name of the municipality.
**Fig. 2** Summarized methodology for the highlightment of French OD clinics preferential recruitment zones. *rnv3p* French National Occupational Diseases Surveillance and Prevention Network, INSEE French National Institute of Statistics and Economic Studies
Three main tools were used to describe the rnv3p data: density, standard deviation ellipse and Thiessen polygons [13]. Rather than simply mapping cases with points, the density is a raster which depicts the concentration of cases, and allows a better visualization of their distribution. Our chosen representation corresponds to a raster with 500 × 500 grid size which ignores administrative boundaries. Since data were located by municipality, a core density tool was applied, the weighting being the number of superposed observations in the same location. From each observation point, the density tool applied a concentric search for other observations within a 10 km radius. Standard deviation ellipses (SDE) were used to summarize the central tendency, dispersion and directional trends of observations made by each OD Clinic. They identify an area comprising 68 % of their information. For this reason, ellipses only give relative information, without any information on the actual number of total observations seen by each clinic. Ellipses might have a larger radius for OD Clinics that have a low number of observations if some of these are located far away from the clinic. In order to include quantitative information useful for interpretation on some of the maps we have added circles proportional to the number of observations recorded by each OD Clinic. Thiessen polygons are a way of representing a purely theoretical preferential recruitment area around clinics. They are totally independent of the real spatial distribution of the observations. They are generated from a set of points (here all OD Clinics) so that any location inside the polygon is closer to that point than any of the other sample points [13].

To achieve our second objective (description of rnv3p data in terms of the underlying workforce), we used data from INSEE on the distribution of five main activity sectors (agriculture, construction, industry, commerce and non-commercial services) at the employment area level (Metropolitan France being partitioned in 304 “employment areas”). The first step was to update the national activity codes in the rnv3p observation tables in order to be comparable to the denominator of the data source. As the INSEE data used the 2008 national activity codes (NAF code) whereas the rnv3p data used the 2003 NAF codes for the period (2001–2012), a merged table [14] between NAF 2003 and 2008 codes was used. The distribution of communes within the 304 employment areas was then used [7]. The second step was to combine data belonging to the same employment areas, in order first to represent the rate of OD per 10,000 workers. Finally, a rate based on the ratio between numbers of rnv3p observed OD and expected OD was calculated for each employment area. The expected number of observations is an estimate taking into account the number of employees by employment area for each activity sector and the average rate of diseases attributed to this sector by the rnv3p nationally. Assuming a homogeneous distribution of disease within the same activity sector, for each of the five sectors considered this indicator gave a rate of OD by employment area. To calculate a national OD rate for each sector, we took into account: the total number of OD per sector, the average number of employees in this sector for the period concerned (12 years, from 2001 to 2012). This national OD rate was then applied to each geographic unit. Depending on the number of employees, the rate calculated the number of expected OD, which enabled us to identify areas with “over” and “under” detection of OD in the rnv3p network. To express this rate, a classification according to standard deviation was chosen. Indeed, this allows one to show the difference between the rate found for each employment area and the average of the rate, by expressing this difference in terms of fractions of the standard deviation of the mean value. Class interruptions were taken with equal ranges and proportional to standard deviation.

Our third objective was to compare the rnv3p data with that from another data source for a given occupational disease. As an example, we chose mesothelioma for the following reasons: the French National Mesothelioma Surveillance Program (PNSM) is a large scale epidemiological surveillance system based on some French counties (“départements”) [15, 16] and this disease is mostly due to occupational exposure to asbestos [17]. PNSM data were only available for the patients’ location and were merged by county. We consider the counties for which the PNSM was still active in 2012 (n = 22), and made the comparison with rnv3p for a period of 5 consecutive years (2008–2012). Under the hypothesis that the PNSM identification of mesothelioma cases is exhaustive on these departments, we estimated the rnv3p catchment rate of this disease by counties. Cases related to either para-occupational exposure or environmental exposures were excluded. While PNSM only identifies pleural mesothelioma, it was not possible to automatically differentiate pleural from peritoneal mesothelioma in the rnv3p data as they are indexed using the same ICD10 code. For this reason, all rnv3p mesothelioma cases were considered. Nevertheless, as the proportion of peritoneal cases is low (8 %, [18]), it was assumed this would not significantly alter the comparison of capture rates between the different OD Clinics.

Two analyses were conducted successively. The first one compared the catchment of all mesothelioma (at patients’ addresses) by the two sources rnv3p and PNSM (subset 2.2 mentioned in Fig. 2). Secondly, only cases for which occupational asbestos exposure was considered as the probable cause of the disease were analysed for both rnv3p and PNSM. Regarding PNSM, only 75 % of the
men and 76 % of the women could undergo an enquiry to determine asbestos exposure (with differences across départements). It was assumed that, at the department level, the proportion of occupationally related mesothelioma was equivalent in the patients that could be interviewed, and in the remaining ones. This was modelled as follows. For instance, for the Manche Département, 48 mesothelioma cases were identified by PNSM among males, 21 of them (44 %) undergo an enquiry regarding asbestos exposure, of which 18 (86 %) were considered as related to occupational asbestos exposure; 27 could not be interviewed. The total expected number of mesothelioma cases related to occupational asbestos exposure according to PNSM in the Manche département was calculated as the sum of the ones with a positive result of the enquiry (n = 18), and of the number of mesothelioma expected to be related to occupation in the 27 remaining subjects (n = 27 × 0.86 = 23), which means a total of n = 41.

Results

Regarding the geocoding process for the Observation table, information has been lost at two successive levels. Firstly when merging the “Observation” and “Patient” tables: only 110,578 of the 162,526 observations could be linked to a workplace. This is partly due to the fact that for retired people who came for the investigation of chronic diseases (such as cancers), it was not possible to record previous company where they were exposed. The second one was in matching the municipality (commune, the smallest French administrative division) address: only 100,597 out of 110,578 observations could be matched. Table 1 summarizes the information lost in the three tables of interest (Patient, Workplace and Observations) and indicates the rate of concordance for each of them.

Since the geocoding process was based on matching tables in which geographic information was already listed, 98.7 % of our data (n = 100,597) linked to a workplace and having an address were successfully geolocated. This means they had a score of 100 indicating a perfect match, an A match (automatically matched) and an M status (the address is matched). Nevertheless, there are important differences in the percentage of geolocated observations between the different OD clinics (from 11 to 93 %) (Table 2). This information should be borne in mind when interpreting the maps.

The 100,597 observations successfully geocoded to the workplace address, mapped by the three following methods (density method, standard deviations ellipses, and Thiessen Polygons) are presented together on Fig. 3. At a first glance, this figure shows an almost complete coverage of the country. Ellipses also show a satisfying distribution of the catchment areas throughout the country. These ellipses are quite similar to the theoretically expected catchment areas shown by the Thiessen polygons (“ideal” geometric catchment). When two OD Clinics are close (e.g. Dijon and Besançon in eastern France), ellipses are not centered on the clinic, but shifted away from the nearby OD clinic, which also corresponds to the region it belongs to. Regarding Paris region, which has five OD Clinics (Paris Cochin, Hôtel-Dieu, Fernand-Widal, Garches and Créteil), there is superposition of the catchment areas. Secondly, the map clearly highlights that observations are mainly located in cities with OD Clinics and their surrounding areas: ellipses are centred on the OD Clinics, with the highest density of observations at their centre. The zones of few observations are those in between ellipses, which mostly correspond to the peripheral zones of the Thiessen polygons.

The SDE representation was then used to distinguish spatial observation areas according to the three main causes of referral to OD Clinics (Fig. 4): work-related assessment of disease and OD diagnosis, work-fitness concerns, systematic screening of exposure to hazardous substances for a limited number of diseases in hospitalized patients (usually lung cancers, but the type of disease screened might vary according to OD Clinic and time period). The assessment of a disease as being

| rnv3p main tables (number of observations) | Observations n = 162,526 | Patients n = 192,281 | Workplaces n = 70,916 |
|-------------------------------------------|-------------------------|---------------------|----------------------|
| No link with the workplace (n=) | 51,948 | | |
| Link with workplace (n=) | 110,578 | | |
| Address not recorded (n=) | 8667 | 24,002 | 4980 |
| Address not found during the geolocalisation process (n=) | 1314 | 16,032 | 2262 |
| Match ratea (%) | 98.7 | 90.5 | 96.6 |
| Total number of rnv3p observations located with reference to the primary rnv3p tables (n=) | 100,597 | 152,247 | 63,674 |
| Percentage of rnv3p observations successfully geolocated | 61.9 | 79.1 | 89.8 |

* Match rate refers to the percentage of addresses successfully geolocated with reference to the only entries that have one address informed.
work-related or a clear OD diagnosis were the main reasons for referring patients to OD Clinics. At the single OD clinic level, we can see some highly specific situations, such as that of Limoges (west centre France), based on a relatively small number of geolocated observations (n = 179/total = 291). The ellipse for work-fitness problems is shifted to the south of the city as the problems were mostly referred to the OD Clinics by occupational physicians employed by companies located south of Limoges (Fig. 4b). A completely different example is that of referral for work-related disease in the Rhône-Alpes region. Until 2012 patients seen in Grenoble OD Clinic for systematic hazardous substances assessment came from workplaces in a more extended area than for the other reasons of referral. As Table 3 shows, for 16 OD Clinics, the ellipse size is relatively large for the assessment of the work-relatedness of diseases and OD diagnosis. For 13 OD Clinics, the ellipse areas for work-fitness concerns are relatively large. For 2 OD Clinics (Creteil and Grenoble), ellipse size is greatest for systematic screening of hazardous exposures. Regarding referral to OD Clinics in Paris and its surrounding area (called the “Ile de France”), the “systematic screening of exposure to hazardous substances” issue is the only reason for referral that displays a very large differences in capture areas. This is because the Creteil OD Clinic is a specialist centre in the systematic screening of patients presenting with lung cancer (Fig. 4c).

In order to take into account the fact that the main cities and suburbs are associated with the greatest density of active workers, Fig. 5 describe the catchment areas taking into account the number of active workers in each employment area (rate of observations with the total number of active workers in the employment area as denominator). 297 of the 304 employment area had cases recorded within rnv3p. There were no observations for seven employment areas of which five are located in the island of Corsica that has no OD Clinic. The two other areas for which there were no observation are “Issoudun” (central France) and “Menton—Vallée de la Roya” (south-eastern France, at the Italian border) that had an average number of active workers in the 2001–2012 period of 9319 and 20,221 respectively. Overall, the mean number of OD per 10,000 workers catched by OD clinics for the period considered is 23.4/10,000 workers. Nevertheless, variance is very important (standard deviation = 26, minimum = 0.5, maximum = 198). The nine employment areas corresponding to the highest part of the distribution (>2.8 deviation standard), are in decreasing order: Lunéville near Nancy (198.2 rnv3p observations per 10,000 workers), Le Havre (rate = 156.9), Toulouse (rate = 149.5), Bordeaux (rate = 142.2), Brest (rate = 118.9), Grenoble (rate = 115.3), Nancy (rate = 109.9), Créteil (rate = 102.3) and Clermont-Ferrand (rate = 97.5). Most of these employment areas coalesce with neighbouring employment areas and show a decreasing rate of observations with increasing distance from the OD clinic. However, employment area with the highest catchment rate are sometimes adjacent to some with the lowest catchment rate (such as Clermont-Ferrand employment zone and the nearby zones of Gueret and Ussel which have capture rate of 2.7 and 3.2 per 10,000 workers). As for Bordeaux, the administrative regional boundary (black line) seems to act like a barrier to referral from the adjacent region. Finally, where

| OD Clinics | Total of observations | Observations linked to the workplace | Observations geolocated |
|------------|----------------------|-------------------------------------|-------------------------|
| Amiens     | 564                  | 213                                 | 122 (22 %)              |
| Angers     | 2652                 | 2456                                | 2386 (90 %)             |
| Besançon   | 487                  | 342                                 | 277 (57 %)              |
| Bordeaux   | 14,269               | 10,639                              | 9626 (67 %)             |
| Brest      | 5514                 | 3239                                | 3118 (57 %)             |
| Caen       | 6322                 | 956                                 | 723 (11 %)              |
| Cherbourg  | 2121                 | 754                                 | 551 (26 %)              |
| Clermont   | 3425                 | 2997                                | 2942 (85 %)             |
| Cochin     | 13,790               | 12,548                              | 12,365 (90 %)           |
| Créteil    | 12,194               | 7759                                | 7519 (62 %)             |
| Dijon      | 564                  | 485                                 | 459 (81 %)              |
| Fernand    | 5921                 | 5582                                | 5471 (92 %)             |
| Garches    | 10,082               | 2190                                | 1816 (18 %)             |
| Grenoble   | 7668                 | 4928                                | 4854 (63 %)             |
| Hôtel-Dieu | 752                  | 661                                 | 544 (72 %)              |
| Le Havre   | 4557                 | 2576                                | 2442 (54 %)             |
| Lille      | 10,212               | 5306                                | 3844 (38 %)             |
| Limoges    | 291                  | 194                                 | 179 (62 %)              |
| Lyon       | 12,751               | 7848                                | 7464 (58 %)             |
| Marseille  | 2121                 | 1765                                | 1573 (74 %)             |
| Montpellier| 861                  | 603                                 | 560 (65 %)              |
| Nancy      | 6129                 | 5599                                | 4725 (77 %)             |
| Nantes     | 9902                 | 8876                                | 5666 (57 %)             |
| Poitiers   | 894                  | 834                                 | 814 (91 %)              |
| Reims      | 3227                 | 1268                                | 1151 (36 %)             |
| Rennes     | 1561                 | 1194                                | 1182 (76 %)             |
| Rouen      | 4573                 | 2245                                | 2121 (46 %)             |
| Saint-Etienne| 2369                 | 2219                                | 2127 (90 %)             |
| Strasbourg | 3641                 | 2536                                | 2431 (67 %)             |
| Toulouse   | 11,176               | 10,487                              | 10,392 (93 %)           |
| Tours      | 1936                 | 1279                                | 1153 (60 %)             |
| **Total**  | **162,526**          | **110,578**                         | **100,597 (62 %)**      |
ellipses overlap (employment areas with two OD Clinics) there does not appear to be better capture of observations. In fact, these employment areas often show an observation rate which is intermediate between those of the nearby cities in which OD Clinics are located (e.g. Angers-Nantes; Lyon-Grenoble).
Fig. 4 Catchment areas of OD Clinics according to the main cause of patient referral: work-relatedness assessment of diseases and diagnosis of OD (a), work-fitness concern (b), systematic screening of hazardous exposures (c). Circles are proportional to the number of observations, and standard deviation ellipses show the main geographical catchment area for each OD clinic. OD clinics: occupational diseases clinics.
Regarding the industrial sector (manufacturing, mining, chemical industry, metallurgy and metal work etc.), it appears that this activity is more concentrated in the northern half of France, whereas the Mediterranean perimeter has a relatively low percentage of industrial workers (Fig. 6). The majority of the employment areas with the highest concentrations of active industrial workers are small. Here, the number of observed cases over the number of expected ones has been studied to highlight employment areas with more referrals than the average. In general the rnv3p pattern of observation for industrial sectors is in line with what has been previously described, but with some exceptions. The employment area with the highest capture rate of OD among industrial workers are Bordeaux (and some neighbouring zones), Toulouse, Grenoble, Nancy, Brest and three zones in Ile de France region. All these employment areas have an OD clinic. We notice that, except for Toulouse, none of these OD clinics belong to the highest class regarding the percentage of geocoded information (the information mapped doesn’t only translate the amount of available information). None of these employment

| OD Clinics         | Observations | Assessment of work-relatedness of diseases and OD diagnosis | Work-fitnes concerns | Systematic screening of exposure to hazardous substances |
|-------------------|--------------|-------------------------------------------------------------|----------------------|----------------------------------------------------------|
|                   | Number       | Ellipse size (km²)                                         | Number               | Ellipse size (km²)                                         | Number               | Ellipse size (km²) |
| Amiens            | 122          | 11,818                                                     | 107                  | 7,262                                                     | 10                   | 8,594              |
| Angers            | 2386         | 7,848                                                     | 1279                 | 7,988                                                     | 314                  | 8,503              |
| Besançon          | 277          | 14,269                                                    | 200                  | 10,442                                                    | 50                   | 16,475             |
| Bordeaux          | 9626         | 16,945                                                    | 7313                 | 17,222                                                    | 1083                 | 21,267             |
| Brest             | 3118         | 15,051                                                    | 2233                 | 8,209                                                     | 213                  | 9,955              |
| Caen              | 723          | 4385                                                      | 422                  | 4518                                                     | 122                  | 3,871              |
| Cherbourg         | 551          | 7,392                                                     | 366                  | 4,801                                                     | 13                   | 2,674              |
| Clermont-Ferrand  | 2942         | 5,987                                                     | 2318                 | 6,590                                                     | 555                  | 4,046              |
| Cochin            | 12,365       | 6,083                                                     | 7754                 | 5,216                                                     | 3470                 | 7,267              |
| Cîteaux           | 7519         | 6,205                                                     | 5797                 | 5,934                                                     | 410                  | 4,444              |
| Dijon             | 459          | 18,421                                                    | 192                  | 17,964                                                    | 262                  | 17,531             |
| Fernand-Widal     | 5471         | 7,272                                                     | 4233                 | 6,610                                                     | 492                  | 1,359              |
| Garches           | 1816         | 2033                                                     | 1340                 | 2,286                                                     | 232                  | 769                |
| Grenoble          | 4854         | 6,889                                                     | 3427                 | 7,542                                                     | 811                  | 3,656              |
| Hôtel-Dieu        | 544          | 1794                                                     | 349                  | 2,159                                                     | 105                  | 952                |
| Le Havre          | 2442         | 2,936                                                     | 928                  | 3,604                                                     | 58                   | 766                |
| Lille             | 3844         | 11,245                                                    | 1908                 | 12,023                                                    | 663                  | 14,232             |
| Limoges           | 179          | 19,141                                                    | 156                  | 15,367                                                    | 9                    | 4,914              |
| Lyon              | 7464         | 13,484                                                    | 5547                 | 12,641                                                    | 1521                 | 16,572             |
| Marseille         | 1573         | 11,705                                                    | 1,263                | 10,293                                                    | 100                  | 8937               |
| Montpellier       | 560          | 19,233                                                    | 451                  | 17,823                                                    | 92                   | 20,667             |
| Nancy             | 4725         | 11,669                                                    | 2218                 | 10,424                                                    | 1702                 | 10,956             |
| Nantes            | 5666         | 16,799                                                    | 4001                 | 12,854                                                    | 1163                 | 9809               |
| Poitiers          | 814          | 17,965                                                    | 640                  | 20,041                                                    | 90                   | 9,418              |
| Reims             | 1151         | 10,956                                                    | 1037                 | 11,042                                                    | 70                   | 3,430              |
| Rennes            | 1182         | 10,260                                                    | 307                  | 7,122                                                     | 530                  | 13,191             |
| Rouen             | 2121         | 5606                                                     | 1140                 | 5,344                                                     | 662                  | 5,330              |
| Saint-Etienne     | 2127         | 4074                                                     | 1698                 | 3,649                                                     | 181                  | 7,342              |
| Strasbourg        | 2431         | 9225                                                     | 1196                 | 9,685                                                     | 512                  | 5,527              |
| Toulouse          | 10,392       | 11,621                                                    | 5327                 | 12,517                                                    | 3776                 | 9,094              |
| Tours             | 1153         | 14,552                                                    | 780                  | 12,609                                                    | 114                  | 18,492             |
| Total             | 100,597      | 311,994                                                   | 65,927               | 291,801                                                   | 19,385               | 270,067           |

Metropolitan France area = 551,500 km²
areas belong to those having the highest proportion of industrial workers; six of them are even in the lowest quintile.

Finally, in order to take into account the five broad categories of occupational activities (agriculture, construction, industry, commerce and non-commercial...
services), the ratios of observed versus expected OD for each category of activity was calculated and mapped for each employment area. This map (Additional File 1: Fig. S1) was exactly similar to the one of the rate of OD per employment areas (Fig. 5), which means the pattern of recruitment was not substantially modified by the distribution of activities across employment areas.

Another issue is the type of diseases in a given activity sector that are investigated by the OD Clinics and which could lead to qualitative differences in observations. Table 4 shows the typology of the OD attributed to work (according to the first ICD-10 digit) in industrial sector for the 11 employment areas with the highest catchment. Overall, there is a predominance of lung diseases (31 %) and psychiatric disorders (19 %), followed by eyes and ears diseases (12 %), dermatological diseases (10 %) and musculoskeletal disorders (10 %), but there are stark differences between OD Clinics, according to the exact nature of the medical supply and expertise they were able to develop.

Regarding mesothelioma, we first mapped the 1178 cases recorded by the rnv3p for the 2001–2012 period at the county (département) level (Fig. 7). Most of the cases investigated in OD clinics came from 11 of the 96 “départements” of mainland France. Most of them are located in the Northern part of France (Seine Maritime where Rouen OD clinic is located, Nord and Pas de Calais mostly captured by the Lille OD clinic, and cases from the Ile de France region captured by OD clinics in the Paris area). Three “départements” with a relatively high number of mesothelioma cases recorded by the rnv3p are located in the southern half of France (Gironde by the Bordeaux OD clinic, and Isère and Rhône in the Rhône-Alpes region, by the Grenoble and Lyon OD clinics).

We then compared, for the same 2008–2012 period, the number of all mesothelioma cases recorded by the epidemiological source considered as the gold standard (PNSM, total = 1718) and by the rnv3p (total = 285 cases), by “département” and sex (Table 5). Both sources had a sex-ratio of 0.3 (number of females’ cases over number of males’ cases). In 5 départements out of 22, no males’ cases have been reported in rnv3p, whereas the inverse situation is encountered in 13 départements. The global rnv3p catchment rate for this disease (PNSM taking as a reference) is 17 % for males and 15 % for females, with strong variations between counties showing a strong OD clinic effect (from 0 to 44 and 59 % respectively for females' and males’ cases, with the highest value associated to Val de Marne). For each clinic, there is usually a wide discrepancy between the capture rates of males’ cases and females’ cases. Usually the capture rate of female's cases for all mesothelioma, is lower than the one for males’ cases, except for 3 départements: Gironde (34 % for women vs 19 % for men), Seine-Saint-Denis (21 vs 11 %), and Calvados (24 and 3 % respectively, but based on a lower number of cases). Then, the rnv3p mesothelioma capture rate was assessed considering only the cases for which an occupational asbestos exposure was certified and considered as the probable cause of the disease (Table 6 for males and Table 7 for females). Regarding males’ cases, the catchment rate did not change globally (191/1107 = 17 %), and the variations in each OD clinics were very limited. Nevertheless, considering women's cases, the catchment rate raised from 15 to 47 % when considering the subset of cases for which the disease was attributed to occupational asbestos exposure (24 cases for rnv3p, and 51 for PNSM). In Calvados 5 cases have been captured by rnv3p over 7 cases for PNSM. Moreover, in Isère and Val-de-Marne, more cases have been related to an occupational exposure to asbestos within rnv3p than within the PNSM (n = 6 vs 4, and 4 vs 3 respectively). We got the confirmation by checking the medical reports that these female cases were occupationally related, and not para-occupational. Again, these analyses show a strong OD clinic effect.

Figure 8a1, a2, b1, b2 shows the geographical distribution of capture rate of rnv3p compared to PNSM for men and women, for all mesothelioma and the subset of mesothelioma attributed to occupational asbestos exposure. The maps highlight the fact that the capture of mesothelioma cases by rnv3p is very low in the southern counties covered by PNSM, with two notable exceptions, namely Isère where Grenoble OD clinic is located, and Gironde with Bordeaux OD clinic and the nearby Dordogne county. The higher the distance with an OD clinic, the lower is the catchment rate (see for instance Alpes Maritimes at the Italian border) or Corsica. The highest catchments are reached in the Paris area (Val de Marne where the Creteil OD clinic located), Seine Maritime county (where Rouen and Le Havre OD clinics are located), whereas the catchment in the neighboring Normandie counties remains several times lower (Manche where Cherbourg OD clinic is located, Calvados, and Orne). In the Eastern France, the catchment is also 3 times higher in the county where Strasbourg OD clinic is located (Bas Rhin), than in the neighbouring county with no OD clinic. To the contrary some area surrounding OD clinics (such Loire Atlantique with Nantes OD clinic, and Bouches du Rhône with Marseille OD clinic) have a low catchment of mesothelioma cases, as their main activity is dedicated to other medical issues. Figure 8a2, b2 clearly highlights a highest rnv3p capture rate for female’s cases for which occupational asbestos exposure was identified and considered as the probable cause of the disease, in 4 départements.
Fig. 6  Distribution of industrial workers in France, and employment area with higher catchment of OD by OD clinics network. OD occupational diseases. Employment rates in the industrial sectors are shown by depth of purple (at the employment areas level), and occupational diseases (OD) reported to the rnv3p by OD Clinics (number of observations) are reported to the expected number (coloured boundaries; highest recruitment zones: red-hatched). Sources rnv3p 2001–2012, and French National Institute of Statistics and Economic Studies (INSEE)
Table 4: Typology of occupational diseases (according to first ICD-10 digit) investigated by the French OD Clinics regarding the industry sector, for the eleven employment areas with the highest catchment

| Employment zone | All observations (industry sector) | Observations related to work-relatedness assessment | Subset of observations for which disease is associated to occupational exposure with strong imputability | First digit of the ICD-10 code (main categories) |
|-----------------|-----------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|
|                 |                                   |                                               |  | B | C | D | E | F | G | H | I | J |
| Bordeaux        | 1627                              | 1173                                          | 470 | 5% | 37% | 4% | 5% | 1% | 20% |       |
| Brest           | 537                               | 317                                           | 191 | 3% | 14% | 3% | 5% | 53% |       |
| Créteil         | 288                               | 214                                           | 143 | 2% | 13% | 3% | 8% | 1% | 40% |       |
| Grenoble        | 1250                              | 937                                           | 572 | 5% | 1% | 5% | 1% | 13% | 1% | 45% |       |
| La Teste-de-Buch| 84                                | 50                                            | 20  | 2% | 20% | 5% | 55% |       |
| Le Havre        | 1225                              | 499                                           | 165 | 5% | 1% | 2% | 5% | 1% | 75% |       |
| Nancy           | 659                               | 303                                           | 173 | 6% | 6% | 14% | 2% | 4% | 29% |       |
| Nemours         | 54                                | 36                                            | 17  | 6% | 6% | 12% | 6% | 47% |       |
| Orly            | 328                               | 243                                           | 130 | 1% | 6% | 1% | 22% | 4% | 10% | 29% |       |
| Pauillac        | 17                                | 15                                            | 6   | 33% | 17% |       |
| Toulouse        | 1610                              | 1021                                          | 774 | 25% | 5% | 21% | 10% |       |
| Total           | 7679                              | 4808                                          | 2661 | 2 | 89 | 24 | 3 | 500 | 86 | 310 | 13 | 821 |

| Employment zone | All observations (industry sector) | Observations related to work-relatedness assessment | Subset of observations for which disease is associated to occupational exposure with strong imputability | First digit of the ICD-10 code (main categories) |
|-----------------|-----------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|
|                 |                                   |                                               |  | K | L | M | N | R | S | T | U | Z |
| Bordeaux        | 1627                              | 1173                                          | 470 | 2% | 14% | 12% | 3% | 1% | 2% | 1% |       |
| Brest           | 537                               | 317                                           | 191 | 10% | 2% | 2% | 1% | 1% | 8% |       |
| Créteil         | 288                               | 214                                           | 143 | 1% | 12% | 13% | 4% | 1% | 1% |       |
| Grenoble        | 1250                              | 937                                           | 572 | 1% | 10% | 5% | 6% | 1% | 3% | 2% |       |
| La Teste-de-Buch| 84                                | 50                                            | 20  | 5% | 15% |       |
| Le Havre        | 1225                              | 499                                           | 165 | 5% | 1% | 1% | 1% | 1% | 2% |       |
| Nancy           | 659                               | 303                                           | 173 | 17% | 11% | 1% | 2% | 3% | 4% |       |
| Nemours         | 54                                | 36                                            | 17  | 6% | 6% |       |
| Orly            | 328                               | 243                                           | 130 | 12% | 6% | 1% | 2% | 3% | 3% |       |
| Pauillac        | 17                                | 15                                            | 6   | 33% | 17% |       |
| Toulouse        | 1610                              | 1021                                          | 774 | 11% | 16% | 3% | 3% | 6% |       |
| Total           | 7679                              | 4808                                          | 2661 | 8 | 274 | 272 | 4 | 86 | 2 | 46 | 39 | 82 |

Percentages are presented by lines. A and B: certain infectious and parasitic diseases; C: neoplasms; D: diseases of the blood and blood-forming organs and certain disorders involving the immune system; E: endocrine, nutritional and metabolic diseases; F: mental and behavioural disorders; G: diseases of the nervous system; H: diseases of the eye, adnexa, ear and mastoid process; I: diseases of the circulatory system; J: diseases of the respiratory system; K: diseases of the digestive system; L: diseases of the skin and subcutaneous tissue; M: diseases of the musculoskeletal system and connective tissue; N: diseases of the genitourinary system; R: symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified; S and T: injury, poisoning and certain other consequences of external causes; U: codes for special purposes; Z: factors influencing health status and contact with health services.
Fig. 7  Mesothelioma cases recorded by the rmv3p at the "département" level for the period 2001–2012
Table 5  All mesothelioma cases identified by PNSM and rnv3p for the 2008–2012 period, by “département” and sex

| Counties identification (number and name of French «départements») | All Mésothélioma (2008–2012) | PNSM | rnv3p | m3p catchment rate (%) |
|---------------------------------------------------------------|--------------------------------|-------|-------|------------------------|
|                                                              | M     | F     | Total | Sex-ratio | M     | F     | Total | Sex-ratio | M     | F     | Total |
| 06—Alpes Maritimes                                            | 60    | 32    | 92    | 0,5       | 0     | 0     | 0     | –         | 0     | 0     | 0     |
| 13—Bouches-du-Rhône                                          | 182   | 40    | 222   | 0,2       | 2     | 0     | 2     | 0         | 1     | 0     | 1     |
| 14—Calvados                                                  | 37    | 25    | 62    | 0,7       | 1     | 6     | 7     | 6         | 3     | 24    | 11    |
| 24—Dordogne                                                  | 19    | 14    | 33    | 0,7       | 6     | 0     | 6     | 0         | 32    | 0     | 18    |
| 25—Doubs                                                    | 14    | 3     | 17    | 0,2       | 2     | 0     | 2     | 0         | 14    | 0     | 12    |
| 2A—Haute-Corse                                              | 5     | 1     | 6     | 0,2       | 0     | 0     | 0     | –         | 0     | 0     | 0     |
| 2B—Corse du Sud                                             | 8     | 2     | 10    | 0,3       | 0     | 0     | 0     | –         | 0     | 0     | 0     |
| 33—Gironde                                                  | 103   | 32    | 135   | 0,3       | 20    | 11    | 31    | 0,6       | 19    | 34    | 23    |
| 38—Isere                                                    | 95    | 28    | 123   | 0,3       | 34    | 9     | 43    | 0,3       | 36    | 32    | 35    |
| 40—Landes                                                   | 23    | 9     | 32    | 0,4       | 0     | 0     | 0     | –         | 0     | 0     | 0     |
| 44—Loire-Atlantique                                         | 133   | 24    | 157   | 0,2       | 1     | 0     | 1     | 0         | 1     | 0     | 1     |
| 47—Lot-et-Garonne                                            | 12    | 3     | 15    | 0,3       | 0     | 0     | 0     | –         | 0     | 0     | 0     |
| 50—Manche                                                   | 48    | 13    | 61    | 0,3       | 5     | 0     | 5     | 0         | 10    | 0     | 8     |
| 61—Ome                                                      | 26    | 7     | 33    | 0,3       | 2     | 0     | 2     | 0         | 8     | 0     | 6     |
| 64—Pyrénées-Atlantiques                                      | 34    | 11    | 45    | 0,3       | 1     | 1     | 2     | 1         | 3     | 9     | 4     |
| 67—Bas-Rhin                                                 | 43    | 11    | 54    | 0,3       | 18    | 2     | 20    | 0,1       | 42    | 18    | 37    |
| 68—Haut-Rhin                                                | 23    | 5     | 28    | 0,2       | 3     | 0     | 3     | 0,0       | 13    | 0     | 11    |
| 76—Seine-Maritime                                            | 161   | 57    | 218   | 0,4       | 74    | 12    | 86    | 0,2       | 46    | 21    | 67    |
| 80—Somme                                                    | 23    | 9     | 32    | 0,4       | 5     | 1     | 6     | 0,2       | 22    | 11    | 19    |
| 83—Var                                                      | 126   | 26    | 152   | 0,2       | 1     | 0     | 1     | 0,0       | 1     | 0     | 1     |
| 93—Seine-Saint-Denis                                         | 64    | 24    | 88    | 0,4       | 7     | 5     | 12    | 0,7       | 11    | 21    | 14    |
| 94—Val-de-Marne                                              | 71    | 32    | 103   | 0,6       | 42    | 14    | 56    | 0,3       | 59    | 44    | 54    |
| Total                                                       | 1310  | 408   | 1718  | 0,3       | 224   | 61    | 285   | 0,3       | 17    | 15    | 17    |

PNSM French National Mesothelioma Surveillance Program («Programme National de Surveillance du Mesothéliome»), Rnv3p French National Occupational Diseases Surveillance and Prevention Network («Réseau National de Vigilance et de Prévention des Pathologies Professionnelles»), M males, F females, sex-ratio F/M
Table 6 Males’ cases of Mesothelioma attributed to occupational asbestos exposure, for PNSM and mv3p, by département and sex (2008–2012)

| Counties identification (number and name of French « départements») | rrn3p | PNSM | Total of males cases (T<sub>PNSM</sub>) | Total of cases investigated (T<sub>PNSM-I</sub>) | Work-related cases among T<sub>PNSM-I</sub> (WR<sub>PNSM</sub>) and related proportion (p) | Total of Cases NOT investigated (T<sub>PNSM-NI</sub>) | Expected work-related cases among those not investigated WR<sub>PNSM-NI</sub> = T<sub>PNSM-NI</sub> × p | Estimated number of work-related cases WR<sub>PNSM</sub> = WR<sub>PNSM-I</sub> + WR<sub>PNSM-NI</sub> | mv3p catchment rate of males’ mesothelioma cases attributed to occupational asbestos exposure C = WR<sub>mv3p</sub>/WR<sub>PNSM</sub> × 100 |
|---|---|---|---|---|---|---|---|---|---|
| 06—Alpes Maritimes | 0 | 60 | 45 | 38 (0.84) | 15 | 13 | 51 | 0 | 13 |
| 13—Bouches-du-Rhône | 2 | 182 | 140 | 131 (0.94) | 42 | 39 | 170 | 1 | 17 |
| 14—Calvados | 1 | 37 | 30 | 25 (0.83) | 7 | 6 | 31 | 3 | 3 |
| 24—Dordogne | 4 | 19 | 14 | 8 (0.57) | 5 | 3 | 11 | 37 |
| 25—Drets | 1 | 14 | 12 | 9 (0.75) | 2 | 2 | 11 | 10 |
| 2A—Haute-Corse | 0 | 5 | 3 | 2 (0.67) | 2 | 1 | 3 | 0 | 0 |
| 28—Corse du Sud | 0 | 8 | 7 | 6 (0.86) | 1 | 1 | 7 | 0 | 0 |
| 33—Gironde | 19 | 103 | 88 | 68 (0.77) | 15 | 12 | 80 | 24 | 24 |
| 38—Isère | 28 | 95 | 72 | 63 (0.88) | 23 | 20 | 83 | 34 | 34 |
| 40—Landes | 0 | 23 | 22 | 17 (0.77) | 1 | 1 | 18 | 0 | 0 |
| 44—Loire-Atlantique | 1 | 133 | 60 | 52 (0.87) | 73 | 63 | 115 | 1 | 1 |
| 47—Lot-et-Garonne | 0 | 12 | 10 | 7 (0.70) | 2 | 1 | 8 | 0 | 0 |
| 50—Manche | 5 | 48 | 21 | 18 (0.86) | 27 | 23 | 41 | 12 | 12 |
| 61—Oise | 2 | 26 | 14 | 12 (0.86) | 12 | 10 | 22 | 9 | 9 |
| 64—Pyrénées-Atlantiques | 1 | 34 | 28 | 22 (0.79) | 6 | 5 | 27 | 4 | 4 |
| 67—Bas-Rhin | 15 | 43 | 39 | 35 (0.90) | 4 | 4 | 39 | 39 | 39 |
| 68—Haut-Rhin | 2 | 23 | 14 | 12 (0.86) | 9 | 8 | 20 | 10 | 10 |
| 76—Seine-Maritime | 63 | 161 | 127 | 112 (0.88) | 34 | 30 | 142 | 44 | 44 |
| 80—Somme | 4 | 23 | 15 | 12 (0.80) | 8 | 6 | 18 | 22 | 22 |
| 83—Var | 1 | 126 | 102 | 91 (0.89) | 24 | 21 | 112 | 1 | 1 |
| 93—Seine-Saint-Denis | 6 | 64 | 57 | 40 (0.70) | 7 | 5 | 45 | 13 | 13 |
| 94—Val-de-Marne | 36 | 71 | 65 | 52 (0.80) | 6 | 5 | 57 | 63 | 63 |
| Total | 191 | 1310 | 985 | 832 (0.84) | 325 | 275 | 1107 | 17 | 17 |

**PNSM** French National Mesothelioma Surveillance Program («Programme National de Surveillance du Mesothéliome»), **Rrn3p** French National Occupational Diseases Surveillance and Prevention Network («Réseau National de Vigilance et de Prévention des Pathologies Professionnelles»), **M** males, **F** females, **sex ratio F/M, NA not attributed**
### Table 7 Females' cases of Mesothelioma attributed to occupational asbestos exposure, for PNSM and rnv3p, by département and sex (2008–2012)

| Counties identification (number and name of French départements) | rnv3p | PNSM | Work-related females cases among rnv3p (WR<sub>rnv3p</sub>) | Total of females cases (T<sub>PNSM</sub>) | Work-related cases among T<sub>PNSM</sub> (n = WR<sub>PNSM</sub>) and related proportion (p) | Total of Cases NOT investigated (T<sub>PNSM-NI</sub>) | Expected work-related cases among those not investigated WR<sub>PNSM-NI</sub> = T<sub>PNSM-NI</sub> × p | Estimated number of work-related cases WR<sub>PNSM</sub> = WR<sub>PNSM-I</sub> + WR<sub>PNSM-NI</sub> | rnv3p catchment rate of females' mesothelioma cases attributed to occupational asbestos exposure C = WR<sub>rnv3p</sub> / WR<sub>PNSM</sub> × 100 |
|---|---|---|---|---|---|---|---|---|---|
| 06—Alpes Maritimes | 0 | 32 | 20 | 0 (0.00) | 12 | 0 | 0 | NA | |
| 13—Bouches-du-Rhône | 0 | 40 | 31 | 0 (0.00) | 9 | 0 | 0 | NA | |
| 14—Calvados | 5 | 25 | 17 | 5 (0.29) | 8 | 2 | 7 | 68 | |
| 24—Dordogne | 0 | 14 | 11 | 1 (0.09) | 3 | 0 | 0 | 1 | NA |
| 25—Doubs | 0 | 3 | 3 | 0 (0.00) | 0 | 0 | 0 | 0 | NA |
| 2A—Haute-Corse | 0 | 1 | 1 | 0 (0.00) | 0 | 0 | 0 | 0 | NA |
| 2B—Corse du Sud | 0 | 2 | 1 | 0 (0.00) | 1 | 0 | 0 | 0 | NA |
| 33—Gironde | 2 | 32 | 29 | 3 (0.10) | 3 | 0 | 0 | 3 | 60 |
| 38—Isère | 6 | 28 | 26 | 4 (0.15) | 2 | 0 | 4 | 139 | |
| 40—Landes | 0 | 9 | 5 | 0 (0.00) | 4 | 0 | 0 | 0 | NA |
| 44—Loire-Atlantique | 0 | 24 | 14 | 3 (0.21) | 10 | 2 | 5 | 0 | |
| 47—Lot-et-Garonne | 0 | 3 | 2 | 0 (0.00) | 1 | 0 | 0 | 0 | NA |
| 50—Manche | 0 | 13 | 6 | 2 (0.33) | 7 | 2 | 4 | 0 | |
| 61—Orne | 0 | 7 | 7 | 1 (0.14) | 0 | 0 | 1 | 0 | |
| 64—Pyrénées-Atlantiques | 0 | 11 | 8 | 0 (0.00) | 3 | 0 | 0 | 0 | NA |
| 67—Bas-Rhin | 1 | 11 | 10 | 1 (0.10) | 1 | 0 | 1 | 91 | |
| 68—Haut-Rhin | 0 | 5 | 1 | 0 (0.00) | 4 | 0 | 0 | 0 | NA |
| 76—Seine-Maritime | 5 | 57 | 43 | 11 (0.26) | 14 | 4 | 15 | 34 | |
| 80—Somme | 0 | 9 | 6 | 1 (0.17) | 3 | 1 | 2 | 0 | |
| 83—Var | 0 | 26 | 17 | 1 (0.06) | 9 | 1 | 2 | 0 | |
| 93—Seine-Saint-Denis | 1 | 24 | 23 | 3 (0.13) | 1 | 0 | 0 | 3 | 32 |
| 94—Val-de-Marne | 4 | 32 | 31 | 3 (0.10) | 1 | 0 | 3 | 129 | |
| Total | 24 | 408 | 312 | 39 (0.13) | 96 | 12 | 51 | 47 | |

*PNMS* French National Mesothelioma Surveillance Program («Programme National de Surveillance du Mesothéliome»), *rnv3p* French National Occupational Diseases Surveillance and Prevention Network («Réseau National de Vigilance et de Prévention des Pathologies Professionnelles»), *M* males, *F* females, *sex ratio F/M*, NA not attributed
Fig. 8 Rnv3p capture rate of mesothelioma cases in comparison with the PNSM, by sex, for all mesothelioma, and for the subset of cases with occupational asbestos exposure (2008–2012). a1 Rnv3p capture rate for all male’s mesothelioma cases. a2 Rnv3p capture rate for male’s mesothelioma cases related to occupational asbestos exposure. b1 Rnv3p capture rate for all female’s mesothelioma cases. b2 Rnv3p capture rate for female’s mesothelioma cases related to occupational asbestos exposure. Rnv3p French National Occupational Diseases Surveillance and Prevention Network, PNSM French National mesothelioma surveillance program (Programme National de Surveillance du Mésothéliome). The capture rate takes the “NA” value, for départements for which no cases have been identified by PNSM. The comparison is available only for the “départements” covered by the PNSM which are the following: 06—Alpes Maritimes, 13—Bouches-du-Rhône, 14—Calvados, 24—Dordogne, 25—Doubs, 2A—Haute-Corse, 2B—Corse du Sud, 33—Gironde, 38—Isère, 40—Landes, 44—Loire-Atlantique, 47—Lot-et-Garonne, 50—Manche, 61—Orne, 64—Pyrénées-Atlantiques, 67—Bas-Rhin, 68—Haut-Rhin, 76—Seine-Maritime, 80—Somme, 83—Var, 93—Seine-Saint-Denis, 94—Val-de-Marne.

In conclusion, the catchment by rnv3p of the most emblematic OD through the OD clinics varies across France, according to the proximity of OD clinic, but also to their specialities, and according to sex, and work-relatedness for the subset of females’ cases. Some counties characterised by an important rnv3p recruitment (Nord, Pas de Calais), could not be studied as not covered by the PNSM.

Discussion
This is the first time that the French OD Clinic network, rnv3p, has been examined from a geographical perspective. The location of OD occurrences (addresses of the workplaces imputed to be sources of disease) has enabled us to describe the catchment zones of OD Clinics, and also of some related surrounding zones. The use of different geographical analysis methods (density, standard deviation ellipses, Thiessen polygons) shows that there is a strong general trend for patients to be referred to OD Clinics in their own employment area or in the neighbouring ones, with a rapid decrease in number of referrals with increasing distance. This attractive force of OD clinics in their neighbouring area might also be related to induced-demand (Roemer’s law [19]), as these zones with teaching hospital correspond to those with the highest provision of health services as shown by the French medical demography atlas [20], except for some of the counties located at the French South border.

We also showed that the “centre effect” can be manifested in different ways, depending on other parameters such as the reason for referral. The catchment was then refined using the size of the underlying active workforce in those “Employment Areas” for which statistical data was available. This revealed some areas associated with a higher capture of cases. We also found a qualitative effect when an OD clinic specialized in a particular type of examination. Taken together, the approach has provided new information to the rnv3p network stakeholders that allows them to better interpret the capture of cases and rnv3p figures. Nevertheless there is still work to do to better describe, within the figures analyzed, what depends from the OD centers’ signatures, from the signature of the underlying economic activity and the related work-related diseases.

The rnv3p data were mapped at the most accurate scale permitted by the availability of the external data sources ("départements" for PNSM, employment areas for INSEE, and municipalities for rnv3p data alone).

The main limitation of our study is the loss of information on observations due to the fact that the “entreprise responsible of the disease” is often a missing data. Indeed, only 59 % of observations were geolocated. There are two main reasons for this. First of all, the “entreprise responsible” could not be recorded when it was not the current one (limitation due to the rnv3p application in its previous version). This affects mainly long latency diseases. Indeed, the percentage of successfully geocoded observations related to a subset of short latency diseases (rhinitis, asthma, contact dermatitis) is 77 %, whereas it is only 24 % for diseases with long latency diseases (cancers, pneumoconioses including asbestosis related pleural plaques). Secondly, the “entreprise address” information was not mandatory, and was filled differently by OD clinics. Even for short latency diseases, there remain differences in the percentages of addresses recorded (Additional File 2: Table S1). From now on, these limitations have been addressed. First of all the new rnv3p information system allows to record previous enterprises, and secondly OD clinics were given the information of the importance to record enterprises addresses, as well as their unique national identifier in order to cross with other databases.

This information had the best quality of geocoding assessed in terms of match rates, match scores, match type and spatial accuracy [21]. This loss of information could induce bias and alter the patterns given by the maps. For this reason, in the legends to the maps we have highlighted the score for geolocation for each OD clinic, so as to alert to caution in interpretation.

Another limitation is that although we highlighted the interaction between the observed catchment and OD Clinic specializations (in terms of emphasis on particular surveillance activities) and the characteristics of the territories in terms of occupational risks; this is still not sufficiently well described and understood at this time. Thus it should not be totally relied on and used to adjust and optimize surveillance missions.
In terms of perspectives, the main challenge is now to design and develop a dynamic cartographic tool, linked to an updated rnv3p database for OD physicians, OH services and stakeholders to enable them to enter and access their data using a systematically mapped and geographic approach. From a technical point of view, the first step will be to put as much emphasis on the coding of geographic information, and identification of the workplace as on the other recorded variables, in order to obtain the most reliable information from the maps. For a better picture of OH, complementary approaches centred on given diseases are needed (e.g. maps of work-related asthma cases and the geographical distribution of their causes). Apart from the specific case of mesothelioma, there are no other surveillance networks which exhaustively cover occupational diseases. Nevertheless, comparisons can be made with some other sources. The most interesting one is the salaried workers’ compensated diseases dataset, which is also available at the workplace level. Comparisons with rnv3p data will allow a more systemic picture of OD across territories to be drawn, and to reassess on-site prevention measures since this information is available on a workplace scale. Data could also be compared with indicators from the Uncompensated Work-Related Diseases Network [22], which draws estimates of non-compensated work-related illnesses at the regional level. Finally, complementary approaches centred on different types of exposures are also needed to advance risk-assessment.

Our work calls for further action. For instance, it would be of interest to examine employment area which have shown no case capture to date (shaded zones of the network). This can be done by initiating exchanges between the nearest OD Clinic and the occupational health services covering these areas.

In the literature, we found no other studies in the occupational health field that attempted to describe this kind of network from a geographical point of view. We also found no other studies which analysed GIS data pertaining to Occupational Diseases, except those cited above for which the limitations are already mentioned.

In France, a GIS-based project aimed at collecting statistical data (mainly about employment) in order to map “work territories” (the ATTLAS project) was initiated in 2006. This project built an open-access on-line tool allowing several indicators to be mapped at different scales [23]. Another research program (GISCOP 93), is using geographic tools such as GIS in order to collect and map risks of occupational exposure to carcinogens in a particular French départment located in the Ile de France Region [24]. Unfortunately, neither of these projects includes data regarding work-related health.

This work, as well as those mentioned above that also use a geographic approach, is in line with one major objective of the French National Plan for Occupational Health 2016–2020, related to knowledge building [25]. Especially the “action 3.13” objective is to give all regions possibilities to identify and map geographically relevant information pertaining to employment and occupational health, in order to build territorial diagnoses of occupational health. The ultimate goal is to promote a regional approach to occupational health risk assessment, prioritize actions, and facilitate cooperation between all players concerned by OH, so as to improve prevention.

Conclusion
The geographic approach to this network, enhanced by the possibilities provided by the GIS tool, allow a better understanding of the coverage of this network at a national level, as well as the visualization of capture rates for all OD clinics. Highlighting geographic and thematic shading zones bring new perspectives to the analysis of occupational health data, and should improve occupational health vigilance and surveillance.

Additional files
Additional file 1: Fig. S1. Employment area with higher catchment of OD by the French OD clinics network (rnv3p) for the broad categories of occupational activities (namely: A. agriculture, B. construction, C. commercial services and D. non-commercial services). Legend: Occupational diseases (OD) reported to the rnv3p by OD Clinics are reported to the expected number for each employment area. For each of these geographical units, the sum of the ratios of observed vs expected OD for each category of activity was calculated and mapped. Sources: rnv3p 2001–2012, and French National Institute of Statistics and Economic Studies (INSEE). For industry, see Fig. 6.

Additional file 2: Table S1. Success in geocoding rnv3p observations, according to the latency of diseases, and for each French OD clinic (rnv3p 2001–2012).

Abbreviations
EA: employment area (geographic entity level for which economic activities figures are given by INSEE); INSEE: French National Institute of Statistics and Economic Studies (“Institut National de la Statistique et des Etudes Economiques”); ICD-10: International Classification of Diseases (10th version); NAF: national activity codes (“Nomenclature d’Activités Française”); OD: occupational diseases; PNSM: French National Mesothelioma Surveillance Program (“Programme National de Surveillance du Mésothéliome”); rnv3p: French National Occupational Diseases Surveillance and Prevention Network (“Réseau National de Surveillance et de Prévention des Pathologies Professionnelles”); SDE: standard deviation ellipses; WRD: work-related diseases.

Authors’ contributions
MD performed the analyses, constructed the maps and contributed to writing the paper. VG supervised Marie Delaunay’s work regarding GIS methods and the geographic approach and contributed to optimizing the paper. MLB contributed to the involvement of the rnv3p network in this project, made it possible to access data, followed the progress of this work and also contributed substantially to the improvement of the paper. AGSI made it possible to access data, followed the progress of this work and also contributed substantially to the improvement of the paper. AGSI made it possible to access data, followed the progress of this work and also contributed substantially to the improvement of the paper. AGSI made it possible to access data, followed the progress of this work and also contributed substantially to the improvement of the paper.
and PNSM data. CA contributed to the analyses, interpretation of the results, and writing the paper. AM contributed to the project, especially in the discussion of the results, and writing of the paper. VB initiated this research, supervised MD’s work, and was strongly involved in the analyses and writing of the paper. All authors read and approved the final manuscript.

Author details
1 TIMC Research Laboratory (UMR CNRS 5525), EPSP Team (Environnement et Prédiction de la Santé des Populations), Université Grenoble Alpes, 38041 Grenoble, France. 2 LADYSS Research Laboratory (UMR CNRS 7533) (Laboratoire Dynamiques sociales et recomposition des espaces), Université Paris 8, 93526 Saint-Denis, France. 3 MSH Paris Nord (Maison des Sciences de l’Homme), Universités Paris 8 et Paris 13, 93210 Saint-Denis, France. 4 Mission RNV3P (French Network for Occupational Diseases Prevention and Vigilance Network), ANSES (French Agency for Health Safety in Food, Environment and Work), 94701 Maisons-Alfort Cedex, France. 5 Occupational Health Department, Santé Publique France (French National Public Health Agency), 94415 Saint-Maurice Cedex, France. 6 Occupational Health Department, CHU Grenoble-Alpes (Grenoble Teaching Hospital), 38043 Grenoble, France. 7 Occupational and Environmental Toxicology Laboratory, CHU Grenoble-Alpes (Grenoble Teaching Hospital), 38043 Grenoble, France.

Acknowledgements
We thank Gerard Lasfargues (Anses scientific director), as well as the rn3p OD clinic members: Amiens (Douillet-Dupilion CP), Angers (Roquelaure P-Y, Petit A.), Bordeaux (Verdun-Esquer C, Leclerc I), Brest (Dewitte JD, Lodde B.), Caen (Clin B), Cherbourg (Marquignon MF), Clermont-Ferrand (Chamoux A, Duthel F), Créteil (Andujar P, Pacon J), Dijon (Smoilick H), Fernandez N, Grenoble (Bonnetiere V, Michel E), Le Havre (Gehanno JF), Lille (Frimat P, Nisse C), Limoges (Drut-Cabanac M), Lyon (Massardier A, Charbotel B), Marseille (Lehucher-Michel MP), Montpellier (Roulet A, Lesage FX), Nancy (Paris C, Perven E), Nantes (Dupas D), Paris-Cochin (Bensafta-Colas L, Choudat D), Paris-Garches (Descatha A, Mediouni Z), Paris-Hôtel-Dieu (Léger D, Bayon V), Paris-Ferrand Widal (Largand J, Villa A), Poitiers (Ben-Brik E, Martinhez H), Reims (Deschamps F), Rennes (Gouget T, Verger C), Rouen (Gisard A, Rollin LR), Saint-Etienne (Fontana L, Péllissier C), Strasbourg (Gonzalez M, Nourry N), Toulouse (Esquirol Y, Hérin F), Tours (Hauguenor K). The authors are grateful to Patrick Brochard and Stéphane Ducamp from the PNSM (French national mesothelioma surveillance program), the members of Marie Delaunay’s Ph.D. thesis scientific committee, namely Serge Faye, Dominique Bicout, Maylis Telle-Lamberton, Jeanne-Marie Amat-Roze. We are grateful to Sylvette Llaudy, documentalist for the help on references. Lastly, we thank Dr. Alison Foote (Grenoble-Alpes University Hospital), who adheres to the European Medical Writers Association guidelines, for critical editing of the manuscript.

Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The data analyzed belong to rn3p and PNSM networks. Request for using their data should be addressed to these networks’ steering committees.

Consent for publication
Permission was obtained from the rn3p network scientific committee, providing the results displayed did not allow any identification of patients. Permission was also obtained from the PNSM to use and present their data.

Ethics approval and consent to participate
The databases analysed (rn3p, PNSM) have the mandatory authorization at French national level (“CNIL” authorization).

Funding
Rn3p network was supported by funds from French Agency for Food, Environmental and Occupational Health & Safety (Anses), the National Health Insurance System for Employees (CNAM-TS), the French Occupational Medicine Society (SFMT), Grenoble University Hospital, the National Health Insurance System for agricultural Workers (CCMSA) and the French Institute for Public Health Surveillance (InVS). The authors would like to thank Anses for a Ph.D research grant to Marie Delaunay, Grenoble-Alpes teaching Hospital and MSH-Paris Nord for funding the publication fees.

Received: 29 May 2016 Accepted: 14 September 2016 Published online: 27 September 2016

References
1. Blot W, Fraumeni J. Geographic patterns of lung cancer: industrial correlations. Am J Epidemiol. 1976;103:539–50.
2. Goldsmith JR. Geographical pathology as a method for detecting occupational cancer. J Occup Med. 1977;19(8):533–9.
3. Stone BJ, Blot WJ, Fraumeni JF. Jr. Geographic patterns of industry in the United States. An aid to the study of occupational disease. J Occup Med. 1978;20(7):472–7.
4. Thouze J-P, Godon D. Géographie du travail et de la santé: le cas de la mortalité par cancers par secteurs d’activité selon les bassins d’emploi au Québec. Espace Popul Soc. 1984(2):47–58.
5. Neff R, Currie F, Burke T. Just in the wrong place...? Geographic tools for occupational injury/illness surveillance. Am J Ind Med. 2008;51(9):680–90.
6. Delaunay M, Van der Wusthuizen H, Godard V, Aguigis R, Le Barbier M, Goderis L et al. Use of GIS in visualization of work-related health problems. Occup Med (Lond). 2015;65(6):682–92.
7. Insee, Définitions et Méthodes, 2015-10-12. http://www.insee.fr/fr/methodes/default.asp?page=zonages_zones_emploi.htl, Accessed 2015-10-12, Archived by WebCite® at http://www.webcitation.org/6cDy1f6kr.
8. Bonnettere V, Faisandier L, Bicout D, Bernardet C, Pioliat J, Amellie J et al. RNV3P, Programmed health surveillance and detection of emerging diseases in occupational health: contribution of the French National Occusal Disease Surveillance and Prevention Network (RNV3P). Occup Environ Med. 2009;67(3):178–86.
9. Bonnettere V, Bicout DJ, Larabi L, Bernardet C et al. Detection of emerging diseases in occupational health: usefulness and limitations of the application of pharmacosurveillance methods to the database of the French National Occupational Disease Surveillance and Prevention Network (rn3p). Occup Environ Med. 2008;65(1):32–7.
10. Amellie J, Hamelin K, Andujar P, Bensefa-Colas L et al. Occupational asthma and occupational rhinitis: the united airways disease model revisited. Occup Environ Med. 2013;70(7):471–5.
11. Paris C, Ngatchou-Wandji J, Luc A, McKenzie R et al. Work-related asthma in France: recent trends for the period 2001-2009. Occup Environ Med. 2012;69(6):391–7.
12. Data.gouv.fr, 2015-10-12. https://www.data.gouv.fr/fr/datasets/correspondance‑entre‑les‑codes‑postaux‑et‑codes‑insee‑des‑communes‑francaises/. Accessed 2015-10-12, Archived by WebCite® at http://www.webcitation.org/6cDy1f6kr.
13. Wade T, Summer S. A to Z GIS: an illustrated dictionary of geographic information systems. USA: Esri Press; 2006.
14. Insee, Définitions et Méthodes, Nomenclature. http://www.insee.fr/fr/methodes/default.asp?page=nomenclatures/revision_naf_2008/produits2008.htm#Tables. Accessed 2015-10-12, Archived by WebCite® at http://www.webcitation.org/6cDy1f6kr
15. Goldberg M, Imbermon E, Rolland P, Gilg Soit I, Avexis M, de Quillacq A, et al. The French National Mesothelioma Surveillance Program. Occup Environ Med. 2008;65(3):178–86.
16. Gilg Soit Ilg A, Ducamp S, Gramond C, Audignon S, Chamändig S, de Quillacq A et al. Programme national de surveillance du mésothéliome (PNSM). Actualisation des principaux résultats. Bull Epidémiol Hebd (BEH). 2015;3:4–28–37.
17. Donovan EP, Donovan BL, McKinley M, Cowan D, Paustenbach D. Evaluation of take home (para occupational) exposure to asbestos and disease: a review of the literature. Cirt Rev Toxicol. 2012;42(9):703–31.
18. Gallo C, Bonnet N, Chéridé-Challine L. Déclaration obligatoire des mésothéliomes en France: principaux résultats, 2012–2013. Bull Epidémiol Hebd (BEH). 2015;3:4–28–37.
19. Delamater PL, Messina JP, Grady SC et al. Do more hospital beds lead to higher hospitalization rates? A spatial examination of Roemer’s Law. PLoS ONE. 2013;8(2):e54900.
20. Conseil de l’ordre des médecins. Atlas de la démographie médicale. http://demographie.medecin.fr/demographie. Last access 8/8/2016.
21. Goldberg DW, Jacquez GM. Advances in geocoding for the health sciences (Editorial). Spat Statim Temporal Epidemiol. 2012;3:1–5.
22. Valenty M, Homère J, Lemaitre A, Plaine J, Ruhlman M, Cohidon C, Imbemon E. Surveillance programme for uncompensated work-related diseases in France. Occup Med (Lond). 2015;65(8):642–50.
23. ANACT, ATTLAS. http://www.anact.fr/web/services/attlas. Accessed 2015-10-22, Archived by WebCite® at http://www.webcitation.org/6cSobDioe.
24. Lysaniuk B, Ciorsté A, Tabeaud M, Counil E. La difficile compilation d’information(s) géographique(s) relative(s) à un cancérigène: étude pilote sur les expositions professionnelles à l’amiante en Seine Saint Denis. Pollution atmosphérique, No. 225, Avril–Juin 2015.
25. Direction générale du travail (DGT), Ministère du Travail, de l’Emploi, de la Formation professionnelle et du Dialogue social. Plan National Santé Travail 2016–2020, Paris; 2016. http://travail-emploi.gouv.fr/IMG/pdf/pst3.pdf. Accessed 2016-02-01 (especially action 3.13 (pp 44–45) objective is to give all regions the ability to provide territorial diagnosis of occupational health).