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Geographical variability in cancer incidence explained by the socioeconomic environment: an example of lung cancer in northwestern France

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ABSTRACT

Background The incidence of lung cancer is unequally distributed in France. Although several studies have shown a link between the socioeconomic environment of populations and the incidence of cancer, the contribution has not been quantified. We aimed to analyse the geographical variability of lung cancer incidence in Normandy and calculate the proportion explained by the socioeconomic environment.

Methods We included 7665 lung cancer cases recorded in the General Tumor Registry of Calvados and the Cancer Registry of Manche. A Bayesian model was used to map the spatial variation in the incidence of lung cancer in the territory, and an innovative approach was used to evaluate the influence of geographical variability in the socioeconomic environment on the spatial heterogeneity of lung cancer incidence.

Results The maps of the spatial components showed high contrasts for both genders, and the socioeconomic environment integration in the model made the maps less contrasting. The socioeconomic environment of the population explained one-third of the spatial variation in the incidence of lung cancer in women and one-fifth in men.

Conclusion The results showed that a non-negligible part of the spatial variation in the incidence of lung cancer could be explained by the geographical distribution of the socioeconomic environment.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In France, lung cancer incidence is higher in deprived neighbourhoods.

WHAT THIS STUDY ADDS

⇒ Using Bayesian models, our study showed strong spatial variation in the risk of lung cancer in Normandy, and that 31.4% of this variation could be explained by the social environment in women and 22.1% in men.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our results will make it easier to implement health policies at the regional level, in particular, to introduce more localised prevention policies in disadvantaged neighbourhoods.

BACKGROUND

Lung cancer is the leading cause of cancer-related deaths among men and the third most prevalent cancer in France, with 52 777 new cases recorded in 2023 (33 438 men and 19 339 women), representing approximately 12% of all new cases of cancer diagnosed.[1] Although the incidence of lung cancer has stabilised or even decreased in men for several years, it has been increasing in women (average annual evolution change: −0.5% in men between 2010 and 2023; +4.3% in women).[1–3] Furthermore, the incidence and mortality rates of lung cancer vary across France.[4 5] In the Meurthe-et-Moselle Department (Department 54), the standardised incidence rate for men between 2007 and 2016 was 70.6 (67.2; 74.2) per 100 000 person-years, whereas, in Ille-et-Vilaine (Department 35), it was 38.8 (36.7; 41.1).

Socioeconomic deprivation of populations refers to a situation in which individuals find themselves in a situation of lack or insufficiency of financial, material, educational or social resources. These populations are often exposed to a set of risks (smoking, exposure to polluted environments, etc) which increase their probability of developing lung cancer. Recent results in France have shown that a disadvantaged socioeconomic environment increases the incidence of lung cancer[6–8] suggesting that the socioeconomic environment may be one of the causes of these territorial inequalities in incidence. Several approaches have been developed to describe spatial heterogeneity in a territory and have been compared in different studies,[9–13] notably the Besag, York and Mollié (BYM) method.[14] This approach, which estimates the relative risks of geographical units by considering both the spatial heterogeneity and autocorrelation of the data, is widely used to measure the geographical variability of a disease.[13 15–18]

Furthermore, the BYM method is used to assess the influence of certain factors, such as the socioeconomic environment, on geographical inequalities in the incidence or mortality of a disease, particularly lung cancer.[9 19 20] However, these studies did not assess the proportion of geographical differences in the incidence/mortality due to social deprivation. We, therefore, aimed to analyse the geographical variability in lung cancer incidence and quantify the spatial heterogeneity explained by its association with the social characteristics of territories in northwestern France.

METHODS

Study population

This study was conducted between 2006 and 2016 in the departments of Manche and Calvados in northwestern France. The two departments cover an area of 11 473 km^2 and had an average population of 1 185 000 over the study period. The study area was divided into 1496 geographical units, called the Ilots Regroupés pour l'Information Statistique (IRIS). The IRIS is the smallest geographical area for which French census data are available (approximately 2000 inhabitants). The IRIS used in this study corresponds to the geographical division of 1 January 2013.

The study population included all incident cases of lung cancer diagnosed between 1 January 2006 and 31 December 2016 in the two departments. Data were obtained from the Calvados General Tumor Register and the Manche Cancer Registry. These registries collect comprehensive data each year on all cancers occurring in people living in these two departments, regardless of the place of diagnosis and treatment of the cancer. To do this, the registries carry out passive and active data collection in all public and private health establishments in the department, neighbouring departments and the main cancer centres in France. The data collected relate to the topography and morphology of the cancer according to the international classification, the place and date of diagnosis, the sociodemographic characteristics and address of the patient, and survival data. The home address of each incident case (at the time of diagnosis) was geocoded and assigned to the IRIS using ArcGIS software.[21] Data on the population at risk in each IRIS stratified by 15-year age groups (under 15, 15–29, 30–44, 45–59, 60–74 and ≥75 years) were provided by the Institut National de la Statistique et des Etudes Economiques (INSEE) in 2011.

Socioeconomic environment

The European Deprivation Index (EDI) was used to measure the socioeconomic status of each IRIS. The EDI is a contextual and aggregated European index of social deprivation, calculated by first using data from the European Individual Disadvantage Survey (European Union-Statistics on Income Living Conditions) and then using population census data. An in-depth description of the methodology is available in previous publications.[22,23] The EDI was available continuously as a score for all IRIS records in France (n=50 006) in 2011; the higher the score, the more disadvantaged the IRIS.

Statistical analysis

Lung cancer age-standardised incidence rates per 100 000 person-years were calculated yearly over the period from 2006 to 2016, in men and women, using France as the reference population (data from the INSEE[24]). Lung cancer incidence was mapped by estimating the relative risk of lung cancer incidence for each IRIS in the study area. Relative risks were estimated by specifying hierarchical Bayesian Poisson models, in which unstructured spatial heterogeneity and spatial autocorrelation can be considered via spatially structured and unstructured random effects (hereafter referred to as spatial components).[25,26] Potthoff-Whittinghill[27] and Moran index tests[28] provided evidence of unstructured spatial heterogeneity (if the crude incidence rates are homogeneous across the entire study area) and spatial autocorrelation (degree of similarity of neighbouring geographical units), respectively. The threshold for statistical significance was set at $p<0.05$. After examining the results of the two previous tests, the incidence of lung cancer was modelled using the model proposed by BYM.[14] For each IRIS, we reported the residual relative risk (ResRR, an exponent of the model's spatial components) and its 95% credibility interval (95% CI). To identify unusual elevations in lung cancer incidence, we used exceedance probabilities that were discretised by thresholds of 0.2 and 0.8 to minimise false positives and negatives[29] (online supplemental file S1).

EDI was introduced as a covariate in the previous model to adjust the spatial distribution of lung cancer incidence to social disadvantage. As an effect size, we reported the relative risk of lung cancer incidence for a 1-unit increase in the EDI and its 95% CI. To test for a potential nonlinear association (departure from the log-linearity assumption), the EDI score was discretised into quartiles, taking the first quartile as the reference (online supplemental file S1, table S1 and figure S1). ResRRs, 95% CIs and exceedance probabilities are also reported.

To quantify the specific contribution of the EDI to the spatial variability of lung cancer incidence, we calculated the relative difference (in %) in the variability of the spatial components between the models without and with EDI adjustment. Because of the differences in lung cancer outcomes between men and women,[30,31] all analyses were stratified by sex.

All mapping was performed using QGIS software (V.3.30.3).[32] Potthoff-Whittinghill's test and Moran's test were performed by using R V.4.1.2 (package spdep and DCluster).

Bayesian models were fitted with WinBUGS software V.1.4.3,[33–35] using a Markov Chain Monte Carlo implementation. A burn-in period of 10 000 iterations was used, and a further 100 000 simulations were performed to estimate the models. Further details on the methodology for selecting the best Bayesian model, model specifications and the choice of prior distributions are available in online supplemental file S1.

RESULTS

Study population

The study included 7665 patients (24.23% women and 75.77% men) with lung cancer who were residents of the Calvados or Manche departments. The median age of the patients was 66 years (IQR=(58–75)) for both sexes combined, 64 years (IQR=(55–76)) for women and 66 years (IQR=(59–75)) for men.

During the period from 2006 to 2016 in the departments of Calvados and Manche, the number of new cases of lung cancer was estimated at 660 per year (491 in men and 169 in women), with an average age-standardised incidence rate of 25.80 (21.78; 29.83) per 100 000 person-years for women and 85.93 (80.40; 91.47) for men. Annual age-standardised incidence rates of lung cancer increased over the period in both sexes (online supplemental file S2, table S2).

Spatial distribution of lung cancer incidence

We observed significant spatial heterogeneity in lung cancer incidence rates (p=0.010 in men and p=0.010 in women, in a Potthoff-Whittinghill test), together with evidence of spatial autocorrelation between the different IRIS units (Moran I statistics=0.118; p=0.003 in men and Moran I statistics=0.084; p=0.002 in women). The minimum and maximum values of all confounded ResRRs are included in table 1 (model 1), for men and women. The spatial distribution of lung cancer incidence in men and women is presented in figure 1.

Women

The map of ResRRs shows a high incidence zone to the east of the study area and a low incidence zone to the west. In the Caen

Table 1 Ranking of residual relative risks*

	Women		Men	
Model	**Value**	**95% CI**	**Value**	**95% CI**
(1) $log\ (\theta_i) = \beta_0 + U_i + V_i$				
min ($ResRR$)	0.64	(0.34; 1.08)	0.48	(0.28; 0.77)
max ($ResRR$)	2.02	(1.04; 3.62)	2.47	(1.63; 3.58)
(2) $log\ (\theta_i) = \beta_0 + \beta_1 EDI + U_i + V_i$				
min ($ResRR$)	0.67	(0.37; 1.08)	0.51	(0.32; 0.75)
max ($ResRR$)	1.89	(1.20; 2.87)	1.93	(1.22; 2.93)

*Without (model 1) or with (model 2) adjustment on social deprivation. Minimum (min) and maximum (max) of each set of ResRR and their 95% credibility intervals, in men and women.
ResRR, residual relative risk.

metropolitan area (main city), a high incidence zone is observed (figure 1a). According to exceedance probabilities, the model predicted areas with a significantly higher incidence in the east of the study area (between Caen, Bayeux and Lisieux) and an area with a significantly low incidence in the southwest (figure 1b).

Men

The map of ResRRs (figure 1c) shows areas of high incidence to the east of the study area, west of Bayeux and east of Cherbourg-en-Cotentin. An area of low incidence is visible to the southwest of the study area. In the Caen conurbation, a zone of significantly high incidence is visible.

The exceedance probability map (figure 1d) shows that there are areas with very high probabilities (Caen and Lisieux, west of Bayeux and east of Cherbourg-en-Cotentin). An area of low incidence is visible to the southwest of the study area.

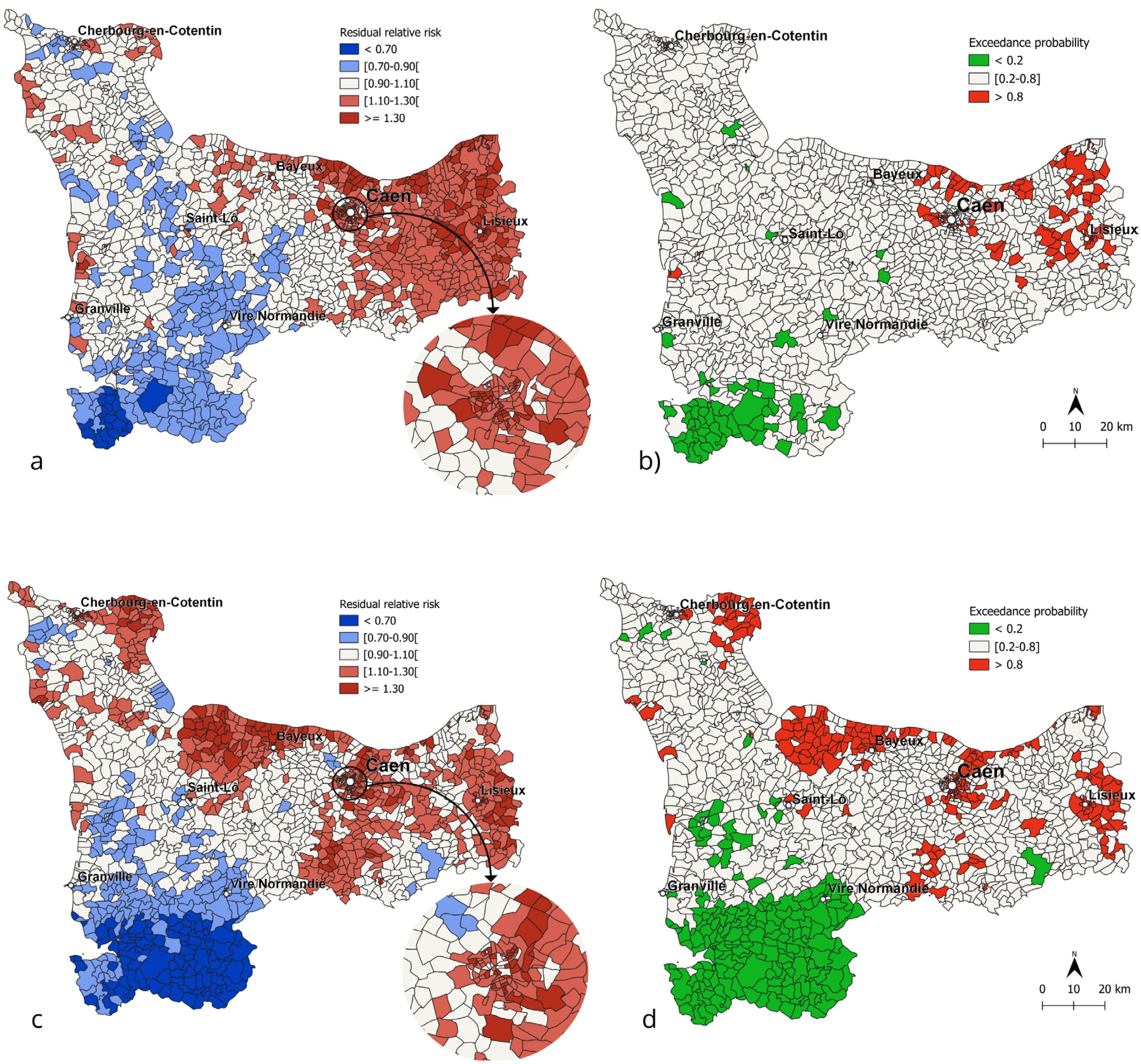

Figure 1 Residual relative risks and exceedance probabilities of lung cancer incidence between 2006 and 2016. Calvados and Manche departments. (a) Residual relative risks in women, (b) exceedance probabilities in women, (c) residual relative risks in men and (d) exceedance probabilities in men.

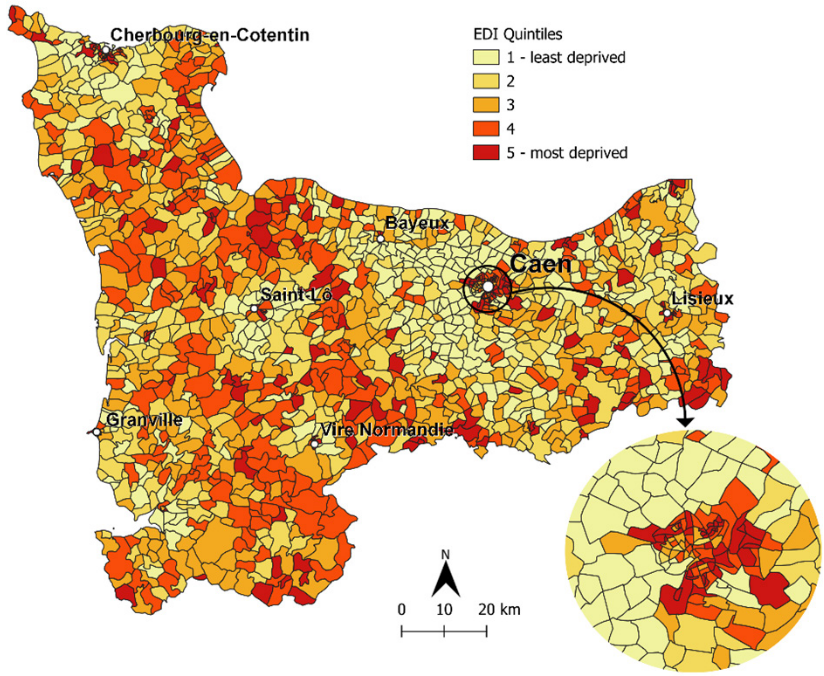

Figure 2 Spatial distribution of EDI Quintiles in Calvados and Manche, 2011. EDI, European Deprivation Index.

Influence of the socioeconomic environment on the spatial distribution of lung cancer incidence

Spatial variability of social deprivation

In France, from 2006 to 2016, the EDI score ranged from −16.40 to 55.65, with a mean of 0.00 (SD=4.56). In our study area, over the same period, the EDI score ranged from −8.12 to 19.80, with a mean of −0.83 (SD=3.28), indicating that our study area is globally less deprived than the entire territory of France. The EDI spatial distribution map shows a disadvantaged region, particularly in the west (figure 2). Zooming in on the Caen metropolitan area shows the existence of the most disadvantaged IRIS units. A richer area is highlighted when moving away from Caen towards Bayeux (clear area).

Association with EDI and lung cancer incidence

Socioeconomic environment was associated with the incidence of lung cancer in both sexes (women RR: 1.044 (95% CI 1.000; 1.044), men RR: 1.044 (95% CI 1.035; 1.053)) for a 1-unit increase in the EDI score (table 2, model 2). Thus, as the EDI score increases, the incidence of lung cancer also increases. For both sexes, no departure from the log-linearity hypothesis was observed for the EDI score when the score was discretised into quartiles (online supplemental file S1, table S1 and figure S1).

Spatial residual distribution after adjustment for social deprivation

The predicted and estimated ResRRs after adjustment for the socioeconomic environment are shown in figure 3 and the minimum and maximum values of all confounded ResRRs are included in table 1 (model 2), for men and women. The residual RR map in women (figure 3a) shows areas with high incidence to the east of the territory and areas with low incidence to the west. An area of high incidence is still visible around the Caen area. In figure 3a,c, we can see that there are fewer IRIS in the extreme categories (<0.70 and ≥1.30) and more IRIS with a

Table 2 Besag-York-Mollié model for lung cancer incidence*

	Women		Men	
Model	**Mean posterior RR**	**95% CI**	**Mean posterior RR**	**95% CI**
(1) $log\left(\theta_i\right) = \beta_0 + U_i + V_i$				
σ^2_U	0.078	(0.024; 0.176)	0.106	(0.055; 0.177)
σ^2_V	0.056	(0.014; 0.111)	0.025	(0.007; 0.049)
σ^2_{U+V}	0.026	(0.024; 0.028)	0.045	(0.042; 0.048)
(2) $log\left(\theta_i\right) = \beta_0 + \beta_1 EDI + U_i + V_i$				
e^{β}	1.044	(1.000; 1.044)	1.044	(1.035; 1.053)
σ^2_U	0.059	(0.016; 0.138)	0.071	(0.038; 0.116)
σ^2_V	0.043	(0.010; 0.089)	0.014	(0.004; 0.030)
σ^2_{U+V}	0.018	(0.017; 0.019)	0.035	(0.032; 0.037)

*Without (model 1) or with (model 2) adjustment on social deprivation. Mean posterior credible and 95% credibility intervals of parameters, in men and women.
RR, relative risk;

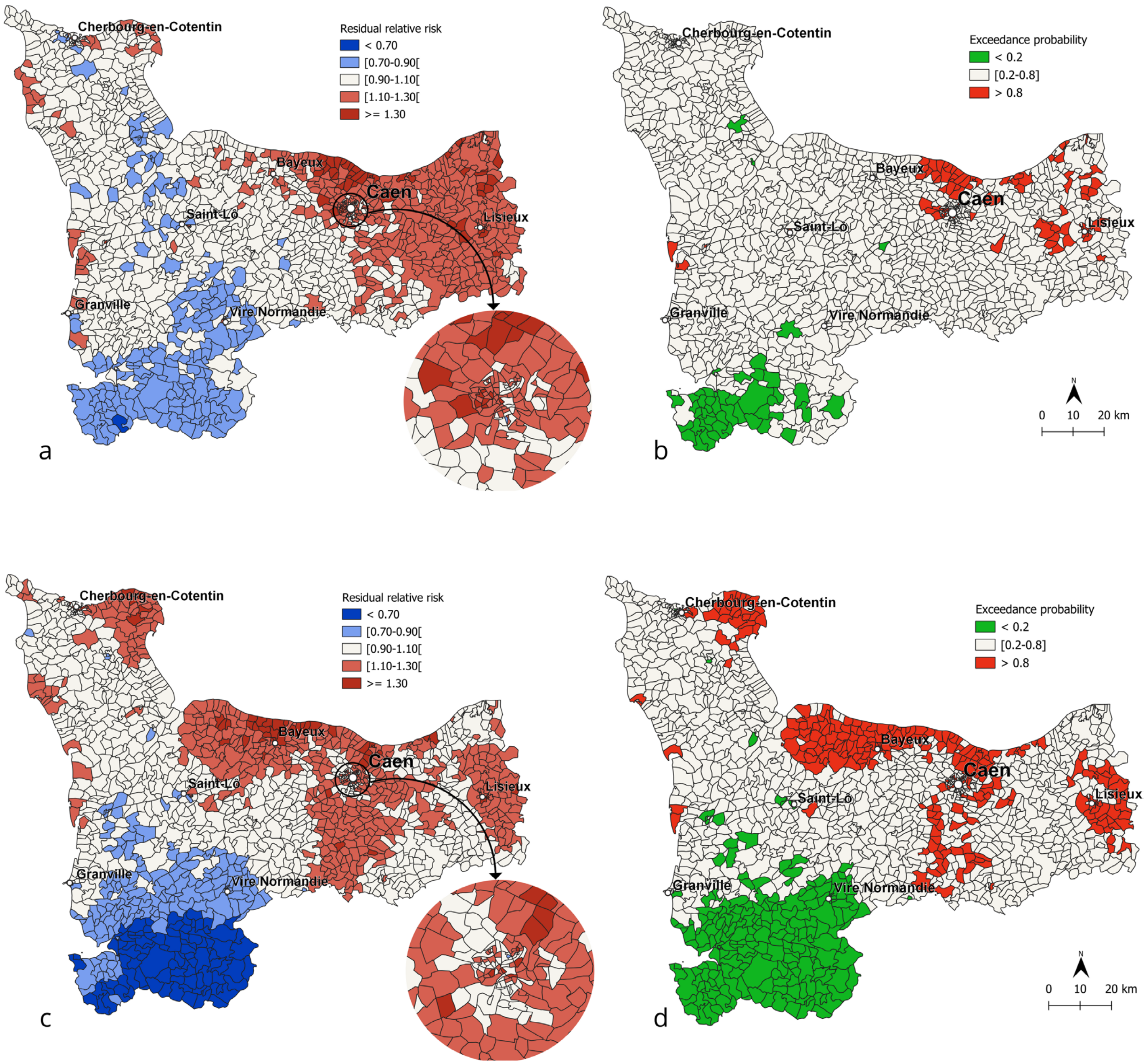

Figure 3 Residual relative risks and exceedance probabilities of lung cancer incidence. Analysis after adjustment for the socioeconomic environment, between 2006 and 2016, Calvados and Manche departments. (a) Residual relative risks in women, (b) exceedance probabilities in women, (c) residual relative risks in men and (d) exceedance probabilities in men.

relative risk close to 1 (white zone) compared with figure 1. The model adjusted on the EDI variable predicted an area with high incidence to the east of the study area (above the city of Caen and around the city of Lisieux) and an area with a significantly low incidence in the western part of the study area (figure 3b).

Regarding men, the ResRR map (figure 3c) shows areas of increased incidence near Cherbourg, Bayeux and Lisieux. Practically, all IRIS had a higher incidence in the Caen metropolitan area (zoomed area). On the exceedance probability map (figure 3d), the model predicted areas with high incidence to the west of Bayeux, around Caen, to the east of Cherbourg and around Lisieux, and areas with low incidence to the southwest of the territory.

Part of the variability is explained by the socioeconomic environment

A calculation of the relative difference in variability allowed us to quantify the contribution of the socioeconomic environment as 31.4% in women and 22.1% in men. This means that approximately one-third of the geographical variability in lung cancer incidence is explained by the socioeconomic environment in women and just over one-fifth in men.

DISCUSSION

The results showed strong spatial variability in the incidence of lung cancer in northwestern France among men and women. Our results suggest that a substantial part of the geographical heterogeneity in the incidence of lung cancer can be attributed to the socioeconomic environment, to a greater extent for females (almost one-third) than for males (one-fifth).

This difference between women and men could be explained by the fact that smoking accounts for a greater proportion of social inequalities in the incidence of lung cancer in women than in men. In France, the prevalence of smoking among disadvantaged groups is higher among women than men. In a recent study, Menvielle *et al*[36] stated that the excess of lung cancer cases in the four most disadvantaged quintiles of the population would be reduced by 43.5% in women and 27.5% in men if there were no smoking inequalities. Accounting for the socioeconomic environment reduces spatially structured contrasts in lung cancer incidence. Furthermore, considering the socioeconomic environment made it possible to reduce the spatial contrasts for lung cancer in men and women in the Caen agglomeration (zoomed areas), where there are many spatial units with disadvantaged municipalities.

To the best of our knowledge, no study has sought to quantify the geographical variability in the incidence of lung cancer as explained by the socioeconomic environment. Only methodological comparison studies have been published, such as those conducted in Isère, France, using the Townsend index.[9] This previous study included all cases of prostate, lung, colorectal and bladder cancers in men diagnosed between 1999 and 2007 and registered in the Cancer Registry of Isère. After comparing different spatial disease mapping methods, the Townsend index was introduced to each method to assess its impact on the spatial distribution of each type of cancer. As in our study, Goungounga *et al* found that accounting for socioeconomic inequalities modifies the spatial variation in lung cancer, but the study did not assess the proportion of this variation explained by the Townsend index.

Another study conducted in the province of Leece, Italy,[20] linked the geographical clustering of lung cancer and social deprivation. This study also uses the BYM model but focuses on mortality rather than on incidence. Provincial-level data were obtained from the Cislaghi Italian Mortality Atlas and Social deprivation was measured using the Cadum Index. The authors concluded that there was no positive linear association between regional lung cancer risk heterogeneity and deprivation.

Our study has several limitations. First, even if the reliability of French cancer registries is regularly attested to by their national accreditation and registry checking neighbouring departments, we cannot definitively rule out that part of the underincidence observed in the south of Manche is at least partly due to underregistration due to the flight of patients to hospitals outside the department of Manche and its neighbouring departments. Second, the EDI used is that of 2011 but the IRIS breakdown is that of 2013. Indeed, the census data provided by INSEE in 2011 are based on the geographical breakdown of 2013, which may constitute another limitation. Finally, as cited previously, no studies have investigated how much of the geographical variability in lung cancer incidence is explained by socioeconomic factors. However, this did not allow us to compare the results.

Our study also had several strengths. To the best of our knowledge, this study is the first to quantify the extent to which geographical variability in cancer incidence can be explained by the socioeconomic environment. The use of data from cancer registries (FRANCIM network) provided quality data with good completeness of diagnosis of lung cancer cases in the study area. The data were geocoded over a period of 11 years, which allows for a long incidence period.

Regarding lung cancer, smoking is undoubtedly the main mediating factor of social determination; if a person lives in a disadvantaged environment, they are more likely to smoke, and therefore, have a higher risk of developing lung cancer.[37 38] Another perspective would be to integrate deprivation indices in further studies investigating environmental risk factors, such as asbestos, silica or air pollution, to explain geographical heterogeneity.[39] Grouping such environmental, behavioural and socioeconomic data could allow us to quantify the influence of each factor and their interactions, which is of great interest from a public health point of view.

CONCLUSIONS

Our results confirmed the link between the socioeconomic environment of the population and lung cancer incidence. In contrast, our study showed that the social determination of incidence could explain a significant part of this geographical heterogeneity: one-third in women and one-fifth in men. These results indicate that a significant proportion of geographical or territorial inequalities is, in fact, explained by social inequalities. Taking into account, the proportion of geographical heterogeneity due to social differences is particularly important for cancers such as lung cancer, part of whose incidence is due to environmental exposure. On the one hand, environmental justice in France needs to be better documented, and on the other, the social dimension needs to be more accounted before searching environmental causes to clusters of incidence. Beyond these initial results, which allowed us to measure the extent of the phenomenon in relation to lung cancer in a restricted geographical area, it would be interesting to use existing databases from cancer registries in France and other countries to confirm these results in larger samples and to explore the same question in relation to other cancer sites.

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Contributors PP, GM, GL and JB designed the study. PP carried out the analysis and wrote the first version of the manuscript. BS and VN participated in the acquisition of the data. PP, GM, GL and JB participated in the interpretation of results, critically revised the paper and approved the final version of the manuscript. PP is the guarantor.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study is based on data from the Calvados General Tumor Register and the Manche Cancer Registry. Each cancer registry involved in this study has received the approval of the French regulatory authorities for the collection and analysis of medical data: the Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le Domaine de la Santé (ethics approval) and the Commission Nationale Informatique et Libertés (legal framework and data protection). In conformity with the French law, patients were individually informed before the start of data collection of the nature of the information provided, the purpose of data processing and their right of access, rectification or objection. The ethics committee, in accordance with French law, did not request informed consent.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available. The data that support the findings of this study came from the Calvados General Tumor Register and the Manche Cancer Registry, but restrictions apply to the availability of these data, which were used under licence for the current study, and so are not publicly available.

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