

Mortality atlas of the main causes of death for the elderly population (≥ 75 years) in Switzerland during 2010–2020

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Summary

BACKGROUND: Mortality atlases provide insight into the health burdens a society is facing and help visualise them spatially. Here we estimate the geographical distribution of different mortality causes in the elderly population (≥ 75 years) in Switzerland. Knowledge of the spatial patterns enables better identification of high-risk areas for specific causes of death and potential risk factors, and can help guide policy, allocate resources and raise awareness in a more targeted manner.

METHODS: We analysed Swiss mortality data, provided by the Swiss Federal Statistical Office, for the elderly population (≥ 75 years) for the period 2010–2020. We employed Bayesian spatial models for areal data to produce smoothed maps presenting the age- and sex-adjusted standardised mortality rates for the 25 main causes of death at the municipality level. Additionally, we evaluated the effects of language, urbanisation and income levels on cause-specific mortality.

RESULTS: Language regions are associated with mortality rates for many causes of death. In particular, the French- and Italian-speaking regions are associated with a lower burden of mortality due to cardiovascular diseases and diabetes compared to German-speaking Switzerland, but this is offset by increased rates of certain cancers. In 2020, most COVID-19 deaths were concentrated in the French- and Italian-speaking regions. Higher income levels tend to be a protective factor for most causes of death.

CONCLUSIONS: We have provided the first model-based mortality maps focusing on the elderly population (≥ 75 years) in Switzerland. Our estimates identify areas with the highest cause-specific mortality rates and indicate potential health services that are needed in specific areas. The maps can also raise awareness of the most prominent health problems of the ageing population in different parts of the country and guide targeted health interventions.

Introduction

Switzerland is a culturally heterogeneous country composed of 26 cantons, each with relative autonomy in legislating in healthcare-related matters. This decentralised approach has led to differences in the design of health policies regarding healthcare premium burden and tax systems, especially affecting healthcare spending per wage bracket [1]. Although the impact of these discrepancies on overall healthcare provisions may be relatively small, it is important to uncover reasons for varying health outcomes in an ageing population [2]. The country's unique linguistic diversity, with a German-speaking population of 62%, a French-speaking population of 23%, an Italian-speaking population of 8% and 0.5% speaking Romansh presents further challenges for effective healthcare delivery such as communication difficulties due to language barriers between health professional and patient, cultural differences or stereotyping [3, 4]. Knowledge of the geographical distribution of the cause-specific mortality rates, particularly among the elderly population, can help physicians, nurses, healthcare professionals and policymakers allocate resources and expertise more effectively. A recurring analysis of spatial variations in health demands can also identify current environmental, societal or cultural risk factors, which may provide a basis for locally adapted preventive measures. This study presents a mortality atlas for Switzerland between 2010 and 2020, focusing on geographical and chronological distribution of the causes of death for the population aged 75 years or older. In 2019, the population aged 75 years or older accounted for 9% of the Swiss population but contributed to 72% of deaths in Switzerland, with cardiovascular disease and cancer being the leading causes. With increased healthy ageing, the Swiss population is living and working longer. In Switzerland, the 65–74 year age group spends more on transport, leisure, food and health than any other age group. However, from 75 years of age, there is a shift of spending more on healthcare [5]. We investigated mortality in this more elderly population aged 75 years or over as this is an often

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underrepresented age group that is particularly vulnerable and requires extensive healthcare.

The Swiss healthcare system is globally recognised for its outstanding performance in various areas, including mandatory health insurance coverage for the entire population and subsidies for lower-income individuals. These factors have contributed to Switzerland's position as one of the European countries with the highest life expectancy [6, 7]. In terms of decision-making power, there are several political actors involved, such as three levels of government (federal, cantonal and municipal), recognised civil society organisations like associations of health insurers and healthcare providers and the Swiss people themselves, who can use public referendums to veto or demand reform. The Swiss federal government regulates vital aspects of healthcare, such as financing through mandatory health insurance; pharmaceutical and medical device safety; infectious disease control; food safety; health promotion; and research and training [8, 9]. Meanwhile, the provision of healthcare services is regulated at the cantonal level, although hospitals from other cantons may also be included in their list of healthcare providers. Cantons finance approximately half of inpatient care. They are also responsible for issuing and implementing a significant portion of health-related legislation and conducting prevention and health promotion activities. To coordinate their efforts, particularly for highly specialised medical care, the cantons collaborate through the Conference of the Cantonal Ministers of Public Health [10–12].

The investigation of the geographical distribution of cause-specific mortality has become a classic approach in epidemiological research. Various studies that related mortality to environmental, socioeconomic, geographic or resource-dependent factors have shown that causes of death and mortality rates may vary by age, sex or region. In Europe, Italy, Spain and Germany have been most active in performing geospatial analyses of mortality data. While Spain mainly focused on the spectrum of different cancer types [13–16], Germany has paid additional attention to diabetes-related deaths [17–19]. Instead of narrowing it down to a specific cause of death, in Italy, a municipality-specific atlas was produced, providing information about the responsible factors behind all-cause mortality [20, 21]. Since the 1990s, mortality studies have become increasingly popular in Switzerland and have been conducted with a particular focus on selected population groups, specific causes of death or with regard to various explanatory variables. In 1997, the first descriptive mortality atlas in Switzerland was obtained by visualising the geographical distribution of all-cause standardised mortality rates (SMRs) [22]. Then the first mortality atlas for Switzerland was produced using modelling techniques to smooth the standardised mortality rate estimates and explanatory variables to assess potential reasons behind the spatial patterns observed [23]. The maps were produced for numerous causes of death as well as for all-cause mortality. Cause-specific mortality was analysed for coronary heart disease or stroke, and compared between citizens from the highlands and lowlands [24], and the number of deaths from lung cancer has also been analysed in smokers and non-smokers [25]. Additionally, mortality rates were compared between migrants and native-born citizens [26] or between

citizens of the French or German language regions [27]. Education, traffic noise, air pollution and altitude were suggested as factors contributing to the observed disparities in mortality rates [24, 28, 29]. Deaths related to myocardial infarctions and cancer were also examined [29, 30]. The latter was also mapped, but only taking into account mortality due to breast cancer among the female population [31, 32].

Our aim was to assess the regional and temporal patterns of mortality among the elderly population aged 75 years or older in Switzerland, and to contribute to the understanding of factors that influence mortality. Consequently, we estimated the space-time distribution of cause-specific mortality in Switzerland at the municipality level for the period 2010–2020, focusing on the elderly population (75 years of age or above). We analysed mortality data from the Swiss Federal Statistical Office and, using Bayesian spatial models, we estimated cause-specific standardised mortality rates at the municipality level, adjusted for age and sex. Using data from 2020, we also aimed to examine the spatial patterns of COVID-19 mortality in Switzerland. We further assessed changes in mortality for different periods and investigated how various sociodemographic factors are associated with the geographical distribution of the standardised mortality rates.

Methods

We estimated municipality-level cause-specific mortality for the elderly population (≥ 75 years) in Switzerland, focusing on the main causes of death between 2010 and 2020. We standardised the mortality rates for age and sex, and used Bayesian spatial models with random effects for areal data to account for the spatial correlation between municipalities and produce smoothed mortality maps. Bayesian spatial models for areal data filter variation due to noise and take into account potential spatial correlation in mortality rates between municipalities by introducing spatially structured random effects. The spatial correlation is modelled via conditionally autoregressive (CAR) models [33, 34] and modifications [35, 36] that are considered prior distributions for the random effects. The models leverage spatial similarities and construct smoothed estimates based on the spatial dependence structure [37]. Below, we outline the data sources, describe the computation of standardised ratios and present the methods used to produce the smoothed cause-specific mortality maps.

Mortality and population data

Mortality data for the 2010–2020 period were provided by the Federal Statistical Office. The data included information on the reported date of death, age, sex, the main and secondary causes of death, the municipality – “*Gemeinde*” in German – of the patient's residence and of death. The data did not include any personal identifiers; therefore, no additional data anonymisation or ethical considerations were required for the analysis. The cause of death was reported according to the International Classification of Diseases, volume 10 (ICD-10, <https://icd.who.int/browse10/2019/en>). As we analysed the cause-specific mortality, the deaths were classified into 39 causes as proposed by the Centres for Disease Control and Prevention for tabulating mortality data [38]. We further grouped the causes into

33 final groupings (summarised in table S1 in the appendix). We looked at major causes, i.e. those accounting for the death of at least 300 people aged 75 years or older in Switzerland every year over the last five years (2015–2019); as a result, 25 causes were used for modelling. We produced mortality atlases for two periods, namely 2010–2014 and 2015–2019. We considered two aggregated periods to overcome any small samples that may produce false patterns. As 2020 was an atypical year due to COVID-19, we only used it to assess the COVID-19 mortality patterns and excluded it when looking at the other causes of death.

Annual population data disaggregated by sex, age and municipality were extracted from the STAT-TAB interactive tables provided by the Federal Statistical Office. Switzerland comprises 26 cantons, which include a total of 143 districts (“*Bezirke*” in German). These districts are further subdivided into the aforementioned municipalities, which represent the lowest administrative division. In 2021, Switzerland comprised 2175 municipalities. The baseline maps with the municipality, district and cantonal borders, as well as lakes, were created using the 2021 swiss-BOUNDARIES3D product. The data were downloaded from the Federal Office of Topography (Swisstopo). Municipalities can undergo structural changes over time, the most common of which is the consolidation of several municipalities into one. These changes occur on a yearly basis so to be able to compare different municipalities through the years, we reshaped our population and mortality data to reflect the boundaries for 2021.

Spatial analysis at a municipality level

Standardised mortality rates

To compare the mortality rates between different municipalities, we used standardised mortality rates, adjusting for age and sex. Standardised mortality rates allow us to compare mortality rates of municipalities with the expected rates based on the reference population’s (Switzerland’s) demographic norms, adjusting for potential distribution differences. In particular, we compared the observed mortality with the expected mortality, in each age- and sex-specific stratum, calculated on the basis of the national mortality rates [39, 40]. We standardised using the indirect method as many strata in a municipality had too few observed deaths to obtain robust mortality rate estimates [41, 42]. Furthermore, the indirect standardisation approach is recommended when looking at within-country variation.

We adjusted for age and sex to account for potential differences in their distributions across municipalities [40]. Age was categorised and adjusted in 5-year bands from 75 to 100, and then in a sixth category for all those aged over 100. We used nationwide mortality rates for the age- and sex-specific strata of interest over the period of interest and applied them to the specific strata in the municipality to obtain the expected number of deaths. We then aggregated the expected and observed numbers over the different strata in the municipality and compared the expected deaths with the observed ones.

An SMR value of 1 indicates that the risk of death is the same as the reference (national) population; an SMR <1 means that the risk of death in the observed population is

lower than would be expected if its age and sex distribution were the same as the reference population, while an SMR >1 means that the risk is greater for the population observed [40]. A municipality’s SMR is considered statistically important if the 95% Bayesian credible interval (BCI) does not include 1.

Spatial models

To obtain smoothed maps for cause-specific standardised mortality rates, we used a Bayesian hierarchical model with spatial random effects. We assumed that the observed number of deaths for a given cause in municipality i follows a negative binomial distribution with cause- and municipality-specific probability of death:

$$Y_i \sim \text{NegBin}(p_i, r)$$

where

$$p_i = r / (r + \mu_i)$$

and relates to the mean number of deaths, μ_i ; and r , which captures the overdispersion. The model is formulated as follows:

$$\log(\mu_i) = \log(E_i) + X^T \beta + \omega_i$$

where μ_i is the mean number of deaths, E_i is the expected number of deaths, X is the matrix of observed covariates, β is the vector of the regression coefficients and ω_i is the spatial random effect for municipality i .

To explain some of the spatial variation seen in the mortality distribution maps, we modelled the cause-specific standardised mortality rates with the addition of covariates (matrix X). We used urbanisation, primary language and net income per capita of each municipality as provided by the Federal Statistical Office. These covariates are available from 2018 and were reshaped to the boundaries of 2021. The reference categories were set to the most frequent categories (*rural* for the Urbanisation covariate and *German* for the Language covariate). As Romansch-speaking areas make up fewer than 10% of the municipalities, these regions were merged with German-speaking ones [23]. The resulting coefficients (β s) are extracted in the form of a mortality risk ratio (MRR). An MRR expresses the mortality rate of people in a specific category compared with the mortality rate of people in the reference category. For example, an MRR of 1.2 for French-speaking Switzerland would mean that the mortality rate is 20% greater in the French-speaking regions than in the German-speaking regions. A covariate is considered statistically important if the 95% BCI for the MRR does not include 1.

To explore the nuances of the mortality data, we performed additional Bayesian spatial analysis for secondary cause of death as well as municipality of death, instead of residence. The analysis also included the addition of covariates to assess how the effects of covariates changes between the different data.

We modelled the municipality-specific random effects (ω_i) using the modified Besag-York-Mollié (BYM) formulation, which includes a structured spatial component and an unstructured one to account for the spatial correlation and non-spatial heterogeneity. The modified BYM approach allows for intuitive interpretations of the conditional mean and variance of the spatial random effects, unlike the original BYM model [36]. While there are other approaches

to modelling the spatial dependence [34, 35, 43, 44], the modified BYM approach generally performs as good as or even better than the commonly used approaches [36].

The BYM2 random effect is then constructed as

$$\omega = \frac{1}{\sqrt{\tau}} \left(\sqrt{1-\varphi} \mathbf{v} + \sqrt{\varphi} \mathbf{u}_* \right)$$

where φ is the mixing parameter, τ is the marginal precision parameter, $\mathbf{v}$ is the unstructured component and $\mathbf{u}_*$ the scaled, structured component.

The hyperparameters are represented as

$$\theta_1 = \log(\tau)$$

and

$$\theta_2 = \log\left(\frac{\varphi}{1-\varphi}\right)$$

and we used the penalised complexity priors with

$$Pr\left(\frac{1}{\sqrt{\tau}} > 1\right) = 0.01$$

and

$$Pr(\varphi < 0.5) = 0.5$$

respectively, as explained in Rieblar et al. (2016) [36]. All modelling was done in R-INLA [45].

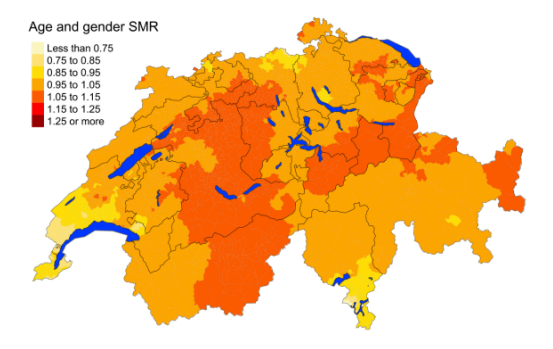
Results

Overall mortality and overview of cause-specific mortality

Between 2010 and 2020, there were 519,468 deaths among the elderly population aged 75 years or older in Switzerland. Approximately 45% of deaths occurred in a municipality other than the municipality of residence; 0.4% of deaths occurred outside Switzerland. The average number of deaths in the elderly, stratified by cause, sex and time period, are presented in table 1. Cardiovascular diseases, specifically heart diseases represent the leading cause of death among the elderly, followed by cancer, with lung cancer causing the most deaths in men and breast cancer in women. Falls also result in a lot of deaths among the elderly. Overall, men tend to have greater mortality rates than women for most causes in all three periods. Women have higher mortality rates for cerebrovascular disease, hypertensive disease, dementia, senility, falls, intestinal diseases, multiple sclerosis, breast cancer and gynaecological cancer. From 2010 to 2019, women also had a higher mortality rate from intestinal infections than men. The year 2020 had the highest mean number of deaths in the elderly per 100,000 people for both males and females. Many causes had lower mean deaths in 2020 compared to the other periods. Exceptions are that for women, deaths from lung cancer are increasing consistently across the periods. COVID-19 also emerged as a new cause of death in 2020.

Figure 1 depicts the spatial distribution of all-cause mortality for the period 2015–2019. Mortality rates have been adjusted for age and sex. We observe slightly increased mortality rates in eastern Valais, Bern, Glarus and parts of Graubünden, St. Gallen, Uri, Schwyz, Solothurn and Aargau. 2010–2014 additionally experienced a higher mortality rate in western Graubünden and central Switzerland (figure S2 in the appendix). Both periods experienced slightly decreased mortality rates in Geneva, southern Vaud and southern Ticino.

Figure 1: Spatial distribution of all-cause mortality for the elderly (≥ 75 years) in Switzerland for the period 2015–2019 adjusted for age and sex. Estimates represent posterior means (PM) of standardised mortality rate (SMR) obtained from a Bayesian conditionally autoregressive (CAR) model without covariates. The black borders delineate the different cantons.



Cardiovascular disease

Cardiovascular disease is the leading cause of mortality, accounting for 36% of deaths among the elderly population (≥ 75 years) of Switzerland in 2015–2019. Figure 2 shows that mortality for overall cardiovascular diseases is lower in the French- and Italian-speaking regions. Heart diseases are more concentrated in the German-speaking regions of Switzerland, with the exception of Graubünden. Cerebrovascular mortality is distributed more evenly throughout the country. Mortality from hypertensive diseases is higher in the German-speaking regions, with the French- and Italian-speaking regions showing standardised mortality rates less than 0.75. Atherosclerosis deaths are least prevalent in western Switzerland. The findings are consistent with the maps produced for the period 2010–2014 (figure S3 in the appendix).

Overall, mortality rates of cardiovascular diseases (heart disease, cerebrovascular disease, atherosclerosis and overall) are statistically lower in the French-speaking regions compared with the German-speaking regions, with mortality risk ratio 0.84 (95% MRR BCI: 0.782, 0.908) (figure S1 in the appendix). Both the French- and Italian-speaking regions have lower standardised mortality rates for hypertension compared to the German-speaking regions, with an MRR of 0.719 (95% MRR BCI: 0.567, 0.912) and 0.348 (95% MRR BCI: 0.205, 0.600), respectively. Regions with higher net income are associated with lower cardiovascular disease with mortality rate decreasing by 2.5% for every increase in municipality-level annual income by CHF 10,000 (95% MRR BCI: 0.965, 0.986). This protective effect of income is emphasised for heart disease. Rural areas compared to periurban and urban areas have higher overall cardiovascular disease deaths, particularly for heart disease. Urban areas have 9% lower mortality rates for overall cardiovascular disease compared to rural areas (95% MRR BCI: 0.883, 0.939).

Cancers

Figure 3 suggests that, overall, cancers are similarly distributed throughout Switzerland, with slightly higher overall standardised mortality rates in southern Ticino. However, the mortality rates from specific cancers vary greatly from region to region. Lung cancer seems to be more fre-

Table 1:Mean number of deaths in the elderly (≥ 75 years) in Switzerland per 100,000 people, stratified by cause, sex and time period.

Causes of death		2010–2014		2015–2019		2020	
		Female	Male	Female	Male	Female	Male
Cardiovascular diseases		2656	2772	2369	2369	2155	2195
	Heart disease	1927	2084	1719	1796	1507	1654
	Cerebrovascular disease	488	450	423	375	401	349
	Hypertensive disease	134	84	135	81	167	88
	Atherosclerosis	107	153	91	118	80	104
All cancers		803	1554	812	1434	771	1327
	Brain cancer	15	26	15	29	18	27
	Breast cancer	161	1	163	2	147	2
	Colorectal cancer	122	197	111	171	99	157
	Gynaecological cancers	87	NA	81	NA	74	NA
	Liver cancer	28	70	28	77	26	69
	Lung cancer	108	315	125	276	136	246
	Melanoma and skin cancer	26	51	26	50	23	55
	Oesophageal, stomach cancer	42	109	40	96	42	85
	Pancreatic cancer	87	92	96	102	90	96
	Prostate cancer	0	411	0	357	NA	321
	Urinary tract cancer	52	155	51	151	45	148
	Non-Hodgkin's lymphoma	38	59	39	59	39	61
	Leukaemia	39	67	39	65	33	60
External causes		222	260	216	251	211	225
	Intentional self-harm	10	52	10	49	12	43
	Fall	212	208	207	202	199	182
COVID-19		NA	NA	NA	NA	867	1206
Chronic respiratory disease		160	313	165	260	127	192
Dementia		933	642	976	628	918	609
Diabetes		144	156	124	145	90	115
Influenza and pneumonia		172	213	203	248	145	186
Intestinal infections		18	15	23	16	16	18
Intestinal diseases		113	87	97	74	85	62
Liver diseases		17	39	17	33	15	32
Multiple sclerosis		7	4	8	5	6	5
Parkinson's		69	135	66	136	63	111
Renal failure		63	84	76	89	88	101
Senility		84	44	85	49	71	43
Sepsis		18	22	19	22	18	26
Spinal muscular atrophy		10	14	10	15	10	12
All other causes		966	1105	1040	1163	1096	1232
All causes		6454	7451	6297	6929	6753	7698

quent in the Italian- and southern French-speaking regions, with mortality rate ratios of 1.260 (95% MRR BCI: 1.087, 1.449) and 1.102 (95% MRR BCI: 1.015, 1.207), respectively. Urinary tract cancer deaths are more prevalent in southern Ticino. Gynaecological cancer deaths are more prevalent in Jura, Neuchâtel, Vaud and eastern Graubünden. Deaths from prostate cancer appear to be more frequent in central and northwestern Switzerland. Non-Hodgkin's lymphoma deaths are higher in Ticino, western Graubünden and Valais, but lower in the northwestern Swiss cantons of Zurich, Schaffhausen, St Gallen and Appenzell. Liver cancer has the greatest contrast in its standardised mortality rates: the French- and Italian-speaking municipalities and surrounding regions face a much higher burden of deaths from liver cancer than the German-speaking regions, with the Italian-speaking municipalities facing almost twice the mortality rate (95% MRR BCI: 1.412, 2.610). Colorectal cancer deaths are slightly more prevalent in Neuchâtel, but overall they are distributed evenly. Cancers of the pancreas, breast, oesophagus and stomach,

and leukaemia do not have notable disparities in their spatial distributions.

For the period 2010–2014, there was a much higher burden of deaths from oesophageal and stomach cancer in southern Switzerland, with deaths being highly concentrated in the cantons of Ticino, Graubünden and Valais (figure S4 in the appendix). Some other differences from the maps for 2010–2014 include decreasing spatial differences in the standardised mortality rates for lung and prostate cancer, as well as leukaemia. On the other hand, non-Hodgkin's lymphoma and gynaecological cancer deaths have increased in their spatial heterogeneity.

Cause-specific mortality rates were highly associated with language regions (figure S1 in the appendix). French- and Italian-speaking regions have statistically higher standardised mortality rates for deaths due to liver and lung cancer, with the Italian-speaking regions experiencing almost twice the mortality rates of liver cancer (95% MRR BCI: 1.412, 2.626) compared to the German-speaking regions. The Italian-speaking regions face a greater burden of overall cancer mortality with a mortality risk ratio of 1.098

(95% MRR BCI: 1.036, 1.163), also specific to urinary tract cancers. Additionally, colorectal and pancreatic cancer mortality rates are higher in urban areas. Lung and urinary tract deaths are more common in urban and periurban areas. With increasing net income, we observed fewer deaths from overall cancer. Specifically, municipality-level net income showed a protective factor for lung and stomach and oesophageal cancer, with a decrease in mortality rates by approximately 5% for an increase in annual net income in the municipality by CHF 10,000 (95% MRR BCI: 0.926, 0.970 and 95% MRR BCI: 0.920, 0.990, respectively).

Figure 2a: Cardiovascular diseases: Spatial distribution of cardiovascular disease mortality for the elderly (≥ 75 years) in Switzerland for the period 2015–2019 adjusted for age and sex. Estimates represent posterior means (PM) of standardised mortality rate (SMR) obtained from a Bayesian conditionally autoregressive (CAR) model without covariates. The black borders delineate the different cantons.

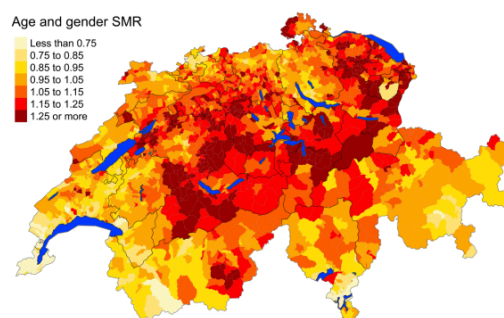


Figure 2b: Heart diseases.

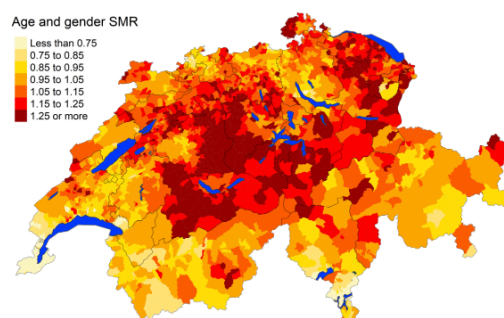


Figure 2c: Cerebrovascular diseases.

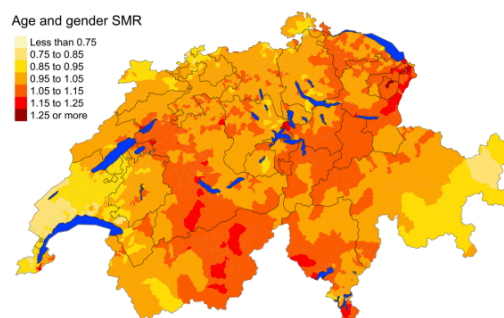


Figure 2d: Hypertensive diseases.

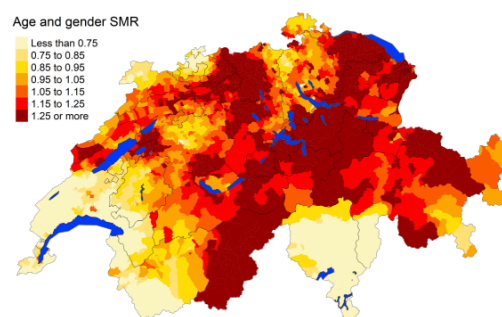


Figure 2e: Atherosclerosis.

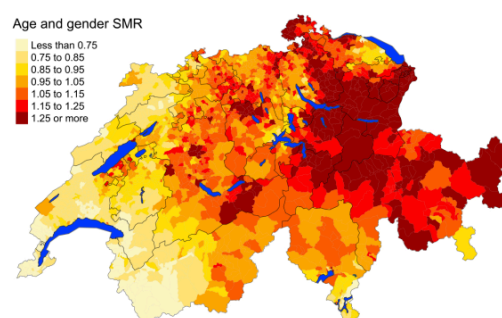


Figure 3a: All cancers: Spatial distribution of cancer mortality for the elderly (≥ 75 years) in Switzerland for the period 2015–2019 adjusted for age and sex. Estimates represent posterior means (PM) of standardised mortality rate (SMR) obtained from a Bayesian conditionally autoregressive (CAR) model without covariates. The black borders delineate the different cantons.

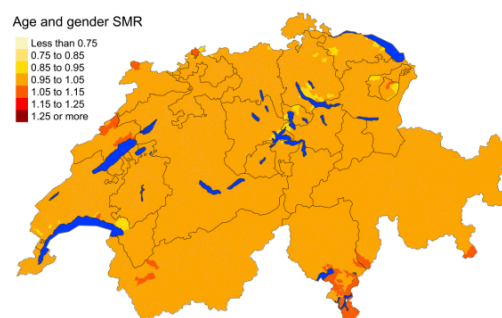
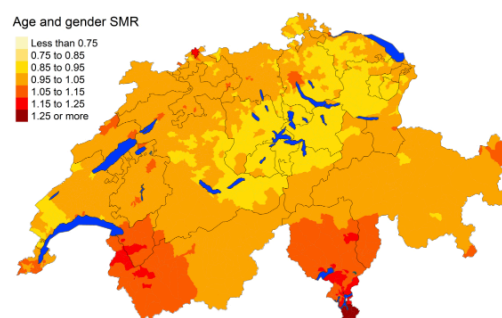


Figure 3b: Lung cancer.



Additional causes

There is a clear spatial disparity in deaths from COVID-19 in the elderly aged 75 years or older (figure 4). Most deaths are concentrated in the French- and Italian-speaking re-

gions. Further looking into the secondary and tertiary causes reported for deaths from COVID-19, the most common comorbidities are diseases of the circulatory and respiratory systems (figure S6 in the appendix). French- and Italian-speaking regions have statistically higher standardised

Figure 3c: Colorectal cancer.

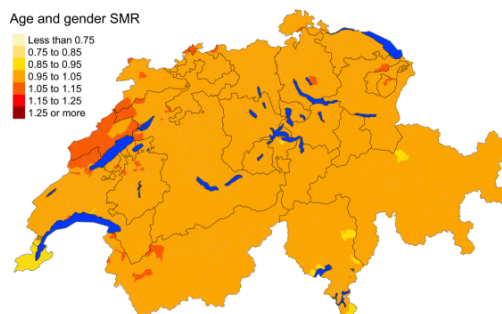


Figure 3g: Urinary tract cancer.

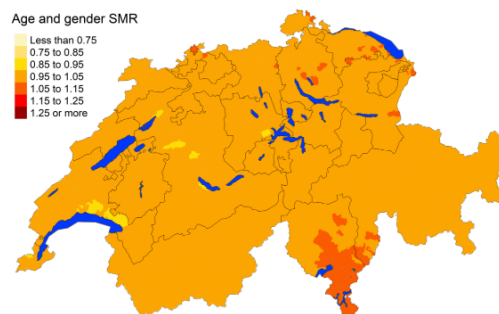


Figure 3d: Breast cancer.

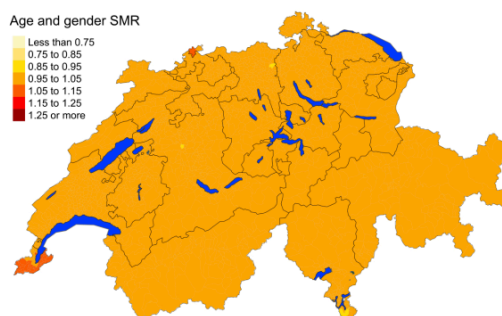


Figure 3h: Gynaecological cancer.

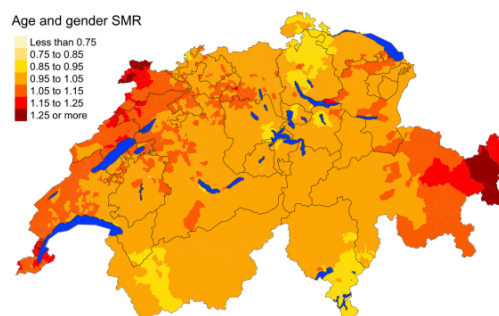


Figure 3e: Prostate cancer.

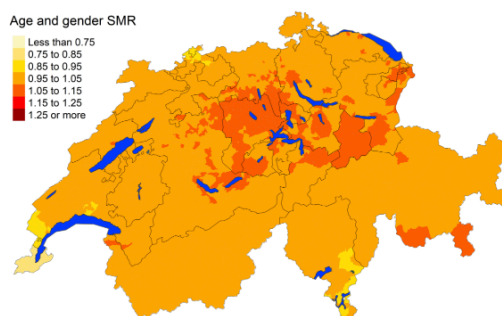


Figure 3i: Leukaemia.

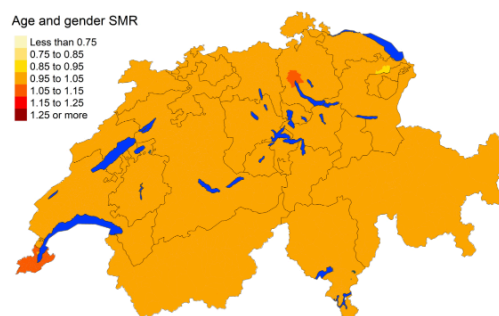


Figure 3f: Pancreas cancer.

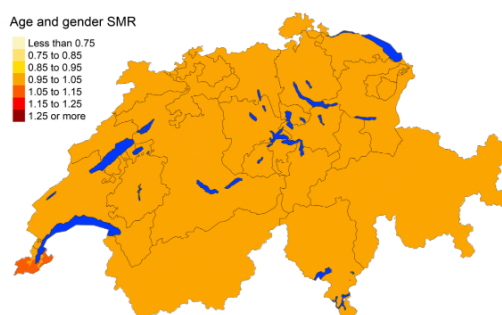
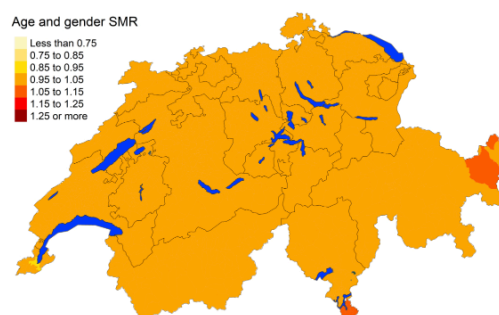


Figure 3j: Oesophagus and stomach cancer.



mortality rates for COVID-19 deaths than the German-speaking regions (figure S1 in the appendix). The French-speaking regions face almost 6.5% greater mortality rates than the German-speaking regions, while the Italian-speaking regions almost 7.8% greater mortality rates.

Maps of all additional main causes are shown in figure 5. Chronic respiratory disease deaths are more prevalent in southern Switzerland. Deaths from senility are generally high, except in Vaud and Neuchâtel and parts of central Switzerland, Solothurn, Basel-Stadt, Basel-Landschaft and Zurich. The German-speaking regions have a higher mortality from diabetes compared to the French and Italian regions, with the exception of Zurich, which also has lower deaths from diabetes. In contrast, the French- and Italian-speaking regions have greater deaths from influenza and pneumonia. Falls are less prevalent in the French- and Italian-speaking regions. Intestinal disease mortality is spread evenly through the country. Parkinson's disease deaths are slightly lower in Ticino, Vaud and western Valais. Results are similar for maps constructed for 2010–2014, with the exception of renal failure, where 2010–2014 deaths were concentrated in southwestern Switzerland while 2015–2019 deaths were more prevalent in northwestern Switzerland and parts of Graubünden (figure S5 in the appendix).

There is a negative association between mortality rates from diabetes, chronic respiratory diseases, influenza and pneumonia and intestinal diseases with income (figure S1 in the appendix). In contrast, higher income areas do have greater deaths from Parkinson's disease. Mortality rates of dementia are 8% greater in urban areas compared to rural areas (95% MRR BCI: 1.021, 1.14). On the other hand, the French- and Italian-speaking regions have statistical-

ly lower standardised mortality rates compared to the German-speaking regions for falls, diabetes and renal failure. The Italian-speaking communities face almost 70% higher mortality rates from influenza and pneumonia (95% MRR BCI: 1.268, 2.247).

Statistically significant mortality maps

Figures S11 to S15 show municipalities with a statistically significant standardised mortality rate. Statistically, a few municipalities in Ticino, Geneva and Vaud experienced

Figure 4: Spatial distribution of COVID-19 mortality for the elderly (≥ 75 years) in Switzerland for 2020 adjusted for age and sex. Estimates represent posterior means (PM) of standardised mortality rate (SMR) obtained from a Bayesian conditionally autoregressive (CAR) model without covariates. The black borders delineate the different cantons.

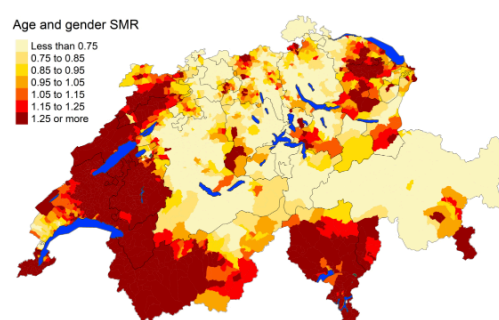


Figure 5a: Chronic respiratory disease: Spatial distribution of additional causes of mortality for the elderly (≥ 75 years) in Switzerland for the period 2015–2019 adjusted for age and sex. Estimates represent posterior means (PM) of standardised mortality rate (SMR) obtained from a Bayesian conditionally autoregressive (CAR) model without covariates. The black borders delineate the different cantons.

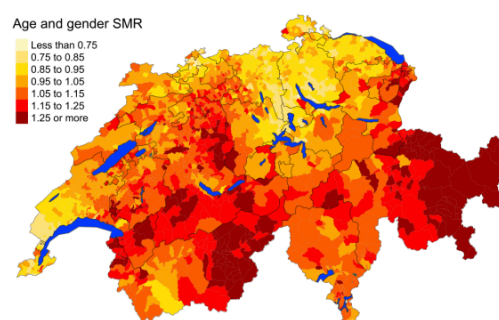


Figure 3k: Non-Hodgkin's lymphoma.

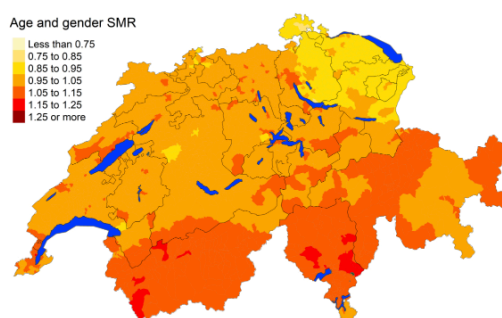


Figure 3l: Liver cancer.

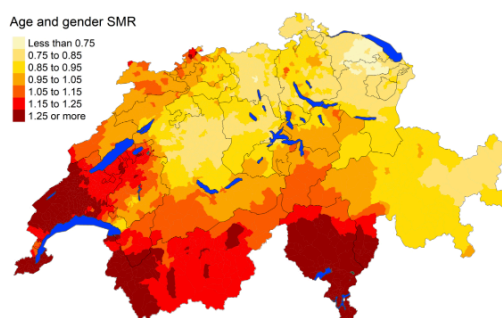
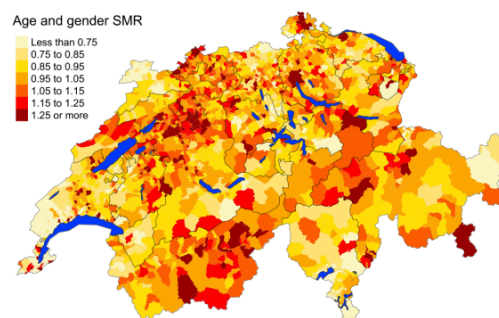


Figure 5b: Dementia.



lower mortality rates for all-cause mortality compared with the national mortality rates. The differences between regions for cerebrovascular mortality are not statistically significant. However, all other cardiovascular disease causes show statistically lower mortality rates in the French- and

Italian-speaking regions, while the German-speaking regions have higher rates. For cancers, Ticino has multiple municipalities with mortality rates statistically higher than the national average for liver cancer. On the other hand, Geneva's municipalities have lower mortality rates for prostate cancer. Ticino has statistically lower mortality rates for diabetes and falls, but higher rates for influenza and pneumonia. The French- and Italian-speaking regions have statistically higher mortality rates due to COVID-19, while the German-speaking regions have lower rates.

Mortality based on secondary causes

We also produced maps based on secondary causes and looked at the effects of covariates (figure S8 in the appendix). We highlighted the spatial maps for mortality due to liver and lung cancer (figure S7 in the appendix). While the spatial distribution of mortality due to liver cancer as a secondary cause is similar to that due to liver cancer as a primary cause, the distribution is complementary for lung

Figure 5c: Senility.

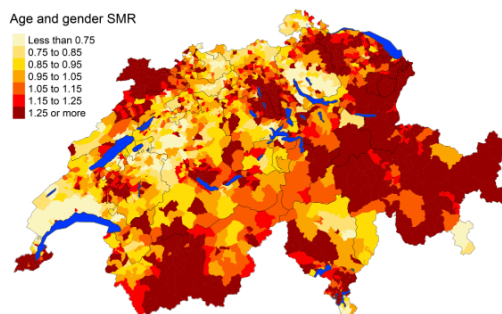


Figure 5d: Diabetes.

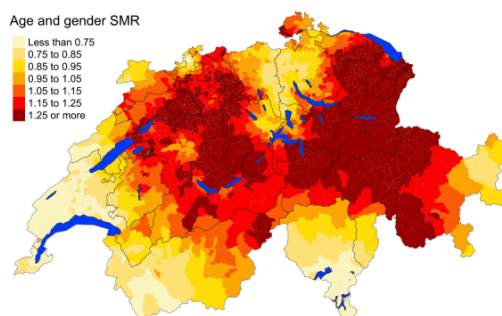


Figure 5g: Intestinal disease.

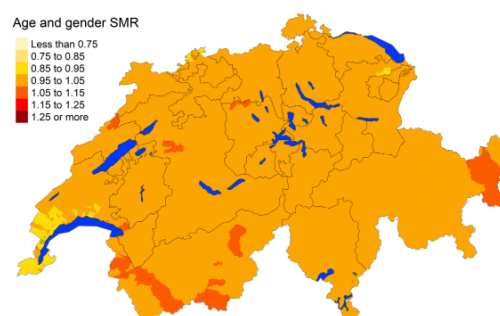


Figure 5e: Influenza and pneumonia.

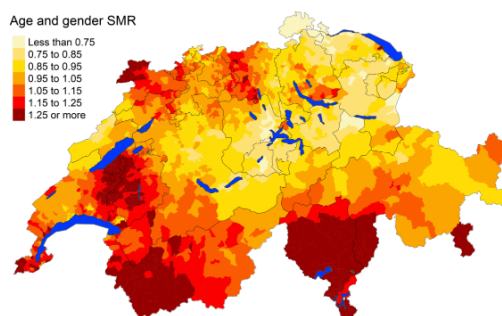


Figure 5h: Parkinson disease.

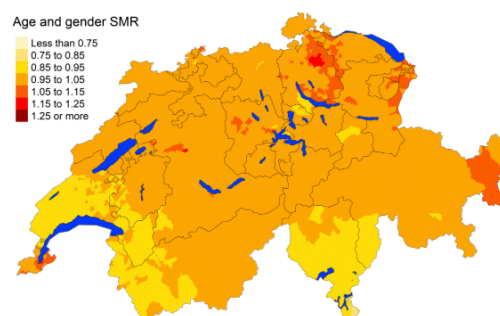


Figure 5f: Falls.

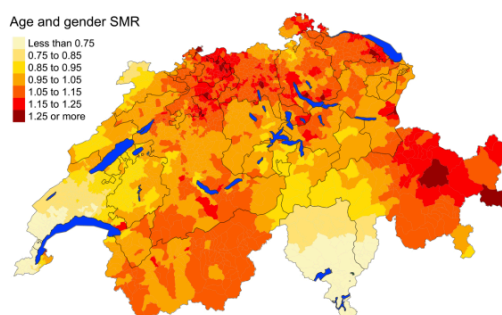
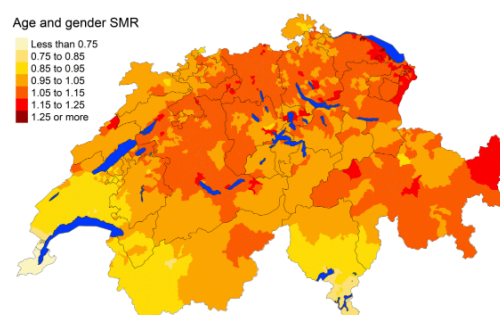


Figure 5i: Renal failure.



cancer. All French-speaking regions have a lower mortality rate compared to German-speaking regions for all secondary causes except liver cancer.

Mortality based on municipality of death

Finally, we produced maps based on the municipality of death and looked at the effects of covariates (figure S10 in the appendix). We highlighted the spatial maps for mortality due to cardiovascular disease and lung cancer (figure S9 in the appendix). The spatial distribution for cause-specific mortality when looking at municipality of death is heterogeneous, with a fraction of municipalities accounting for a large number of deaths. There is an association with urbanisation for all causes, except for deaths occurring from senility and hypertensive diseases.

Discussion

Our study offers a contemporary overview of mortality patterns in Switzerland for the elderly population (aged 75 years or over) between 2010 and 2020, and provides a comprehensive analysis of the spatial distribution of potential risk factors. We used Bayesian spatial models for areal data to generate smoothed maps of standardised mortality rates at the municipality level for a wide range of mortality causes, including COVID-19 mortality in 2020. Switzerland is a culturally heterogeneous country with regional variations in healthcare services due to various factors. Differences in demand-side factors, such as demographic structure, patient attitudes and socioeconomic living conditions, as well as supply-driven variation such as medical guidelines, funding schemes and differences in access to care, can contribute to regional variations in healthcare services [46]. We assessed geographical disparities in standardised mortality rates related to urbanisation, income and language regions. Our study underscores the importance of considering the spatial distribution of mortality and associated risk factors when developing public health interventions and highlights the need for targeted interventions in areas with high cause-specific mortality rates.

The mortality rates of overall cardiovascular diseases were statistically lower in the French-speaking regions of Switzerland compared to the German-speaking regions, by 16% (95% MRR BCI: 0.775, 0.909). These results were particularly pronounced for hypertensive diseases and atherosclerosis and, to a lesser extent, heart diseases. The Swiss Health Survey of 2017 found that residents of German-speaking Switzerland are significantly more likely to meet the physical activity recommendations (79%) than people living in Italian-speaking (68%) and French-speaking (67%) parts of the country [47]. However, the Swiss Health Observatory (Obsan) conducted a study on socioeconomic and cultural inequalities in the health behaviour of the Swiss population and found that the German-speaking population recorded a higher proportion of obese individuals and a higher average BMI compared to the French-speaking population [48]. These findings from Obsan align with a comparison among EU member states, which reported overweight rates of 46% among Italian adults and 47% among French adults, while in Germany, the rate was considerably higher at 54% [49]. As obesity was described as one of the main causes of high blood pressure, diabetes and subsequent heart problems [50–52], this pattern is re-

flected in the geographic distribution of mortality due to these diseases.

There is some evidence that moderate wine consumption may be inversely associated with cardiovascular mortality [53–55]. As wine consumption in the French-speaking regions is significantly higher compared to the rest of Switzerland, it could further explain why mortality rates due to cardiovascular diseases were lower in western Switzerland [56]. Similar findings supporting the positive effect of moderate wine consumption in terms of heart disease mortality have been reported in France [57, 58]. Overall, France was identified as the European country with the lowest mortality rates for stroke and ischaemic heart disease [59], which is also reflected in the geographical pattern of the Swiss heart mortality maps. Within Switzerland, a study investigating the Mediterranean diet and mortality observed that alcohol consumption was associated with a decrease in cardiovascular disease mortality [60]. Additionally, a study investigating the differences in mortality between the Swiss German- and French-speaking regions between 1990 and 2000 also observed similar results with reduced risk from cardiovascular disease mortality, but increased risk from some cancers. These studies looked at extended dietary factors such as vegetable intake, fat intake and physical activity, among others. Even after accounting for these factors, there is a protective effect of alcohol on coronary heart disease and stroke that is observed in many French-speaking regions, though this effect may be influenced by a healthier lifestyle [27].

Another factor that tends to play a beneficial role in reducing the risk of cardiovascular disease is urbanisation, with urban areas having mortality rates almost 9% lower than rural areas (95% MRR BCI: 0.885, 0.946). Urban areas have been shown to be linked to fewer deaths from heart diseases [61–63]. This finding may be due to the generally higher socioeconomic standards of people living in urban regions, such as Basel, Bern, Zurich or Geneva, compared to the rural population of Switzerland. Families in lower income categories were found to engage in less physical activity and have unhealthier diets, which are important risk factors in the development of heart disease [48]. In addition, a Swiss study investigating driving times and cardiovascular mortality found that for those above 65 years of age, increased driving times to the nearest central and university hospitals were associated with increased acute myocardial infarction and stroke mortality [64]. Urban areas tend to have better accessibility to hospitals and medical facilities, with large agglomerations having the highest share of municipalities with good accessibility. In contrast, smaller agglomerations and urban communities outside agglomerations tend to rank lowest in terms of accessibility [65].

Finally, a study investigating disease risk in relation to screening, prevalence and management of high blood pressure throughout Switzerland provided additional possibilities for the pronounced geographical differences in hypertension mortality. Results showed that cholesterol levels are screened much more frequently in the French- and Italian-speaking parts of Switzerland than in the German-speaking regions [66]. The Swiss Health Care Atlas further confirms this increase in screening in the French- and Italian-speaking regions. The indicator for low-density

lipoprotein (LDL cholesterol) testing, a risk factor for cardiovascular diseases, shows a greater standardised rate of testing in the French- and Italian-speaking regions compared with the German-speaking regions, with Ticino and Geneva consistently having the highest frequency of testing [67]. Therefore, a possible explanation for these regional differences may be a higher level of education resulting in higher disease awareness, but also a higher awareness of this risk factor among medical staff in the French- and Italian-speaking regions. The high screening rates in the French- and Italian-speaking regions suggest that relatively simple medical measures can effectively manage hypertension, and hence the geographical distribution of the cause of death from hypertension in Switzerland may be attributed to these screening rates.

Certain types of cancer, such as lung cancer, have been increasingly recorded as causes of death for women since 2010. Generally, a relatively homogeneous distribution of deaths due to cancer was found across Switzerland. However, an unusual geographical pattern was discovered in the case of liver cancer. The Italian-speaking regions had almost twice the death rates, and the French-speaking regions almost 40% greater death rates from liver cancer than the German-speaking regions. The main risk factors for liver cancer include alcoholism, often paired with a condition of liver cirrhosis, or tobacco use [68]. A possible explanation for the observed geographical differences could be due to the lower consideration of guidelines for safe alcohol consumption (which affects drinking habits) in the French-speaking regions, potentially leading to higher likelihood of heavy drinking [69]. Similar findings of the association between alcohol levels, language regions and cancer mortality were observed in two studies that examined data from a cross-sectional Swiss National Nutrition Survey, menuCH. These studies recorded extended data about dietary, sociodemographic and lifestyle factors [69, 70]. Alcohol was associated with increased liver cancer mortality, and French- and Italian-speaking regions were associated with higher alcohol consumption. Another study investigating the components of the Mediterranean diet and mortality in Switzerland also observed the association between alcohol consumption and increased cancer mortality [60]. Furthermore, a higher proportion of smokers was reported in the western part of Switzerland [48]. Smoking patterns between neighbouring countries are similar; France, with 35.9% of the population smoking tobacco, ranks the highest, compared to Austria with 28.3% of the population smoking cigarettes, Germany with only 25.8% smokers, and closely followed by Italy with 24.6% [71]. Smoking patterns are also inherently linked to lung cancer rates. A higher mortality rate due to lung cancer in western Switzerland has already been observed; the same study also projected a decline in the mortality rates for lung cancer from 2014 onward in the cantons of Vaud and Neuchâtel, which is consistent with our findings of decreasing heterogeneity of lung cancer deaths in western Switzerland from 2010–2014 to 2015–2019 (figures 3 and S4) [25]. A study based on mortality data to 2008 found that Italianity is associated with lower prostate cancer mortality in Switzerland [72]. This reduced mortality of prostate cancer in the Italian-speaking part is consistent with the findings from the period 2010–2014, but is no longer seen for the period 2015–2019 (figures 3 and S4).

For oesophageal and stomach cancer one would expect higher mortality in Italian-speaking Switzerland due to higher prevalence of a resistant *Helicobacter pylori* strain [73]. While this is true for the period 2010–2014 (figure S4 in the appendix), it is not the case for the period 2015–2019, where the distribution seems consistent throughout Switzerland. An observational study based on Swiss claims found that, overall, French- and Italian-speaking regions had higher utilisation rates for screening types [74]. The study also observed an increase in colonoscopy frequency from 2014 to 2018. Screening colonoscopies are associated with decreased colorectal cancer mortality risk [75]. Furthermore, the Swiss Health Care Atlas indicates that Ticino is the canton with the highest frequency of colonoscopies [67]. The overall increase in colonoscopies over time, combined with the higher likelihood of receiving a colonoscopy in the Italian-speaking region, could help explain the observed reduction in mortality risk for oesophageal and stomach cancer in these regions in 2015–2019.

Our analysis showed a 6–7% lower mortality rate due to COVID-19 in German-speaking Switzerland compared to French- and Italian-speaking Switzerland. Interventions addressing mobility for non-essential activities were significantly less restrictive in the German-speaking cantons than in the French-speaking cantons. Less movement usually translates to lower social contact and therefore a smaller transmission risk and lower mortality. However, areas with higher trust in public institutions and officials were found to have a lower decrease in mobility [76]. This suggests that the willingness to follow public health guidelines, such as wearing masks and social distancing, was greater in German-speaking Switzerland. This offers a possible explanation for lower COVID-19 transmission rates and, ultimately, lower mortality rates in these cantons.

Socioeconomic factors such as income, education and place of residence are important health determinants and may further help to explain geographical differences in cause of death. First, an inverse relationship between social class and mortality has been well established, meaning that higher income levels were consistently associated with a lower risk of mortality [77]. A possible explanation for this relationship may be that lower income levels are often linked to a poorer diet, fewer social amenities and worse working conditions [77], which may contribute to higher mortality rate of individuals in lower social classes. Even after accounting for potential confounding factors, inadequate income is still associated with a higher risk of mortality. In the United States, lower socioeconomic status was linked to a higher incidence of diseases such as heart disease, hypertension, diabetes, respiratory infections and lung cancer [78]. Similarly, a study of 11 European countries found that mortality inequalities persisted across different age groups, with house owners and those with higher levels of education facing lower mortality rates [79]. Overall, house owners and those with higher education, as a proxy for socioeconomic status, faced lower mortality rates [79]. Additionally, people with lower socioeconomic status were found to be more likely to develop chronic diseases such as diabetes, heart disease and cancer [80]. Another plausible reason for increased mortality and chronic conditions in those with lower incomes is use of preventive

medicine and access to healthcare. A study examining variation in the use of preventive care in 14 European countries found that those with higher incomes and higher education use more preventive services including cancer screening and have a higher probability of consulting a general practitioner [81]. Our analysis aligns with these findings and suggests that lower-income municipalities may be risk factors for a range of mortality causes, including cardiovascular disease, cancers, diabetes, chronic respiratory diseases, influenza and pneumonia and intestinal diseases. However, we should be cautious when considering municipality per capita income, as our target population is those individuals aged 75 years or more who no longer form part of the working population. Therefore, in this context, net income serves as a proxy for municipalities with higher overall salary levels rather than reflecting current earnings.

The cause of death is reported using the ICD-10, which is known to have variability and some internal inconsistencies [82]. A study conducted in three cities in France independently classified causes of death as per the national mortality register. The study found significant differences in classification particularly for deaths from cardiovascular disease and ill-defined causes. The proportion of disagreement increased for individuals greater than 85 years of age [83]. A study reviewing the cancer mortality trends in Switzerland also observed an increasing error when attributing cause of death among the elderly due to increased disease possibilities and comorbidities, which are not usually classified as the main underlying cause [84]. These inconsistencies, especially among the elderly population, raise awareness about the inherent variability when assigning cause of death. Literature suggests that conditions such as chronic obstructive pulmonary disease and suicides are clinically underreported on death certificates [85, 86]. The potential for inconsistency in determining cause of death was highlighted when the analysis for secondary causes showed systematic language-level differences, with the French-speaking regions having lower mortality rates for 23 out of 24 causes compared to the German-speaking regions. Another consideration is that we link cause of death to the municipality of last residence, but we do not know the duration of time spent, and related exposures to risk factors in the municipality. However, performing the analysis spatially at the population level reduces potential biases due to differences between municipality of exposure and municipality of residence. Almost half of the deaths occurred in municipalities other than the municipality of residence, with a very small number occurring abroad. Nevertheless, we primarily looked at municipality of residence and not municipality of death as the latter reflects the urbanisation status and related health service offerings rather than exposure to specific risk factors. Further analysis could be conducted to better understand the temporal trends and factors behind the difference in patterns between the municipality of residence and municipality of death. Additional aspects to consider when extending the analysis include looking into other explanatory environmental and geographical covariates when exploring the potential associations in the spatial maps, such as access to healthcare. Possibilities for future extensions include constructing spatiotemporal models that assume temporally varying spatial patterns. Additionally, factors that differ at cantonal level could be included in the model as covari-

ates to quantify their effect and thus better understand differences in mortality at the cantonal level.

We present the first mortality atlas in Switzerland for the elderly population aged 75 years or older using the latest cause-specific mortality data and rigorous modelling. Our estimates identify areas with the highest cause-specific mortality rates and indicate potential health services that are needed in specific areas. The maps therefore can raise awareness of the most prominent health problems of the ageing population in different parts of the country and can guide targeted health interventions.

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Potential competing interests

All authors have completed and submitted the International Committee of Medical Journal Editors form for disclosure of potential conflicts of interest. No potential conflict of interest related to the content of this manuscript was disclosed.

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Appendix

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