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Use of GIS in visualization of work-related health problems

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Background Occupational health and safety (OHS) information is often complex, diverse and unstructured and suffers from a lack of integration which usually precludes any systemic insight of the situation.

Aims To analyse to what extent the use of geographical information systems (GISs) can help to integrate, analyse and present OHS data in a comprehensive and communicable way relevant for surveillance purposes.

Methods We first developed a 'macro-approach' (from national to local level), mapping data related to economic activity (denominator of active workers displayed by activity sectors), as well as work-related ill-health (numerators of workers suffering from work-related ill-health). The latter data are composed of compensated occupational diseases on the one hand and work-related diseases investigated by specialized clinics on the other hand. Then, a 'micro-approach' was worked out, integrating at a plant level, using computer-aided drawing, occupational risks data and OHS surveillance data (e.g. use of medication and sickness absence data).

Results At the macro-level, microelectronics companies and workers were mapped at different scales. For the first time, we were able to compare, up to the enterprise level, complementary data showing different pictures of work-related ill-health, allowing a better understanding of OH issues in this sector. At the micro-level, new information arose from the integration of risk assessment data and medical data.

Conclusions This work illustrates to what extent GIS is a promising tool in the OHS field, and discusses related challenges (technical, ethical, biases and interpretation) and research perspectives.

Key words Databases; epidemiology; exposures; geographic information systems; geostatistics; occupational diseases; occupational health; occupational hygiene.

Introduction

Occupational health and safety (OHS) data are available at different scales, from very local (enterprise), here referred to as micro-level, to regional, national and even international—here referred to as macro-level. These data are often complex, diverse, unstructured or structured in different ways, as they are built for different purposes without any prior intention of matching them. Furthermore, they often belong to different stakeholders: companies, occupational health services, insurance companies, local institutions, health surveillance agencies, states, research groups, etc. Combining these data from the macro as well as the micro-level could theoretically offer a more comprehensive insight into OHS and its determinants, as well as the relative specificities of the different data sources. Consolidating data into one standardized database could potentially help the management of OHS locally, nationally and perhaps internationally. Nevertheless in practice the splitting up of these data as well as their disparity (various formats) constitute an obstacle to the monitoring of known work-related adverse events (surveillance purposes) as well as for alerting to the possibility of previously unrecognized hazards (vigilance purposes). Even at company level, data about workers' health [e.g. absenteeism, occupational diseases (ODs) and work-related diseases (WRDs), risk assessments, sampling results, company policies and strategic plans] are found in various formats [1,2] and need to be consolidated and integrated for descriptive analyses and predictions.

Another issue of importance in making these different data useful for occupational health decision-makers, as well as for prevention and surveillance stakeholders, is to process the results in order to communicate information in a quickly understandable way. Some suggest that bulky or technical information should be conveyed by visual means, e.g. tables, graphs, diagrams, pictograms, maps, flow charts, cartoons [3] or 'dashboards'. Therefore, the data have to be processed before it can be communicated during meetings and reported as information.

Geographical information systems (GISs) are now used in many disciplines [4]. Although their promise in OHS research and practice was first suggested 37 years ago [5,6], very few papers have followed. Ecological studies have found links between the spatial distribution of asbestos-related diseases at national level and some occupational activity sectors associated with high asbestos use [7,8]. The few studies relating to GIS and OHS addressed very specific situations [9–12]. Recently, one publication from the USA [13] began to explore a more systematic use of GIS for improving OH surveillance, the county being the smallest geographic area considered. This work mapped work-related absenteeism without any additional information regarding illnesses thus precluding application for preventive purposes. Recent research using GIS addressed the geographical variation of work-related heat illnesses [14] or occupational heat stress risk [15], with surveillance (identification of hotspots) and predictive purposes, respectively.

At the EU level, the COST-funded Modernet network (Monitoring Occupational Diseases and New Emerging Risks Network) has a strong interest in the identification of existing relevant data and the development, test and assessment of new methods. One specific goal was to study the potential of integrating sparse information related to occupational health. The use of GIS was considered in order to combine these data, consider their spatial dimension and facilitate their visualization and 'communicability' with occupational health and prevention stakeholders. The relevance of this approach was addressed at two levels: macro (regions, country) for surveillance purpose, as well as micro (within companies).

The aim of this work was to analyse whether combining relevant spatial and primarily non-spatial information from different data sources through GIS could help in building and sharing occupational health knowledge and whether it would be of interest for surveillance, vigilance, preventive and research purposes.

Methods

We explored two approaches at different scales. The 'macro-approach' illustrates from national to local level how data related to economic activity, occupational health service coverage, compensated ODs as well as WRDs investigated by specialized clinics can be integrated. The 'micro-approach' integrates, at site level, information regarding hazards as well as workers' health (e.g. use of medication and sickness absence data).

The following steps were successively followed and are explained in detail below: (i) identification of relevant databases, (ii) GIS use (creating a geodatabase), (iii) displaying maps and analyses and (iv) interpretation.

To illustrate the macro-approach, we chose the example of the French microelectronics industry, with a special focus on semiconductor production. This is a relatively new industry, with fast evolving processes and chemical risks, for which vigilance is required [16,17]. The subset of *potentially* relevant companies was first broadly identified through a national activity code (code NAF 2008 taking the value '2611Z', meaning 'production of electronic components'). The corresponding file was transmitted by the National Health Insurance System for Salaried Workers (CNAM-TS). It encompasses the companies of this sector, active in 2011, with their addresses and numbers of salaried and office workers. This information is recorded by the insurer as the insurance premium is lower for office workers compared to production workers. We were able to identify companies producing semiconductors more precisely thanks to a more specific 'hazard code' used by the CNAM ('production of active electronic components', value '321BA'). In the present work, we considered only people working in the production area so as to study risks specific to this activity. This selected population corresponded to the 'denominator' of workers in this field. At a local level, the subcontractors of these companies (sharing the risks, but belonging to other activity codes from an administrative point of view) were further highlighted through a register of companies active in the microelectronics field and from partnership with occupational physicians. Data concerning exposures in these companies arose mainly from information available at a local level (OD clinic and partnership with occupational physicians). The information about occupational health coverage used here came from occupational health services themselves. Data about compensated diseases were obtained from dedicated regional and national registries after a convention was signed for this project (CNAM-TS; years: 2007–11). Data about other WRD were obtained from the French occupational diseases surveillance and prevention network RNV3P, composed of 31 OD clinics (years: 2001–12) [18]. In view of confidentiality issues (to avoid the identification of cases), the diagnoses displayed in this article were summarized in large unidentified groups, which correspond to the following broad categories: musculoskeletal disorders (MSD), chemically related diseases, psychosocial related health issues and 'others'.

At the micro-level, we assessed the applicability and relevance of GIS in a secondary aluminium plant. The company annually generates and collects large amounts of OHS data. Every worker exposed to occupational hazards is subject to annual health surveillance and risk assessments are regularly carried out at workplaces in accordance with Belgian legislation [19]. Most of these data are collected through several applications, e.g. electronic medical files and workplace assessment applications, and stored in filing cabinets, servers or databases. Data pertaining to localities of stressors (e.g. ergonomics, noise, metal fumes) and actual exposure levels within this industrial plant, as well as medical interventions, were obtained from company records after obtaining the required permission. The data covered a period of 10 years and originated from company, consultant and medical records. Care was taken not to link exposures to individual workers but to groups of workers to guarantee privacy. The project was approved by the Ethics Committee of Cape Peninsula University of Technology (ref number: 10/2014).

ArcGis software versions 9 and 10 were used. The principle is to add different information layers within a specific GIS structure called a geodatabase. These information layers (also named 'attribute tables') are files (such as Excel or Access files) comprising variables either allowing direct geolocation (i.e. with XY coordinates) or with a common identifier allowing a link to be made with such a file. To ensure the use of GIS, it is necessary to have information about a metric and to use the same coordinates system to allow relevant projections. Background information about the maps is first collected. At the macro-level, this concerns information about the perimeters of countries and regions and the names of streets. Addresses of companies are used and an address locator (created with the GIS software tools) produces their XY coordinates (projection referential to be chosen), allowing cartography (projecting data on maps). Interoperability with the other databases used (health data) needed common identifiers of enterprises in order to ensure automatic projection of health data on the companies information layer. For that purpose, the French unique identifier for each workplace of each enterprise (SIRET number) was used to relate the different databases.

The same principles and techniques were applied to the micro-approach, the main difference being that a computer-aided drawing (CAD) instead of a geographic map was used as a base layer onto which other layers of data were superimposed. Electronic copies of the CAD layout plan of the plant were obtained and drawn into GIS. This layer was set as a base layer (foundation) for future data layers. Categories of layers were then created for different data sets that were to be added by creating polygons (outlines) of working areas or points on the floor plan for sampling: e.g. layers were created for risk assessments, management plans, clinical data and occupational hygiene. Within the sampling layer, subcategories were created for different sampling and monitoring types, e.g. chemical sampling and noise monitoring, and within the agent layer the various agents that workers could be exposed to. Anonymized OH data sets containing clinical and sampling data were arranged into Excel sheets providing the respective information layers through the GIS software.

Displaying maps with current software is relatively easy when compared with previous work involving suitable database identification, data acquisition, choice of relevant variables and search for common identifiers. Practically, each column of the attribute tables describing a qualitative or quantitative variable might be used as an information layer which can be displayed on maps interactively. Each individual characteristic (e.g. enterprise, etc. in lines in the attribute tables) can be identified from the tables to the map or from the map to the table. Maps might be displayed interactively at several scales in order to allow a comprehensive insight into available information on OH issues and some of its possible determinants.

Whether geostatistical analyses are justified depends on the type of data used and the objectives followed. For instance, in order to identify the OD clinics most likely to obtain an indication of work-related health risks in semiconductor production, we highlighted the preferential recruitment area of each of them using an ArcGIS method named 'standard deviational ellipses'. The ellipses include for each OD clinic 68% of the occupational health problems investigated there, located at the related enterprise.

Interpretation of the maps and results is the final step. The challenge is to identify real signals of concern within the information displayed and to distinguish them from false signals due to biased data (i.e. limitations in terms of data capture and collection, coding, etc that will be different for each database), or confounded by other factors (e.g. legislation for compensation issues, awareness campaigns for some ODs that will increase reporting, etc). A strong collaboration with all stakeholders involved in data collection is mandatory to rule out obvious false signals and to investigate further the resulting hypotheses.

Results

The microelectronics activity sector (55 948 production workers) and the production of active electronic components, including semiconductor production (31 262 production workers), are displayed at French national level in Figure 1. It highlights the three main regions concerned with semiconductors: Rhône-Alpes (38% of workers, n = 11 981, most (9889) of them in the Isère area), followed by Provence-Alpes-Cote d'Azur (7265 workers, all located in the Marseille area 'Bouches-du-Rhone') and Ile de France (3283, of which 2040 are in the Yvelines area). This figure also highlights that most of the semiconductor workers are in the preferential recruitment area of French OD clinics (70%), making it more likely for them to highlight a health signal of concern. There are five OD clinics whose recruitment area overlaps in Ile de France. Figure 2 focuses on the Rhône-Alpes region and depicts the spatial distribution of occupational health services ensuring medical surveillance of companies. Figure 3A displays, at the Grenoble area level, a more precise typology of enterprises according to their main activity and adds subcontractors who are involved in high-level risk activities such as maintenance of equipment [20]. Figure 3B represents present or past exposure to two known hazards (refractory ceramic fibres and arsenic) in this activity sector. Finally, Figure 3C represents the distribution of compensated OD as well as WRD investigated in the local OD clinic. This demonstrates that MSD is almost the only compensated OD and raises the possibility that other work-related effects may be a 'blind spot' for the national health insurance company. It shows the different points of view of different stakeholders and the potential benefit for all of them to share and cross-compare their data. New perspectives were detected from the maps: for the first time, we were able not only to take into account the spatial and sectorial distribution of the economic activity, but also to highlight and compare geographical shading zones (i.e zones with lower recruitment for RNV3P) with thematic shading zones (i.e. for the national insurance company for salaried workers). At the macro-level, physicians in OD centres, prevention stakeholders and surveillance stakeholders are now aware of the potential of a tool producing simultaneous pictures of industry, OD and WRD in their area of concern.

To illustrate the micro-approach, Figure 4 displays the map of the secondary aluminium plant studied, enriched in Figure 5 by layers containing agents to which workers may potentially be exposed (layers were activated which resulted in a view of the hazards per work area). As a result, the number and nature of exposures may be detected at a glance. This illustrates the ability of GIS to accommodate various types of occupational hygiene data within its database and to represent it in the format that the user requests. Due to an interactive link between the data table and the visual display [graphic user interface (GUI)], it is possible to conduct queries on data. As the OH field encompasses, amongst others, occupational hygiene and occupational medicine data, we linked data from ergonomic risk assessments (occupational hygiene) with data on medication use for locomotor problems (medical) in Figure 6. The purpose was to ascertain whether new perspectives could actually be obtained by simultaneously viewing data from the two fields. The use of medication for locomotor problems was expressed as percentages in order to prevent individuals from being identified. This enables the user to form a comprehensive informative picture of an OH-related situation. New information became available in that it was possible to detect at a glance where the high-risk areas were and how they correlated with the medical data. Discrepancies and gaps in data were visible that would normally not be detected in the traditional formats. Stakeholders concerned with prevention better identified which workers were exposed to specific risks. Further investigation into the causes of these phenomena could serve either to improve management of systems and stressors or by further research, identify indicators that could serve as early warning of OD.

Discussion

We were able to demonstrate that GIS software could be used to integrate and map existing occupational health-related data. This approach proved to be useful in providing new insights on OH issues at both a macro-level (national to local level) and a micro-level (within companies).

In terms of strengths, the macro-approach could rely on the most accurate data available on the subject at French national level, namely the CNAM and RNV3P databases, enriched by information collected at local level. For the first time, these databases were cross-compared at different scales. The micro-approach also relied on the most accurate data available at the company level.

In terms of weaknesses in identifying outcomes, whereas the probability of being compensated for an OD is thought to be homogenous at a French national level (CNAM data), there is undeniably a spatial component in patients referred to RNV3P, as this is based on a network of OD centres throughout France. Another bias was identified, namely that the RNV3P information system had not allowed the recording of companies presumed to be responsible for past

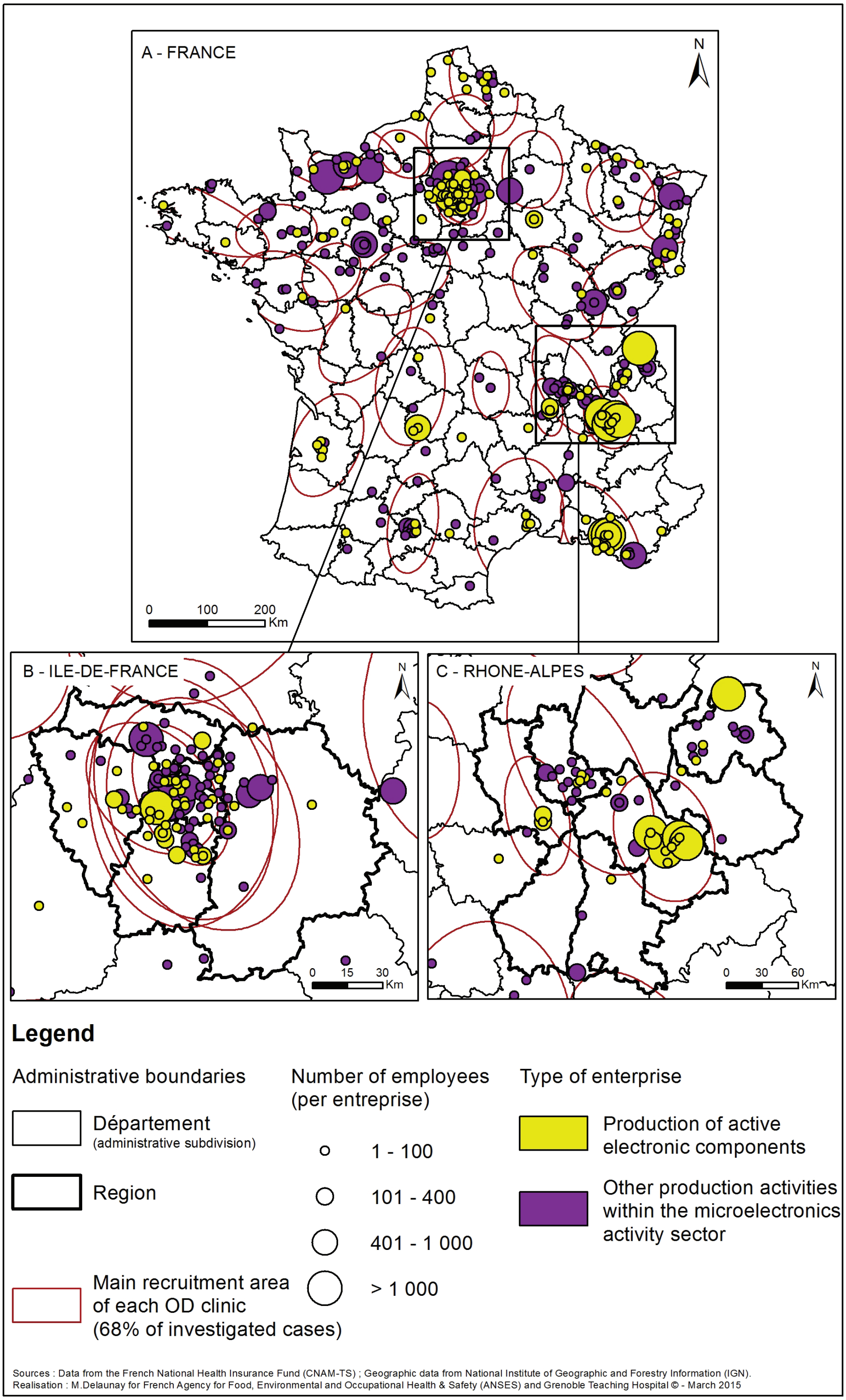

Figure 1. The microelectronics activity sector in France.

exposures when diseases were related to previous occupations. Similarly, for CNAM, many cancers (such as asbestos-related ones) were not attributed to one specific company when the worker was thought to have been exposed in several enterprises. Thus, a large portion of observed occupational cancers or other chronic potentially WRD cannot be

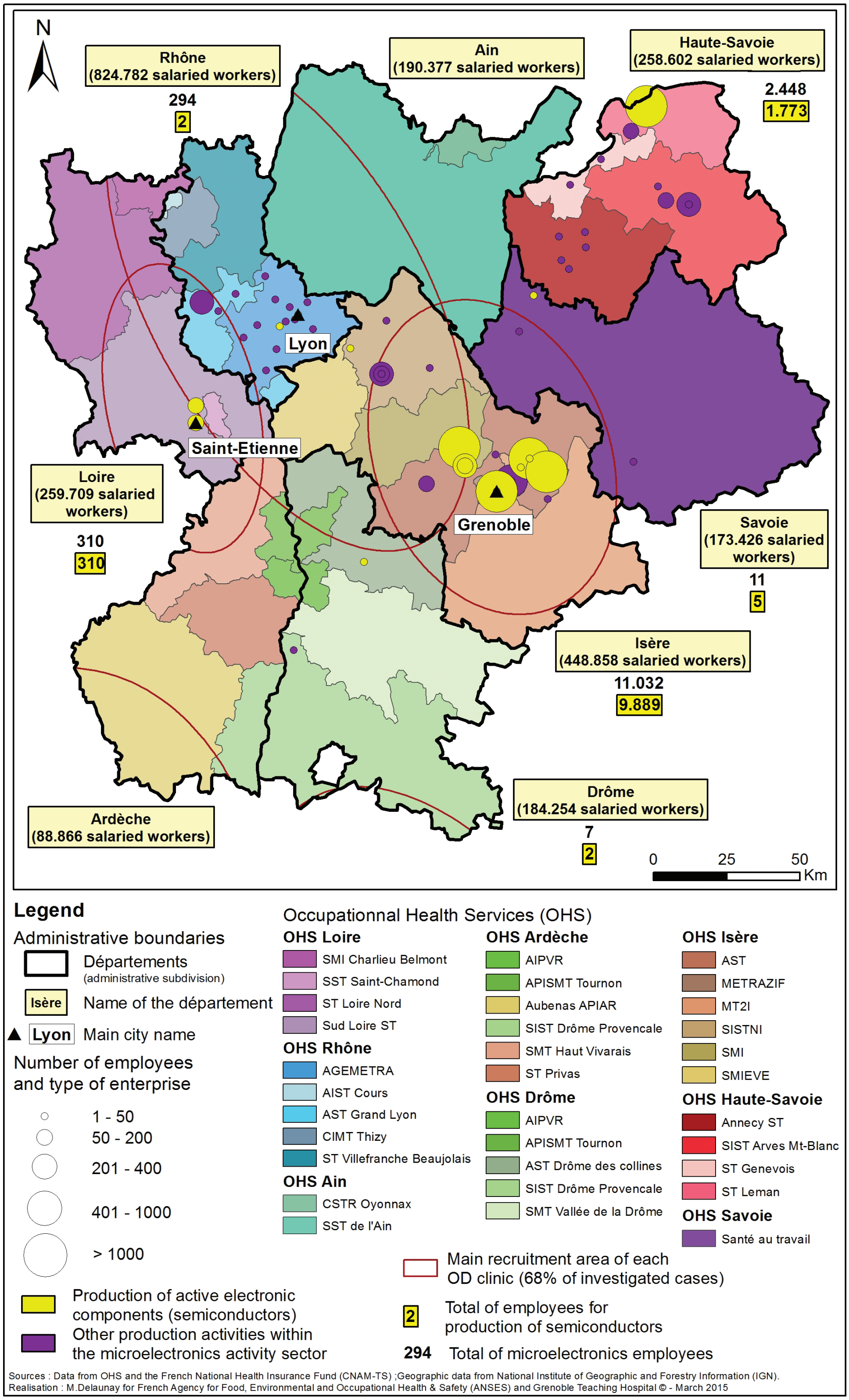

Figure 2. The microelectronics activity sector in the French Rhône-Alpes region.

represented on maps of the workplaces potentially responsible for the causal exposures. This illustrates to what extent a good understanding of the scope, magnitude and variations of inaccuracies in geocoding is essential, because these inaccuracies are often non-random in their distribution [21]. Finally, Koehler [22] warned against problems that may arise during the interpretation of hazard maps, and the micro-approach described here is no exception.

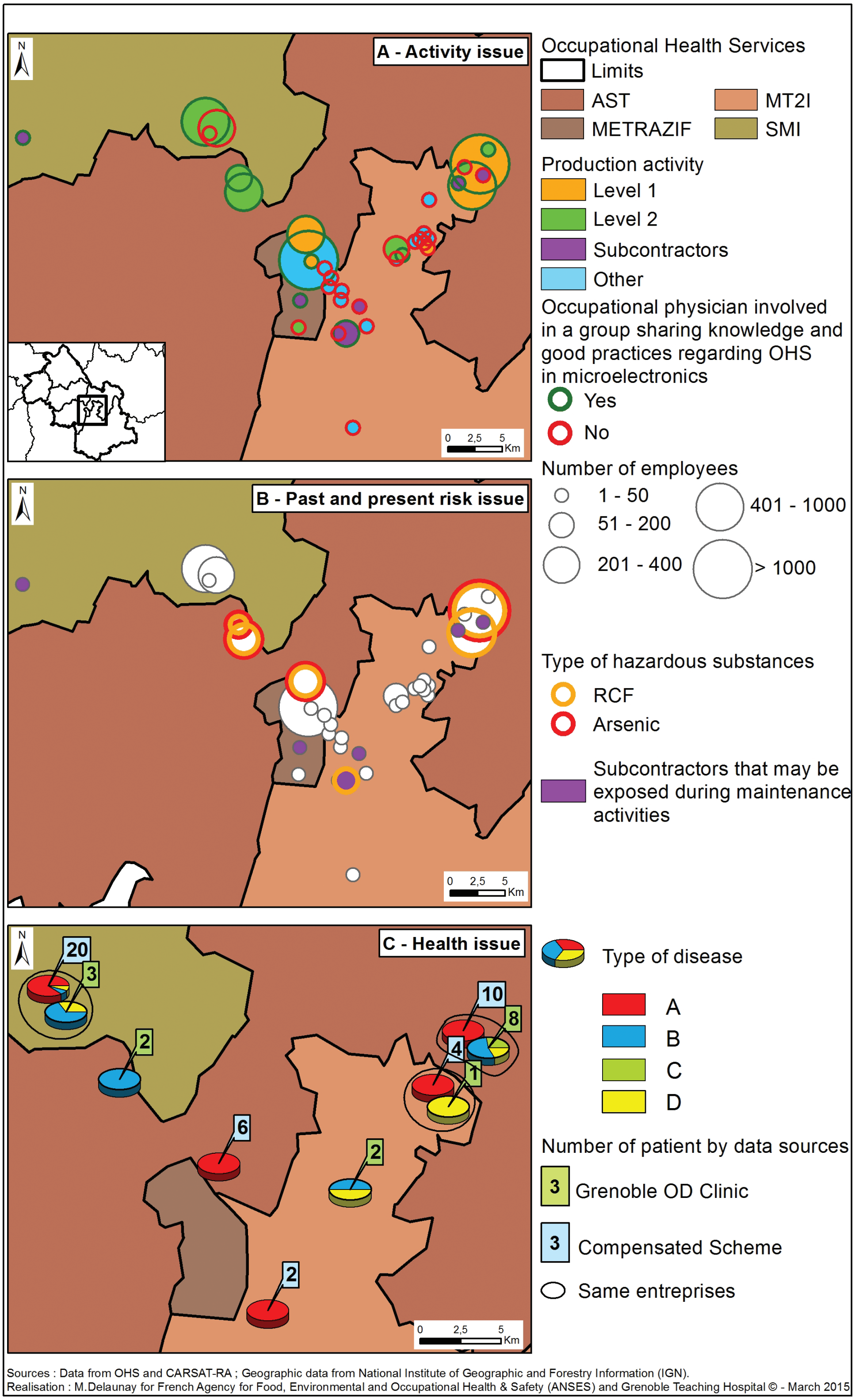

Figure 3. The microelectronics activity sector in Grenoble area. (Production Activity: Level 1 refers to production sites of wafers and semiconductors; Level 2 refers to high-tech products partly designed from chips; Subcontractors undertake cleaning and maintenance tasks of machinery and components for production level 1; 'Other' include microelectronics machinery, design for microarchitecture of the chips, research activities, etc. RCF, refractory ceramic fibres. Type of diseases: A, musculoskeletal disorders; B, chemically related; C, psychosocial; D, others.)

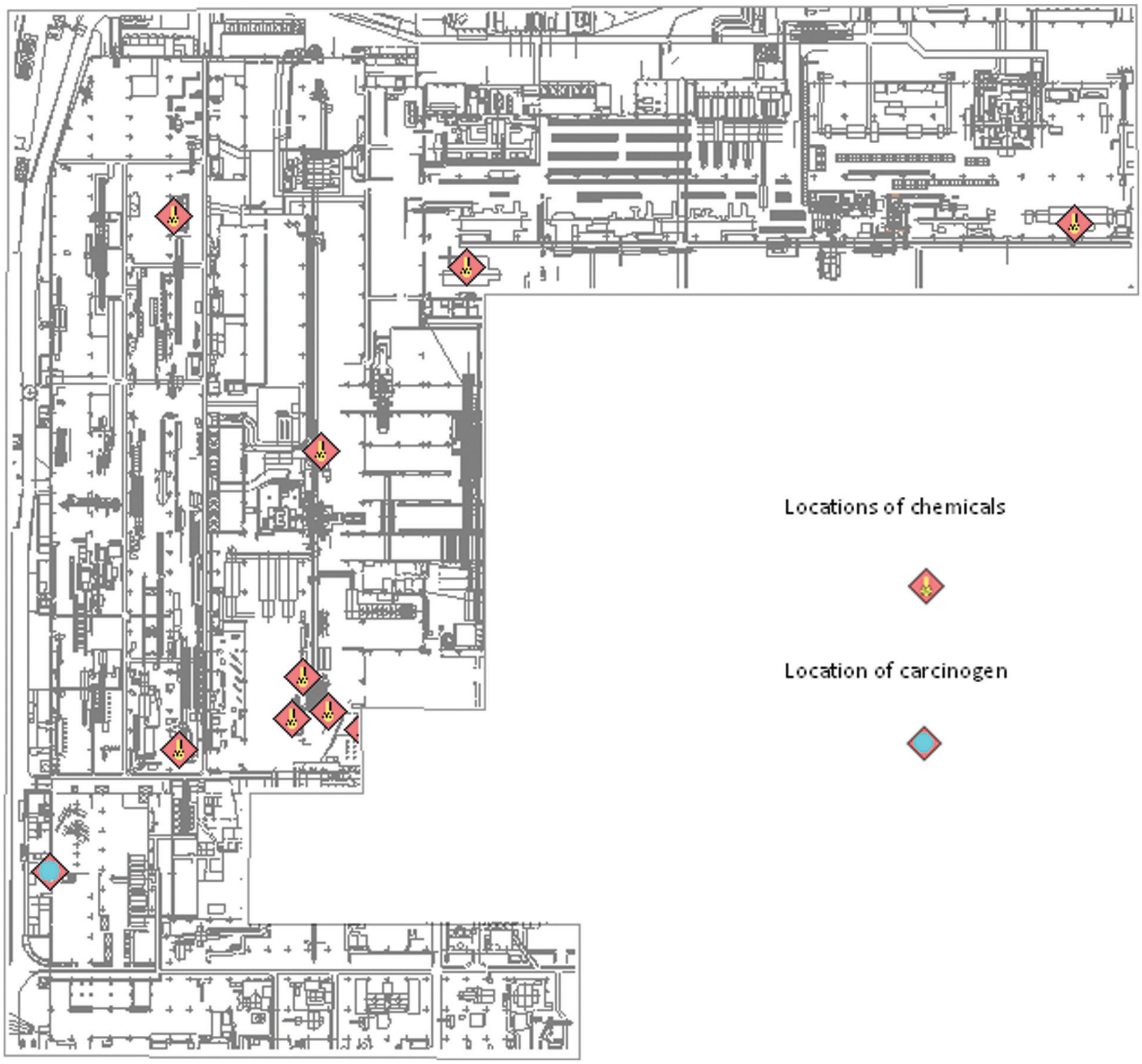

Figure 4. CAD map of the secondary aluminium plant, displayed with one supplementary information layer (here chemical hazards: red diamonds specify locations of all chemicals, superimposed blue dots specify location of carcinogens).

Compared with previous studies assessing the use of GIS for OH surveillance purposes [13–15], this study goes one step further by integrating information on occupational exposures and diverse ODs and WRDs. For instance, previous work sponsored by US-NIOSH [13] identified at US level some counties with an apparently increased risk of absenteeism due to OD and accidents. However, this study could neither provide information on causal diseases nor on exposures that could be related to the diseases. Consequently, the application of this technique to a global understanding of the determinants of OD and applying this information to prevention may be limited.

The implications for clinicians, surveillance stakeholders and researchers are as follows: clinicians with a specific interest in WRD could learn from the macro-approach which displays an entire industry and associated WRD/OD in their referral area. Stakeholders concerned with prevention at both micro- and macro-level usually need more accurate information to identify and prioritize workplaces to be assessed and therefore could also take advantage of this approach to target intervention. Epidemiologists (e.g. for OD surveillance schemes) might use GIS to better understand the links between the figures and trends they identify and the geographical distribution of activity sectors, occupations and exposures. They might also identify 'shadow' zones with no apparent capture of cases by surveillance networks or analyse referrals according to many geographical parameters (e.g. isochrones). When numerators and denominators are available, incidence rates might be calculated and mapped, in order to identify disparities and highlight zones (or even companies) with the highest incidence rates. Stakeholders involved in surveillance and vigilance could benefit from such tools highlighting clusters of cases associated with some specific workplaces. This kind of signal could be strengthened by searching for new cases. This can be exemplified by a signal of a lung disease highlighted in specific workplaces of activity sector 'A'. It is conceivable that all chest physicians in a defined buffer zone around each company in this activity sector could be

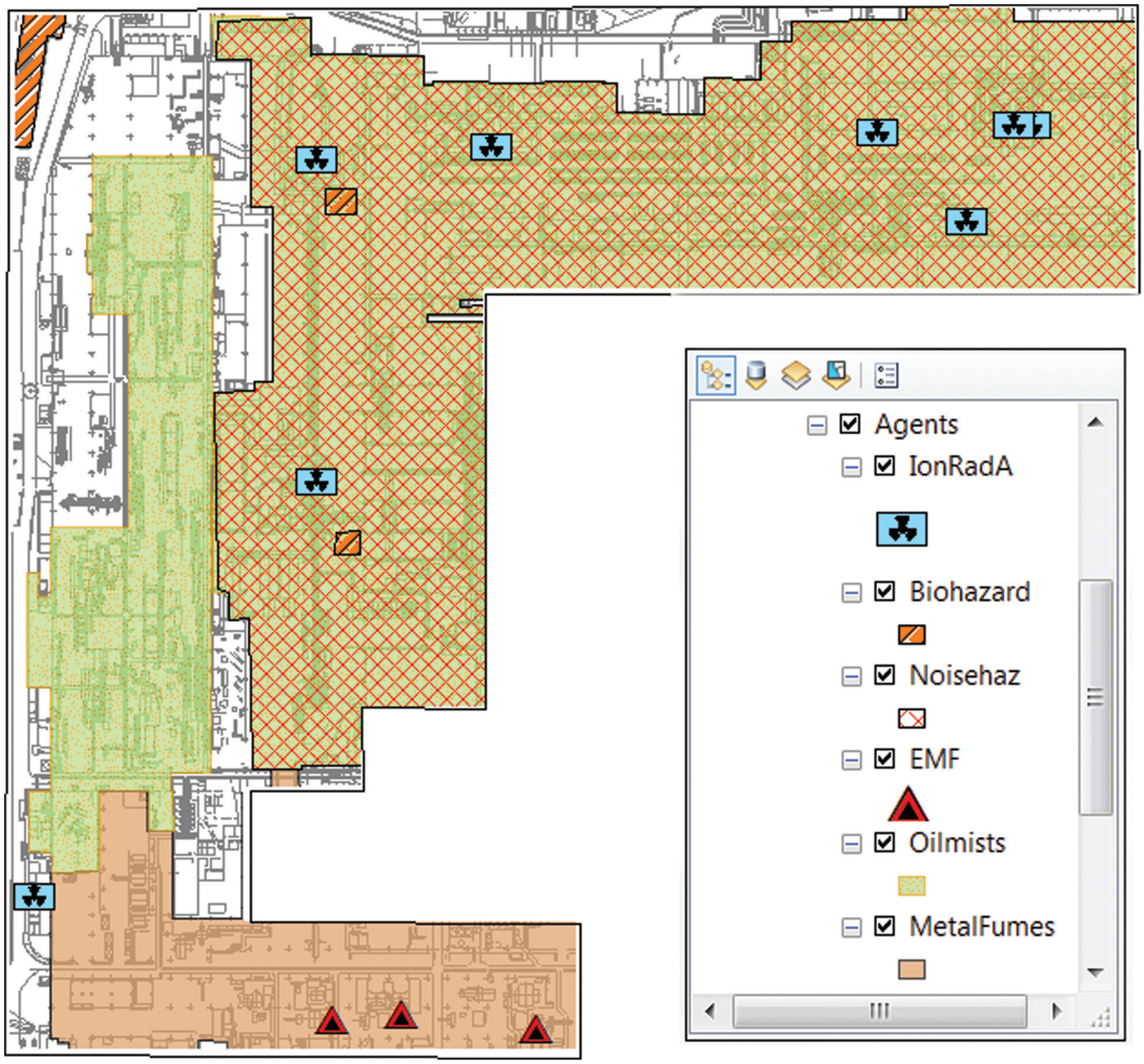

Figure 5. Integrated insight of all identified hazards per work area within the aluminium plant studied. (IonRadA, Ionizing Radiations Hazard, Noisehaz, Noise Hazard; EMF, ElectroMagnetic Fields Hazard.)

asked to search for similar cases. The micro-approach is not only limited to hazard and risk mapping but may also be utilized for assessing the effectiveness of implemented measures, through ensuing changes in trends in occupational stressors and diseases.

Further research is needed to test and develop these approaches in different contexts and at different levels. The main challenges of such studies are not related to the use of GIS software itself but rather to the underlying steps: (i) identification of suitable data to address the specific aims; (ii) the collection of existing data and/or their acquisition when not previously collected; (iii) their quality control; (iv) the optimization of their interoperability (i.e. to have common identifiers to describe and link the same entities); and (v) dealing with specific concerns related to confidentiality (medical ethics, sometimes commercial secrecy). Indeed if medical data are to be communicated outside the medical community protection of the privacy of workers requires grouping (aggregation) into geographical units with sufficient number of workers and broad categorization. Thereafter, the interpretation of these combined data mapped together will have to highlight real issues of concern from an occupational health point of view and differentiate them from bias related to limitations of data sources. One more challenge for surveillance purposes is the question of timeliness (to keep a dynamic insight), as the macro-level is constantly evolving (due to enterprises closing and opening, downsizing, etc.), as well as the micro-level, due to changing management, equipment and processes, etc. Therefore, it would be necessary to accumulate historical data and build a dynamic system automatically updated with new data.

Starting to build an EU-wide vigilance system for ODs is one of the long-term aims of the Modernet network. To be able to study the distribution of disease by activity sectors and by geographical and temporal dimensions

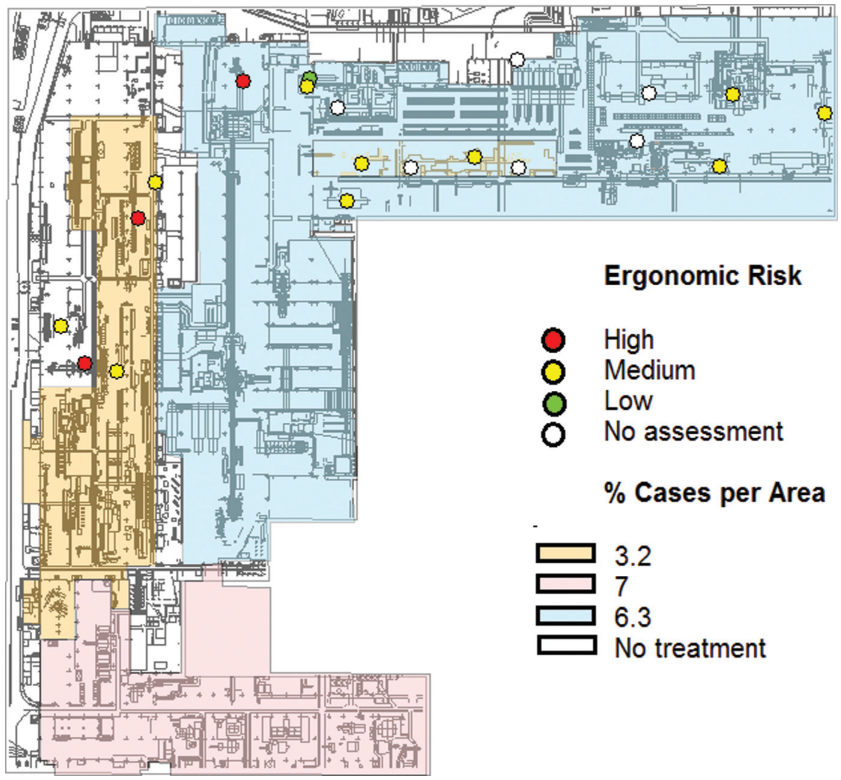

Figure 6. Linking data of ergonomic risk assessments (occupational hygiene) with data on medication use for locomotor problems (medical) provide insight into causes and consequences. (Coloured dots indicate where risk assessments for ergonomic exposures were done and indicate the degree of risk at each specific point at the time that the risk assessment was done. By comparing the two layers, it can be seen that no risk assessment was done in the blue area where there is a relative high percentage use of medication for locomotor problems. On the other hand, it may be seen in the white area that there are work stations with high and medium ergonomic risks but no percentage medication use is recorded. Both cases illustrate a new perspective on the existing data, which prompts investigation. Finding the causes for the suspected anomalies could result in improved management of OH.)

throughout Europe would be of great interest in the future. GIS tools could help achieve that objective.

Key points

- Geographical information systems have the ability to integrate data by superimposing layers of different sets of data; this enables the user to view related data from different levels, sources or disciplines in new contexts.
- This approach might be helpful for surveillance and preventive purposes but also to open avenues for research including the geographical patterns of referrals or of reporting and the differential capture of various systems.
- The analysis and interpretation of maps have to take account of potential biases that arise from non-random inaccuracies in the geocoding process.

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Conflicts of interest

None declared.

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