

Mortality atlas of the main causes of death in Switzerland, 2008–2012

Frédérique Chammartin^{a,b}, Nicole Probst-Hensch^{a,b}, Jürg Utzinger^{a,b}, Penelope Vounatsou^{a,b}

^a Swiss Tropical and Public Health Institute, Basel, Switzerland

^b University of Basel, Basel, Switzerland

Summary

PRINCIPLES: Analysis of the spatial distribution of mortality data is important for identification of high-risk areas, which in turn might guide prevention, and modify behaviour and health resources allocation. This study aimed to update the Swiss mortality atlas by analysing recent data using Bayesian statistical methods. We present average pattern for the major causes of death in Switzerland.

METHODS: We analysed Swiss mortality data from death certificates for the period 2008–2012. Bayesian conditional autoregressive models were employed to smooth the standardised mortality rates and assess average patterns. Additionally, we developed models for age- and gender-specific sub-groups that account for urbanisation and linguistic areas in order to assess their effects on the different sub-groups.

RESULTS: We describe the spatial pattern of the major causes of death that occurred in Switzerland between 2008 and 2012, namely 4 cardiovascular diseases, 10 different kinds of cancer, 2 external causes of death, as well as chronic respiratory diseases, Alzheimer's disease, diabetes, influenza and pneumonia, and liver diseases. In-depth analysis of age- and gender-specific mortality rates revealed significant disparities between urbanisation and linguistic areas.

CONCLUSIONS: We provide a contemporary overview of the spatial distribution of the main causes of death in Switzerland. Our estimates and maps can help future research to deepen our understanding of the spatial variation of major causes of death in Switzerland, which in turn is crucial for targeting preventive measures, changing behaviours and a more cost-effective allocation of health resources.

Key words: mortality atlas; Bayesian conditional autoregressive model; Switzerland

Introduction

Life expectancy in Switzerland is among the highest in the world at 80.4 and 85.4 years for males and females, respectively, in 2014 [1]. Mortality rates and causes of death vary according to age, gender and place of residence. A

rigorous identification of the spatial distribution of cause-specific mortality rates is important because it provides insight for underlying risk factors that can be environmental, sociocultural or health systems related. From a public health perspective, it enables areas (e.g. municipalities) to be identified where interventions, preventive measures and modifying behaviour might be warranted, and hence will assist in health resource allocation.

Geographical representation of the age- and gender-standardised mortality ratio (SMR) enables health professionals and politicians to identify areas of high mortality. Maps of raw rates might be dominated by sparse data influenced by the size of population at risk [2]. Bayesian statistical models filter out the noise and produce smooth maps that more readily identify spatial patterns and clusters.

Mortality atlases have been released for Spain [3] and the United States of America [4]. In Switzerland, a cancer mortality atlas was published in 1997 that covered the years 1970–1990 [5]. More recently, maps at municipality level in Switzerland have been released by Schmidlin et al. [6] on all-cause mortality from 1991 to 2008 and by Jürgens et al. [7] on tobacco-related cancer mortality from 1969 to 2002.

This study aimed to complete and update the Swiss mortality atlas by analysing data from death certificates for the period 2008 to 2012. After classification of the main causes of death, we present a model-based atlas of the major causes of death in Switzerland.

Methods

Mortality data

Mortality data were provided with information about age, gender and municipality of residence of each case for the period 2008–2012 by the Swiss Federal Statistical Office (FSO). Since data were provided without personal identifiers, there were no specific ethical considerations for the current analysis. Primary causes of death were recorded according to the International Classification of Diseases ICD-10 (<http://www.who.int/classifications/icd/>). As the aim of our work was to study the geographical distribution of cause-specific mortality, we followed the classification proposed by the Centers for Disease Control and Preven-

tion (CDC) for studies assessing geographical patterns of mortality [8] and grouped the data into 32 causes of death that are relevant for Switzerland (see appendix 1 for more details about the allocation of the ICD-10 codes). Age at death was classified into 18 age groups of 5 years each, ranging from 0–4 to ≥ 85 years. To overcome issues related to the numerous mergers of Swiss municipalities, we standardised the municipalities of residence according to the most recent official register of municipalities of 2014. We restricted our analysis to the major causes of death that record an average annual number of cases superior to 300.

Population data

Population data from the census 2010 were available by gender for each municipality and grouped by 5-year age categories. Due to the lack of disaggregated inter-censal population data, we assumed that the population over the period 2008–2012 was constant and equal to the 2010 census population. We reshaped municipality boundaries according to the 2014 territorial status for spatial alignment with mortality data.

National statistics

Differences between gender age-adjusted and gender-specific age groups death rates were explored at national level for the major causes of death in Switzerland. Details on age adjustment are given in appendix 2.

Spatial analysis at municipality level

The SMR represents the number of observed deaths with respect to the expected deaths in the general population. In order to highlight the spatial pattern of the different causes of death, we smoothed the observed SMR by borrowing strength across neighbouring municipalities. Thus, we used Bayesian spatial statistical models where spatial correlation and residual noise are modelled through a conditional autoregressive (CAR) effect [9, 10] and an unstructured effect, respectively. Observed SMRs were age- and gender-standardised through their corresponding expected deaths based on the average national mortality rate (indirect standardisation). Thus, our models estimate municipality-specific smooth age- and gender-SMR. Several likelihood functions were explored to model the death counts. The final model was the one that showed the best goodness of fit according to the deviance information criterion [11].

We additionally developed gender- and age-specific Bayesian spatial statistical models for age categories contributing to more than 5% of the deaths that occur in the total population (number of deaths by cause, age and gender are presented in appendix 3, table A3). Those models account for urbanisation (rural *versus* urban) and linguistic areas (French and Italian *versus* German). This enabled us to assess the effect of the covariates for different groups, i.e. male and female allocated to 6 age categories, namely 0–14, 15–29, 30–44, 45–59, 60–74 and ≥ 75 years. As the data were initially grouped into 5-year age groups, expected deaths have been age-standardised. In the absence of significant effects of the Romansh-speaking areas observed in a preliminary analysis, we included the Romansh-speaking areas within the German-speaking areas.

A joint analysis with a shared component model [12] was developed for cardiovascular diseases and diabetes, as well as for lung cancer and chronic obstructive pulmonary disease (COPD). Such a model is able to capture a latent shared spatial structure that is not explained by the covariates used in the model and the shared underlying structure might reflect spatial variation of common risk factors that have not been observed. We chose to analyse groups of disease that share strong risk factors. Complete details on model specification and implementation are given in appendix 4.

Boundary detection

A technique called wombling was used to detect boundaries of spatial clusters [13, 14]. In brief, we highlighted borders in black if the 95% Bayesian credible interval of the difference between two adjacency smoothed displayed quantities (SMRs or spatial random effect) was significantly different from zero.

Results

The average annual numbers of deaths, stratified by cause and gender, in Switzerland over the period 2008–2012, are reported in table 1. The main causes of death were cardiovascular diseases and cancers that mainly affect lungs, colon or rectum, breast and prostate. External causes of death come in third position and are mostly represented by intentional self-harm (suicide). A smooth map of the geographical distribution of all-cause mortality risk is presented in figure 1.

Cardiovascular diseases

Cardiovascular diseases accounted for 36% of deaths and were therefore the leading cause of mortality in Switzerland during the period 2008–2012. Such deaths occurred more frequently among males older than 60 years of age (see figs A1 and A2 in appendix 3 for a comparison of gender-specific age-adjusted death rates and age distribution of death rates, respectively).

We divided cardiovascular diseases into different subgroups, the most important of which were heart diseases, cerebrovascular diseases (stroke), hypertensive diseases (hypertension and hypertensive renal disease) and ather-

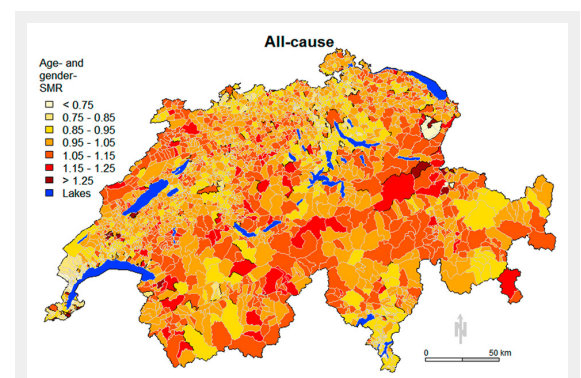


Figure 1

Geographical distribution of all-cause mortality risk in Switzerland, 2008–2012.

osclerosis, which accounted for 73%, 18%, 4% and 2% of the cardiovascular disease cases, respectively. Smooth maps of the age- and gender-SMR of those diseases resulting from Bayesian CAR models fitted to the dataset of the entire population are presented in figure 2. Deaths due to cardiovascular diseases were more frequent in the eastern Swiss regions of Glarus, St. Gallen, Thurgau and Appenzell.

We further analysed the main cardiovascular diseases, stratified by gender and age categories, by accounting for urbanisation and linguistic areas in the CAR spatial model. Results from those analyses are presented with a summary of the estimated effects of urbanisation and linguistic areas (see appendix 3, fig. A3). Linguistic areas had an effect on mortality caused by heart and hypertensive diseases, as well as on atherosclerosis. Indeed, hypertensive diseases and atherosclerosis SMRs were smaller in French- and Italian-speaking areas and the heart disease SMR was smaller in the French-speaking areas among people aged 75 years and above in comparison with the reference German-speaking. This result reflects higher mortality rates in the German-speaking communities from cardiovascular diseases. The mortality due to cardiovascular diseases was also more important in rural than urban settings, as reflected by several significantly negative effects of the variable urban on the SMR among gender, different age and cardiovascular diseases subgroup categories.

Cancers

Cancers were responsible for 27% of the deaths in Switzerland during the period 2008–2012. For both genders combined, the most deadly cancers were the ones affecting lungs and colon or rectum. However, breast cancer was the cancer that killed the most females, while prostate cancer ranked just after lung cancer in the male population (table 1).

Deaths due to cancers usually affected men more often than women, with the exception of breast and gynaecological cancers that are gender-specific (see appendix 3, fig. A1). The smooth map of the age and gender SMR of the differ-

ent types of cancer is presented in figure 3. The geographical pattern of cancers in general followed the pattern of the majority cancer, lung cancer. In-depth analysis highlighted differences between linguistic regions and urbanisation (see appendix 3, fig. A4 for a summary of the effect estimates of model covariates).

For lung cancer, the SMR was greater in the French-speaking area compared with the German-speaking area for all sub-groups analysed, except for males aged 75 years and above, where the mortality risk was higher in the Italian-speaking part. Mortality due to breast cancer was lower in the French-speaking part for females aged 75 years and above, as shown by the estimates of coefficient (appendix 3, fig. A4). For prostate cancer, the SMR was lower in the Italian-speaking part of Switzerland than in the German-speaking part. For people aged 75 years and above, the SMR was also lower in urban than in rural settings. Deaths due to cancer of pancreas were lower in the French-speaking part of Switzerland compared with the German-speaking part for females aged 45–59 years. For males above 75 years, there was a higher risk in urban than in rural settings. For urinary tract cancer, the SMR was greater in the French-speaking part of Switzerland for males aged 45–59 and 60–74 years, and in the Italian-speaking part for males aged 45–59 years. With regard to stomach cancer, deaths were lower in urban settings for both males and females aged 75 years and above. Compared with the German-speaking part of Switzerland, the SMR was lower for males aged 60–74 years living in the French-speaking part and higher for females aged 75 years and above in the Italian-speaking part. This is reflected in the average pattern of stomach cancer in Switzerland, which exhibits a high SMR in the Italian-speaking part of Switzerland. Non-Hodgkin's lymphoma showed a higher SMR among males aged 45–59 years in the French-speaking part of Switzerland and among females aged 75 years and above living in the Italian-speaking part compared with the German-speaking part. For colorectal cancer, gynaecological cancer and leukaemia, no significant associations were found with urbanisation and linguistic zones of Switzerland.

External causes of death

External causes of death were responsible for 6% of the recorded deaths in Switzerland in the study period 2008–2012. Intentional self-harm and motor vehicle accident represented 30% and 8% of the external causes of death, respectively (table 1).

Deaths due to both intentional self-harm and motor vehicle accidents were considerably more prominent in men than in women (see appendix 3, figs A1 and A2). Smooth maps of the age- and gender-SMR of the major types of external causes of death are presented in figure 4.

Intentional self-harm SMR was lower in urban settings for males aged 15–29 and 30–44 years. Compared with the German-speaking part, the SMR was larger in the French-speaking part of Switzerland for females aged 30–74 years and males aged 30–44 years. SMR was lower for males aged 15–29 years living in the French-speaking part and males aged 45–59 and ≥ 75 years living in the Italian-speaking part (see appendix 3, fig. A5).

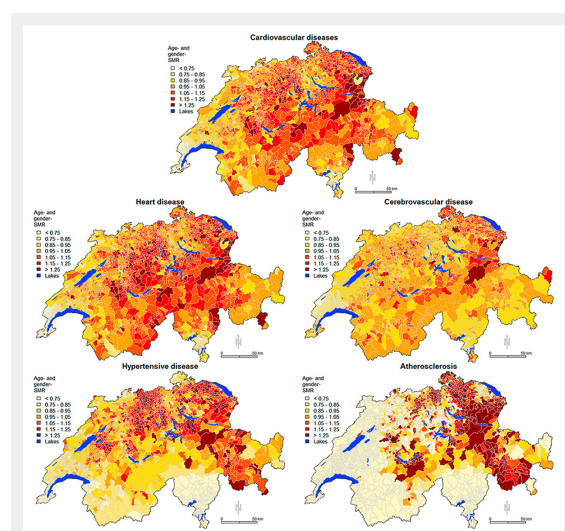


Figure 2

Geographical distribution of mortality risk due to cardiovascular diseases in Switzerland, 2008–2012.

For motor vehicle accidents, mortality was lower in urban settings for all male age categories, with the exception of the age group 30–44 years. Mortality was also higher in the French-speaking part for males aged 15–29 and 30–44 years and in the Italian-speaking part for males aged 15–29 years.

Additional causes of death

Additional causes of death were studied, namely chronic respiratory disease, Alzheimer's disease, diabetes, influenza and pneumonia, and liver disease. The corresponding smooth maps of the age- and gender-SMRs are shown in figure 5. Furthermore, we present in an appendix the results of an analysis stratified by gender and age categories that accounted for urbanisation and linguistic areas (see appendix 3, fig. A5 for a summary of the effects of the covariates).

The map of the average pattern of chronic respiratory diseases SMR (fig. 5) highlights a higher mortality rate in Graubünden and High-Wallis, while industrialised areas such as the Zürich area and the Lemman Arch showed lower mortality rates. Urban areas were associated with a lower

SMR compared with rural settings among males aged 75 years and above (appendix 3, fig. A5).

Mortality due to Alzheimer's disease was higher in the French- and Italian-speaking parts of Switzerland (fig. 5). In particular, living in a French- or Italian-speaking area had an important effect on both males and females aged 75 years and above (appendix 3, fig. A5). Alzheimer's disease had a higher mortality rate among females than males (appendix 3, fig. A1).

Rates of deaths due to diabetes were lower in the French- and Italian-speaking parts of Switzerland compared with the German-speaking part (fig. 5).

Mortality due to influenza and pneumonia was higher in the French-speaking part of Switzerland, as well as for females aged ≥ 75 years living in urban settings.

For liver diseases, the death rate in males was about twice that in females (appendix 3, fig. A1). An urban setting was related to a higher SMR among females aged 45–59 years and among males and females aged ≥ 75 years (appendix 3, fig. A5).

Table 1: Average annual number of deaths, stratified by cause and gender in Switzerland during 2008–2012.

Cause of death	Male	Female	Total
Cardiovascular diseases	9 725	11 972	21 697
Heart disease	7 356	8 555	15 911
Cerebrovascular disease	1 500	2 316	3 816
Hypertensive disease (hypertension and hypertensive renal disease)	306	564	870
Atherosclerosis	192	296	488
All cancers	9 003	7 252	16 255
Lung cancer	2 010	1 080	3 090
Colorectal cancer	936	770	1 706
Breast cancer	8	1 397	1 405
Prostate cancer	1 331	0	1 331
Pancreas cancer	542	574	1 116
Urinary tract cancer	621	294	915
Gynaecological cancers (cervix uteri, corpus uteri and ovary)	0	714	714
Leukaemia	300	254	554
Stomach cancer	317	193	510
Non-Hodgkin's lymphoma	258	232	490
External causes of death	2 168	1 471	3 639
Intentional self-harm (suicide)	786	316	1 102
Motor vehicle accidents	232	73	305
Assault (homicide)	23	22	45
Chronic respiratory disease	1 105	826	1 931
Alzheimer's disease	456	1 054	1 510
Diabetes	610	721	1 331
Influenza and pneumonia	580	702	1 282
Liver disease	439	217	656
Nephritis, nephrotic syndrome and nephrosis	260	269	529
Congenital malformations, deformations and chromosomal abnormalities	124	114	238
Certain conditions originating in the perinatal period	91	85	176
Peptic ulcer	68	80	148
Human immunodeficiency virus	31	15	46
Tuberculosis	10	8	18
Sudden infant death syndrome	7	4	11
Pregnancy, childbirth and the puerperium	0	5	5
Syphilis	2	1	3
All other diseases	4 447	6 466	10 913
All causes	29 126	31 262	60 388

Shared spatial pattern

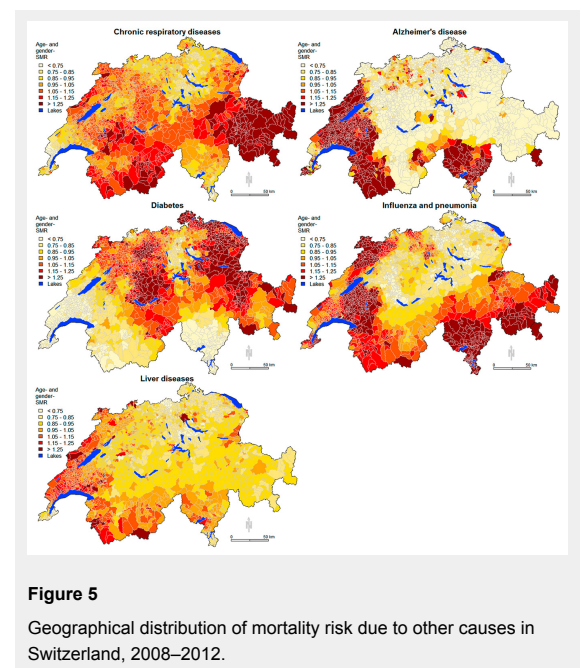
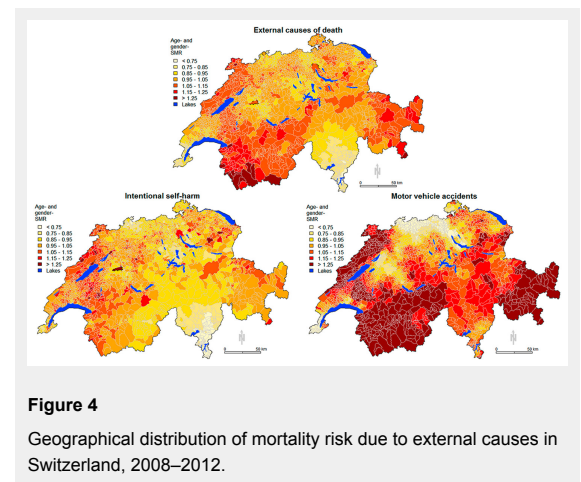
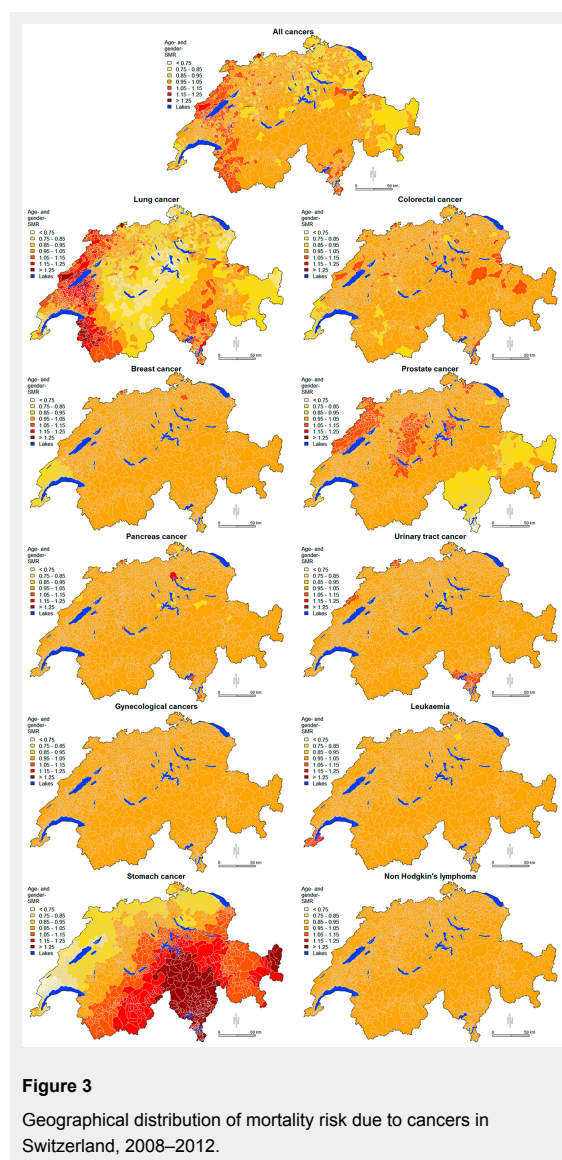
Disease-specific and shared spatial dependences between lung cancer and COPD, as well as between diabetes and cardiovascular diseases are presented in appendix 3, figure A6. For lung cancer and COPD, we identified high shared high-risk areas in Graubünden and in the eastern areas of the French-speaking part of Switzerland. For diabetes and cardiovascular diseases, shared risk was higher in the German part of Switzerland. However, the wombling technique did not reveal significant shared spatial clusters.

Discussion

We present a contemporary overview of the geographical distribution of the major causes of death in Switzerland. The Bayesian CAR methodology employed allowed us to obtain maps with smooth estimates of the municipalities' SMR that highlight spatial pattern. Furthermore, our in-depth analysis of age- and gender-specific mortality rates enabled us to assess disparities between urbanisation and linguistic areas, after accounting for spatial correlation.

We discuss and explain the results of our analysis by comparing them with other studies that investigated causes of death in neighbouring countries and beyond. Spatial

patterns in the mortality rate reflect spatial variation in the risk factors. Apart from heredity, other important risk factors for cardiovascular diseases are high blood pressure, smoking, lack of exercise and overweight. They can be modified by adopting a healthy lifestyle and it is therefore reasonable to assume that the risk of dying from such diseases might vary between urban and rural settings and/or from one language zone to another across Switzerland, probably because of cultural differences and area-specific behaviours. Our analysis highlights lifestyle differences according to language zones, and extent of urbanisation, as we found that people living in the French- and Italian-speaking parts of Switzerland and those in urban settings are at lower risk of death due to cardiovascular diseases, in particular heart and hypertensive diseases. Our result coincides with findings of the Global Burden of Disease (GBD) 2010 study that estimated the burden of 291 diseases and injuries worldwide [15]. Indeed, for France and Italy, it has been estimated that ischaemic heart disease (the major cardiovascular disease) represented 10.1% and 14.8% of the total years of life lost (YLLs), compared with 18.4% in Germany (<http://vizhub.healthdata.org/gbd-compare/>).



The most important risk factor for lung cancer is tobacco consumption [16]. Faeh and Bopp [17] have reported a significantly higher prevalence in smoking in the French-speaking part of Switzerland than in the German-speaking part, especially among women. European countries have shown heterogeneous trends of lung cancer epidemic with the largest rise of lung cancer rate among young French women [18]. Thus, it is not surprising if cultural smoking behaviours influence spatial pattern of lung cancer mortality. Furthermore, the GBD 2010 study [15] estimated slightly higher percentage of total YLLs attributed to lung cancer in France (7.4%) than in Italy (7.0%) and Germany (6.9%). The geographic pattern of lung cancer mortality identified in our analysis reflects the particularity of Switzerland with its different cultural influences. We also highlight the well-known role of smoking in lung cancer in Switzerland [7]. Additionally, the SMR was higher in urban settings among females aged 75 years and above. One might explain this result in the face of urbanisation and women's emancipation with an unfortunate increase of smoking in the middle of the twentieth century [19]. Early menarche and late menopause are factors that favour breast cancer [20] and Switzerland has shown high spatial variability of reproductive characteristics [21]. The Swiss FSO [22] has reported that breast cancer was more common in the French- and Italian-speaking parts compared with the German-speaking part. However, we found that mortality was lower in the French-speaking part for females aged 75 years and above. Differences between mortality and incidence patterns might reflect geographical disparities in mammography screening [23]. Regarding screening practices, d'Ambrosio et al. [24] reported that, in Italy, the practice of prostate cancer preventive testing has increased over the past several years, and hence is often performed without any clear indications. It would be interesting to assess if this trend is cultural, because if prostate screening is more widespread in the Italian-speaking part of Switzerland, it might partially explain why we observed fewer deaths in this region. In addition, lower prostate cancer mortality in the Italian-speaking part of Switzerland might be explained by lifestyle and a Mediterranean diet [25]. Furthermore, our observation of a higher SMR in urban than in rural settings among people aged 75 years and above might reflect inequality in prostate cancer screening between urban and rural settings, as shown in a previous European study [26]. For stomach cancer, our finding of lower death rates in urban compared with rural settings confirms previous studies elsewhere in Europe and in Asia [27, 28]. The reasons have yet to be fully elucidated, but it might reflect differences in diet between people living in urban and rural settings. Furthermore, a high incidence of gastric cancer has been observed in the northern part of Italy and the Italian-speaking part of Switzerland and has been associated with resistant strain of *Helicobacter pylori* [29].

Important differences between urban and rural settings were highlighted with regard to the external causes of deaths (intentional self-harm and motor vehicle accidents) that are higher among males from rural areas. Interestingly, there is no difference between rural and urban settings and the predominant linguistic areas for females. Surprisingly,

people living in urban settings were at a lower risk of mortality due to chronic respiratory diseases. However, COPD, the most deadly chronic respiratory disease, has been reported to cause more deaths in rural and in poor areas in the United States of America as a result of the potential contributions of occupational exposures, fuel sources and indoor air pollutants [30]. This observation might, at least partly, explain our results. For Alzheimer's disease, despite quite similar age mortality curves between genders (appendix 3, fig. A2), we observed higher mortality rates among females. This might be linked to the fact that, on average, women in Switzerland live several years longer than men, and hence are more prone to Alzheimer's disease, which mainly affects the elderly. In addition, Alzheimer's disease might be confused with other forms of dementia. However, the analysis of deaths due to other forms of dementia combined with the deaths due to Alzheimer's disease revealed similar pattern to that of Alzheimer's disease only (result not presented here). Therefore, we do not have evidence of different diagnostic practices among linguistic areas.

Our study has strengths and weaknesses that are offered for discussion. The main strength of our work is the methodology. Indeed, we employed a zero-inflated negative binomial model, which can overcome the over-dispersion and poor fit that might arise with data characterised by a high proportion of zero counts. The purpose of our cross-sectional approach was to update the Swiss mortality atlas, using the most recent available data. The study of the geographical distribution over time was not within the scope of the present work and a spatiotemporal analysis would have required inter-censal age-, gender- and municipality-specific population estimates that are not available. Unfortunately, it is difficult to assess the reliability of the allocations of causes of death. For example, COPD is a cause of death that has been under-reported on death certificates [31]. Cross-national variations on coding practices of ischaemic heart diseases have been also documented [32]. In particular, France is suspected to under-report such causes of death and it is difficult to assess whether this issue also pertains in the French-speaking part of Switzerland. Socioeconomic factors, differential access to health care and diagnostic work-up (including differences in death coding) as well as inequalities of care might also influence mortality patterns. However, few attempts have been made to build socioeconomic indexes [33] and good proxies that would enable us to measure those effects are currently lacking for Switzerland. The Swiss National Cohort [34], a large longitudinal study of the resident Swiss population that links death certificates with census information, offers a comprehensive database that allows further investigation on socioeconomic determinant of mortality. For example, Clough-Gorr et al. [35] recently reported what they called a Swiss paradox, since they found that high income inequalities were unexpectedly associated with lower mortality due to cardiovascular disease or cancer across Switzerland. Our results are in line with those findings since we also showed lower mortality risk due to cardiovascular diseases and cancer in areas that were identified with important health inequalities, such as in the Lemman Arch, and the Zürich, Bern, Basel and St. Gallen areas. Recently, health economists reported in the mass media that the risk

for death from specific diseases showed large differences between Swiss hospitals (<http://www.tagesanzeiger.ch/wissen/medizin-und-psychologie/Stark-abweichende-Sterberaten-in-Schweizer-Spitaelern/story/12792299>, http://www.schweizsamsonntag.ch/ressort/nachrichten/todesrisiko_spital_liste_zeigt_grosse_unterschiede/). It would be interesting to substantiate this claim by linking hospital and other medical institutional quality of care to mortality in a spatially explicit manner. For cardiovascular diseases in particular, rapidity of interventions in the acute phase, adequate treatment and appropriate rehabilitation are additional factors that influence mortality. They could also present geographic variations that influence the mortality pattern.

Similarities between spatial patterns might reflect common risk factors. For example, smoking and air pollution are known risk factors for both lung cancer and COPD, while diabetes is itself a risk factor for cardiovascular diseases. However, the joint analysis in this work did not identify significant shared underlying structures that capture spatial variation of latent risk factors.

In conclusion, our research provides the first model-based, cause-specific mortality atlas for Switzerland. The atlas will be updated annually and can be accessed via our online platform which currently includes the 2013 mortality estimates (www.swisstph.ch/swiss-mortality-atlas). We hope it will assist in future research into causes of spatial differences, health resource allocation and monitoring of prevention and control interventions that aim to further improve health and wellbeing of the Swiss population.

Disclosure statement: This work was supported by the Swiss National Science Foundation, grant number 32003B_135769.

Correspondence: Penelope Vounatsou, PhD, Swiss Tropical and Public Health Institute, Socinstrasse 57, CH-4051 Basel, [penelope.vounatsou\[at\]unibas.ch](mailto:penelope.vounatsou[at]unibas.ch)

References

- World Health Organization. World health statistics 2014. A wealth of information on global public health. Geneva: World Health Organization; 2014.
- Richardson S, Thomson A, Best N, Elliott P. Interpreting posterior relative risk estimates in disease-mapping studies. *Environ Health Perspect*. 2004;112(9):1016–25.
- López-Abente G, Pollán M, Escolar A, Errezola M, Abraira V, et al. Atlas of cancer mortality and other causes of death in Spain 1978–1992. Madrid: Fundación Científica de la Asociación Española Contra el Cáncer; 1996.
- Pickle LW, Mungiole M, Jones GK, White AA. Exploring spatial patterns of mortality: the new atlas of United States mortality. *Stat Med*. 1999;18(3):3211–20.
- Bopp M, Schüler G. The Swiss Cancer Mortality Atlas: 1970–1990. Basel: Birkhäuser Verlag; 1997.
- Schmidlin K, Spoerri A, Egger M, Zwahlen M, Stuck A, Clough-Gorr KM. Cancer, a disease of aging (part 2) – risk factors for older adult cancer mortality in Switzerland 1991–2008. *Swiss Med Wkly*. 2012;142:w13607.
- Jürgens V, Ess S, Phuleria HC, Früh M, Schwenkgenks M, Frick H, et al. Bayesian spatio-temporal modelling of tobacco-related cancer mortality in Switzerland. *Geospat Health*. 2013;7(2):219–36.
- Centers for Disease Control and Prevention. Instruction manual, part 9, ICD-10 cause-of-death lists for tabulating mortality statistics (updated March 2009 to include WHO updates to ICD-10 for data year 2009). Hyattsville: Centers for Disease Control and Prevention/National Center for Health Statistics; 2009.
- Besag J, York J, Mollie A. Bayesian image-restoration, with 2 applications in spatial statistics. *Ann Inst Stat Math*. 1991;43(1):1–20.
- Bernardinelli L, Montomoli C. Empirical Bayes versus fully Bayesian analysis of geographical variation in disease risk. *Stat Med*. 1992;11(8):983–1007.
- Spiegelhalter DJ, Best NG, Carlin BR, van der Linde A. Bayesian measures of model complexity and fit. *J R Stat Soc Ser B Stat Methodol*. 2002;64:583–616.
- Knorr-Held L, Best NG. A shared component model for detecting joint and selective clustering of two diseases. *J R Stat Soc Ser A Stat Soc*. 2001;164:73–85.
- Liang SD, Banerjee S, Carlin BP. Bayesian wombling for spatial point processes. *Biometrics*. 2009;65(4):1243–53.
- Fitzpatrick MC, Preisser EL, Porter A, Elkinton J, Waller LA, Carlin BP, et al. Ecological boundary detection using Bayesian areal wombling. *Ecology*. 2010;91(12):3448–55.
- Murray CJL, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380(9859):2197–223.
- Parkin DM, Boyd L. The fraction of cancer attributable to lifestyle and environmental factors in the UK in 2010. *J Epidemiol Community Health*. 2011;65:A143.
- Faeh D, Bopp M. Educational inequalities in mortality and associated risk factors: German- versus French-speaking Switzerland. *BMC Public Health* 2010;22:10.
- Levi F, Bosetti C, Fernandez E, Hill C, Lucchini F, Negri E, et al. Trends in lung cancer among young European women: the rising epidemic in France and Spain. *Int J Cancer*. 2007; 121(2), 462–5.
- Curtin F, Morabia A, Bernstein M. Smoking behavior in a Swiss urban population: the role of gender and education. *Prev Med*. 1997;26(5):658–63.
- Sasco AJ. Epidemiology of breast cancer: an environmental disease? *Apmis*. 2001;109(S103):S80–92.
- Dratva J, Zemp E, Staedele P, Schindler C, Constanza MC, Gerbase M, et al. Variability of reproductive history across the Swiss SAPALDIA cohort-patterns and main determinants. *Ann Hum Biol*. 2007;34(4):437–53.
- Federal Statistical Office, National Institute for Cancer Epidemiology and Registration, and Swiss Childhood Cancer Registry. Cancer in Switzerland: situation and development from 1983 to 2007. Neuchâtel: Federal Statistical Office; 2011.
- Wanner P, Raymond L, Bouchardy C. Geographical disparities in self-reported use of mammography and breast self-examination according to the Swiss Health Survey. *Ann Oncol*. 2001;12(4):573–4.
- D'Ambrosio GG, Campo S, Cancian M, Pecchioli S, Mazzaglia G. Opportunistic prostate-specific antigen screening in Italy: 6 years of monitoring from the Italian general practice database. *Eur J Cancer Prev*. 2010;19(6):413–6.
- Richard A, Faeh D, Rohrmann S, Braun, J, Tarnutzer S, Bopp M. Italianity is associated with lower risk of prostate cancer mortality in Switzerland. *Cancer Causes Control*. 2014; 25(11):1523–9.
- Stamatiou K, Skolarikos A. Rural residence and prostate cancer screening with prostate-specific antigen. *Rural Remote Health*. 2009;9:1227.
- Yang L. Incidence and mortality of gastric cancer in China. *World J Gastroenterol*. 2006;12(1):17–20.
- Aguilar I, Compes L, Feja C, Rabanaque MJ, Martos C. Gastric cancer incidence and geographical variations: the influence of gender and rural and socioeconomic factors, Zaragoza (Spain). *Gastric Cancer*. 2013;16(2):245–53.
- Maggi-Solca N, Valsangiacomo C, Piffaretti JC. Prevalence of *Helicobacter pylori* resistant strains in the southern part of Switzerland. *Clin Microbiol Infect*. 2000;6(1):38–40.

- 30 American College of Chest Physicians. Poverty, rural living linked to increased COPD mortality in the US. Glenview: American College of Chest Physicians; 2012.
- 31 Jensen HH, Godtfredsen NS, Lange P, Vestbo J. Potential misclassification of causes of death from COPD. *Eur Respir J*. 2006;28(4):781–5.
- 32 Lozano R, Murray CJL, Lopez AD, Satoh T. Miscoding and misclassification of ischaemic heart disease mortality. Geneva: World Health Organization; 2001 (Global Programme on Evidence for Health Policy, Working Paper No. 12).
- 33 Panczak R, Galobardes B, Voorpostel M, Spoerri A, Zwahlen M, Egger M. A Swiss neighbourhood index of socioeconomic position: development and association with mortality. *J Epidemiol Community Health*. 2012;66(12):1129–36.
- 34 Spoerri A, Zwahlen M, Egger M, Bopp M. The Swiss National Cohort: a unique database for national and international researchers. *Int J Public Health*. 2010;55(4):239–42.
- 35 Clough-Gorr KM, Egger M, Spoerri A. A Swiss paradox? Higher income inequality of municipalities is associated with lower mortality in Switzerland. *Eur J Epidemiol*. 2015;1–10.

Appendix

[Appendix \(PDF file\)](#)

Figures (large format)

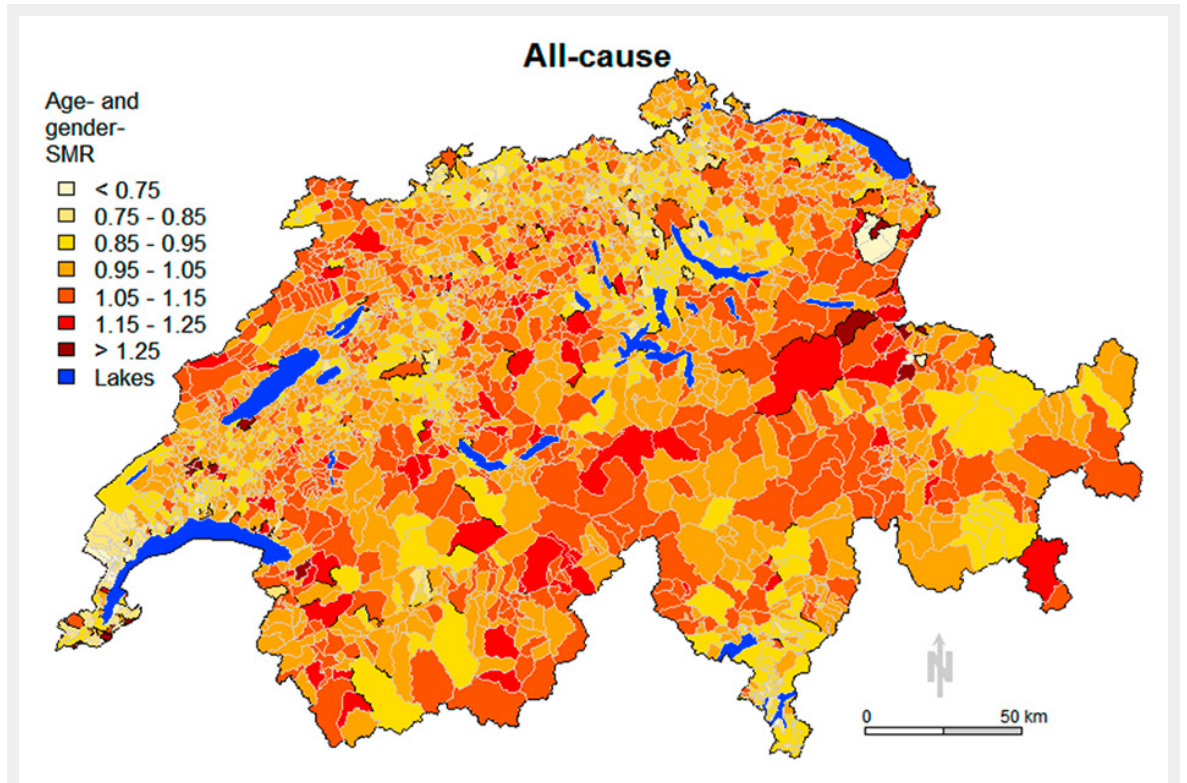


Figure 1
Geographical distribution of all-cause mortality risk in Switzerland, 2008–2012.

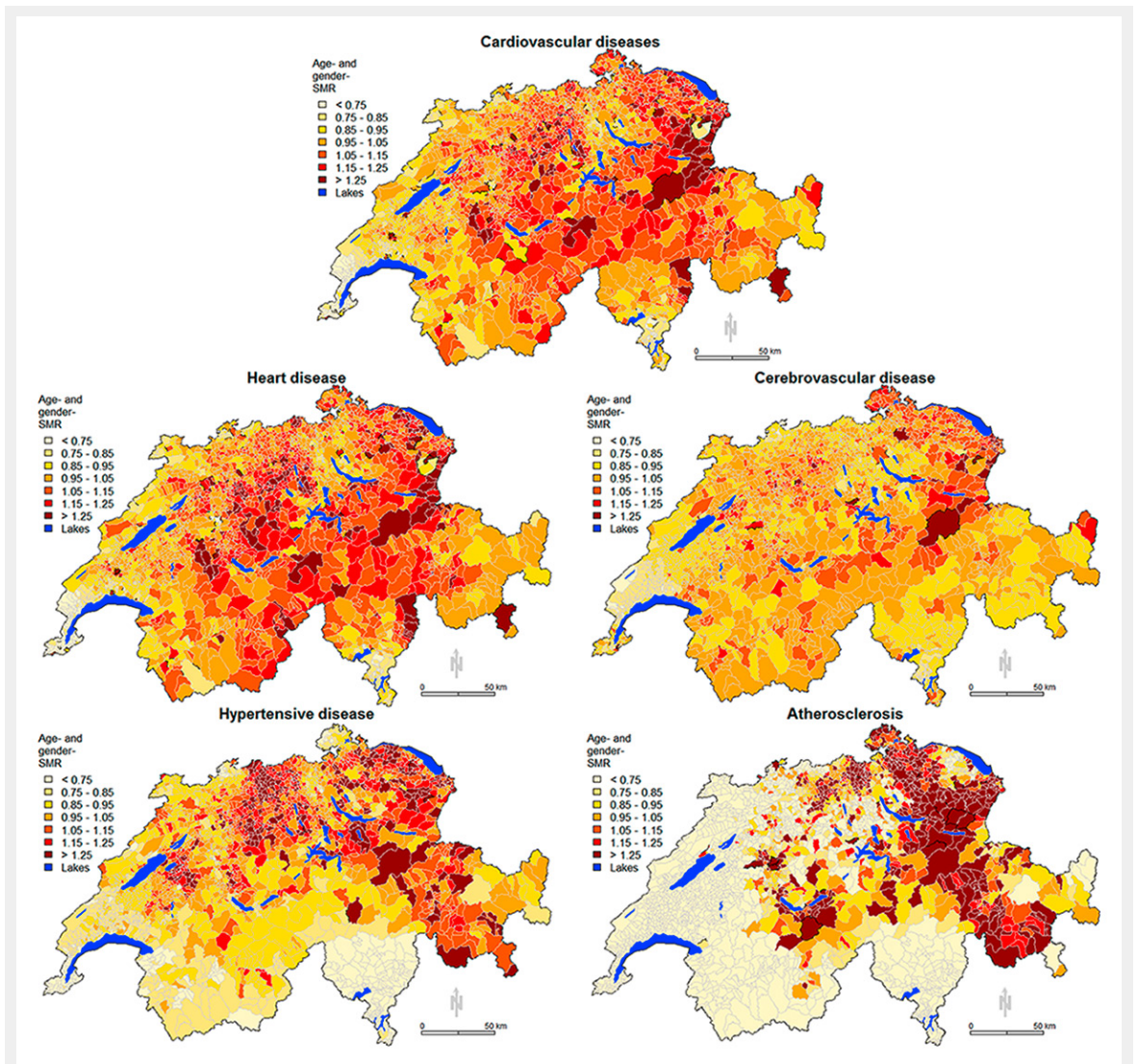


Figure 2
Geographical distribution of mortality risk due to cardiovascular diseases in Switzerland, 2008–2012.

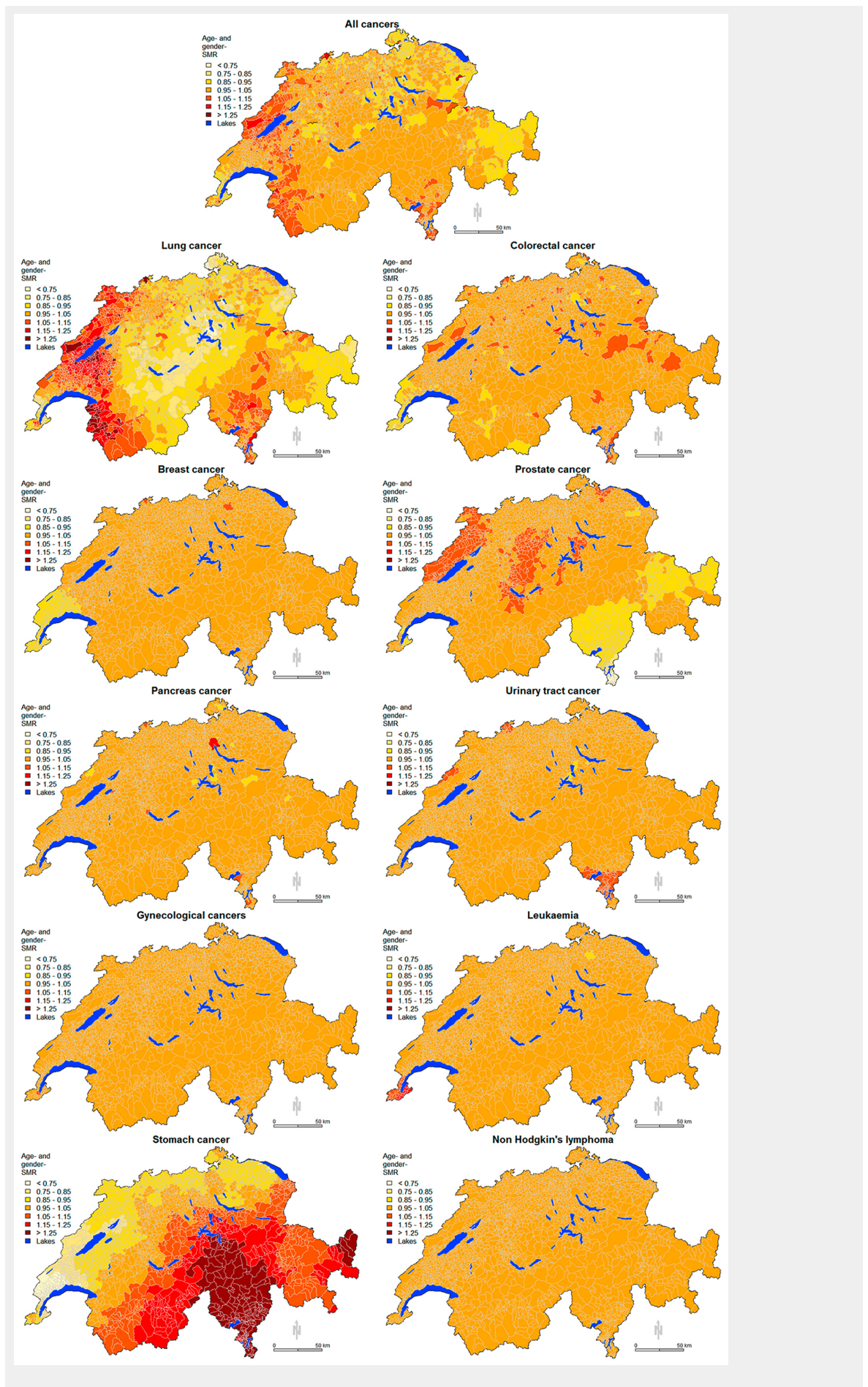


Figure 3
Geographical distribution of mortality risk due to cancers in Switzerland, 2008–2012.

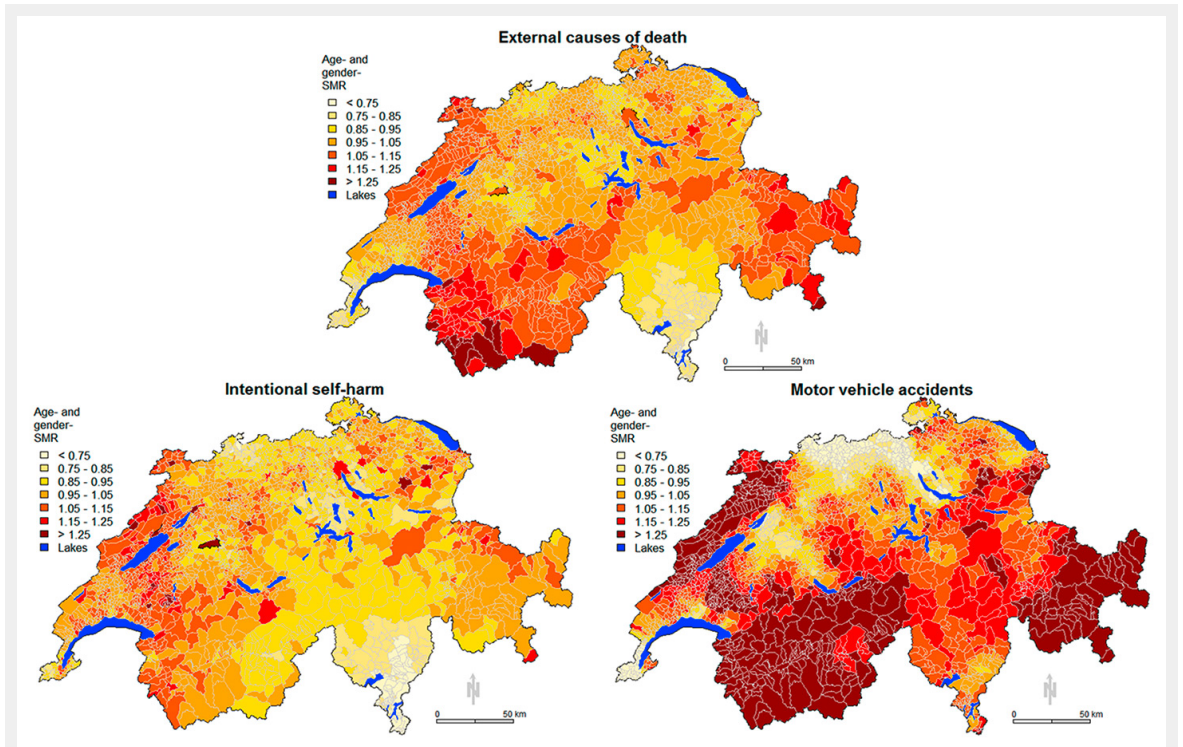


Figure 4
Geographical distribution of mortality risk due to external causes in Switzerland, 2008–2012.

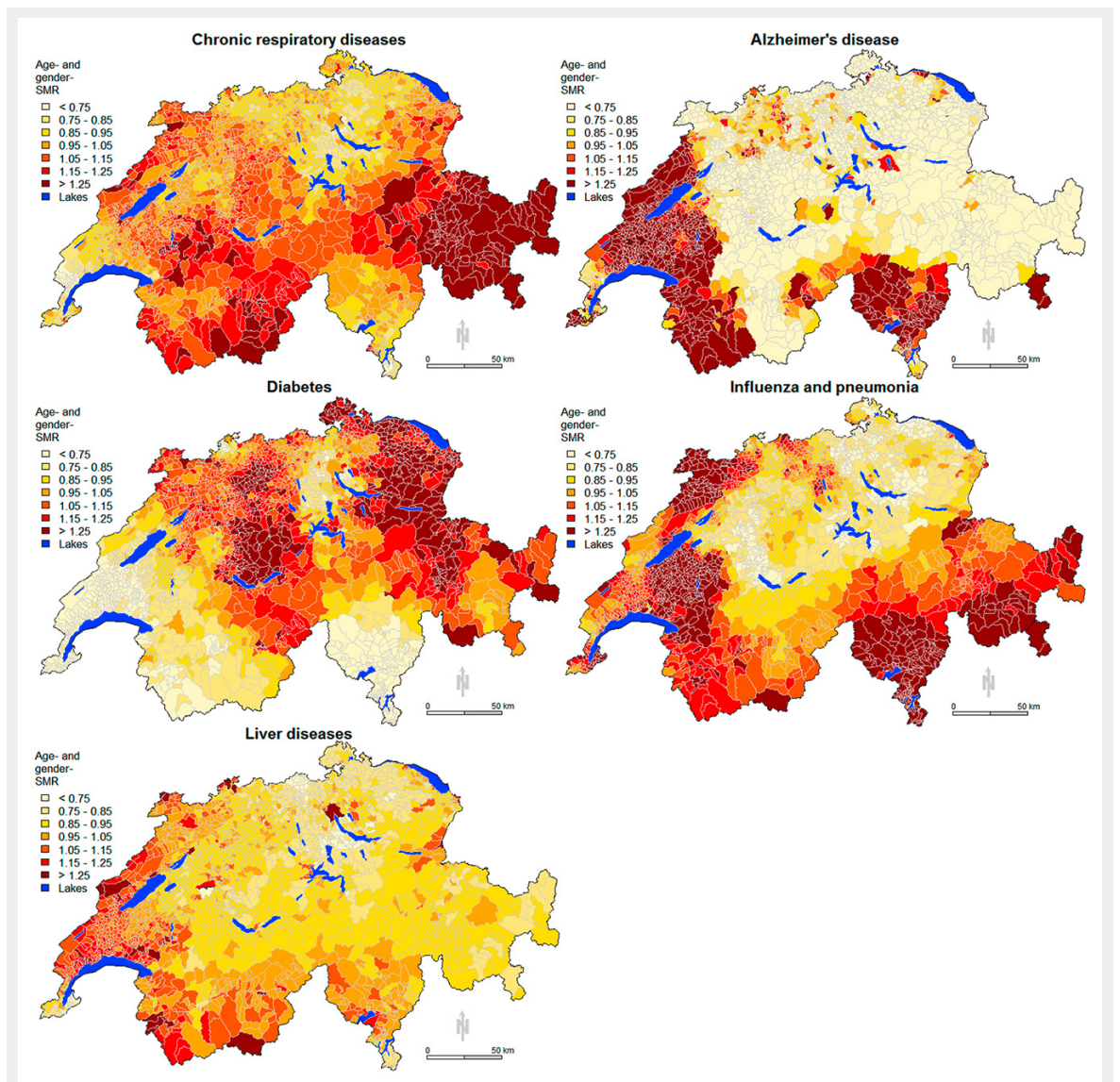


Figure 5
Geographical distribution of mortality risk due to other causes in Switzerland, 2008–2012.