A closer look: Additional study of relationship between indoor radon exposure and the Covid-19 case fatality rate

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Abstract. In September 2022, the author of this text asked the scientific community an astonishing question: is there a connection between the Covid-19 case fatality rate and the radon exposure in interior spaces? And – if so – is it a correlation? Is it just a coincidence or even a causality? Radon exposure is particularly high in regions that have seen high mortality rates related to SARS-CoV-2. It was demonstrated that there is at least a correlation. This statement based on a comparison of four states of Germany. Of course, such a comparison is rather vague due to various geological situations. It is relatively rough, as the measures against the spread of the SARS-CoV-2 have been different from one state in Germany to another. Due to that, this paper takes a closer look to that phenomenon. It focuses on three districts in northern Bavaria: Ansbach, Bad Kissingen and Wunsiedel. The last one is situated close to Thuringia as well as the Czech Republic. It was declared as radon preservation area – the only one in Bavaria – and is rather affected by radon. Bad Kissingen represents a region with a medium average indoor radon activity concentration. It is located at the north at the border to Hesse. Ansbach is characterized of a lower risk to get affected by radon. It is in the vicinity to Baden Wuerttemberg in the west. Even this second comparison cannot provide a definitive answer to the questions named above. Nevertheless, this article will push that topic a little forward and by that support the answer to a possible relationship between indoor radon activity concentration and the Covid-19 case fatality rate. Possibly it puts little more focus more on radon protection than it happened during the pandemic years.

1 Introduction

For almost three years, the pandemic declared by the WHO in response to the SARS-CoV-2 virus widely impacted the daily lives of many people worldwide due to the measures taken to mitigate its spread. The vast majority have returned to their normal lives, some are working to a greater or lesser extent to understand the medical [1], legal [2] and political [3,4] errors made during this time and others tried to obtain learnings for the future even during the crisis itself [5] (previously quoted references are examples only). The time was primarily taken up

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with debates involving various medical scientists, largely accompanied by economists, lawyers, statisticians and certain scientists in the humanities discipline. With the exception of wastewater monitoring [6] and ventilation systems, engineers were and are rarely involved in the discussions.

In autumn 2022, this changed when the author of this article brought the topic of construction into the debate at the WMCAUS conference held in Prague [7]. In addition, the fundamentals of the investigation are outlined in this introduction again. The following diagrams in Fig. 1 highlight the reason for establishing a correlation.

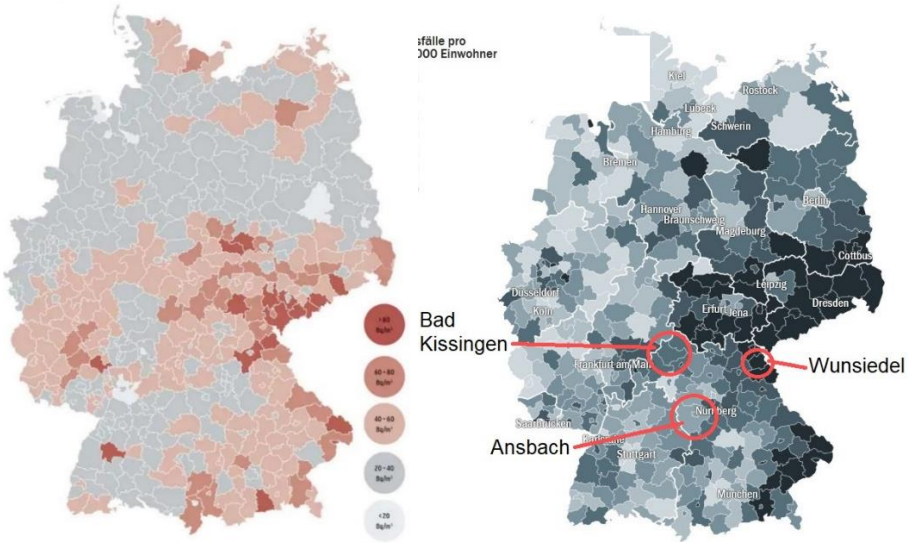

Fig. 1. Average concentration of radon in German homes according to the Federal Office for Radiation Protection, quoted in [8] (left) and instances of deaths related to Covid-19 in Germany per 100,000 inhabitants according to the Robert Koch Institute, quoted in [9] (right, version dated 07/2023), represented by district with the districts Ansbach, Bad Kissingen and Wunsiedel marked by the author.

Radon is a chemical element (Rn). It occurs as a colourless, tasteless and odourless noble gas, whose decay products are all radioactive. If it accumulates indoors, it leads to an increased risk of lung cancer [8], [10]. The causality is undisputed despite the fact that there is no proven link between exposition and illness [11]. The link between a severe case of Covid-19 and pre-existing lung conditions was already known back in 2020; however, there is no indication of a connection between severe disease and a lung already damaged due to geogenic radiation [12]. While 2021 saw an increased awareness of radon-related health prevention due to several online articles [13,14], no link was established between the health effects of radon indoors and a Covid-19 case fatality rate. The Federal Office for Radiation Protection also denies this [15].

Interestingly, the regions with the highest number of deaths related to Covid-19 are those where an elevated average radon concentration was measured in homes. In 2022, the Covid-19 case fatality rates were thus analysed in the four German federal states of Bavaria, Lower Saxony, Saxony and Thuringia. This was carried out on a general basis as well as in 6-month instalments. The latter took into account the decreased risk of the virus due to mutations. Upon comparison, Saxony and Thuringia almost always exhibit a higher case fatality rate than the two other federal states. The latter are – incidentally or not – also far less affected by radon. This article compares the situation within a federal state in continuation of the

analysis conducted in 2022. It will further address the question of a potential link or even causality.

2 Discussion

2.1 Limitations, methods and potential errors

It is recognised that many factors exist which may cast doubt on the observations stated here. This includes unclear data, for one thing. Unfortunately, this is the case for both the levels of radon as well as the coronavirus figures. In January 2022, the German Federal Office for Radiation Protection published a revised map of the concentration of radon in the soil (Fig. 2 left) [16] to replace the version published in 2019 [10]. However, the concentration of radon indoors is significant to user risk. Only data from 2006 is available in Juli 2023 in [10]. From the deviations between [10] and [16] for radon concentration in the soil air, it can be deduced that there is a need for additional, more recent data on indoor concentrations.

This particularly applies for the data available in Germany relating to Covid-19. In large part, insufficient data was collected for over three years. In Germany, "flying blind" has long since been the topic of conversation [17,18]. For example, no differentiation was made between death "from Covid-19" and "relating to Covid-19", which is important for the question raised in this publication. Furthermore, the author does not have all the necessary data for the entire duration as some sites were sometimes updated daily [19] whereas the Robert Koch Institute published weekly reports [20]. Matters are complicated by the fact that various corrections were issued involving fewer cases or even lower death figures. For example, nine deaths were deleted on 1st of February 2021 in Bavaria, followed by three on 1st of April 2021, one on 17th of April, three on 18th of April, two on 21st of April, etc. [19]. The - subsequently corrected - figures can be found on the Robert Koch Institute website but only by district from November 2020 and without any information about deaths. Further, the publications do not indicate whether only first-time infections were included in the case numbers or not. However, this is relevant for the number of cases and deaths per 100,000 inhabitants. The case fatality rate was rarely published; focus lay on cases and 7-day incidences.

The comparison of regions within a federal state should indicate that the recording of cases and death rates was carried out identically and is thus "correct" or "insufficient" to the same degree. Bavaria has regions which are heavily, mildly and barely affected by radon. It is therefore an ideal choice for the closer look taken here.

Due to the temporal difference in sections of typically six months, the mutation of the virus was taken into account. This likely reduced the case fatality rate (cf. [7]) even if this is disputed [21]. The gradual increase in testing ability during the period under observation also resulted in an increased number of asymptomatic cases being recorded (almost exclusively those who were unvaccinated at certain time periods), and significantly reduced the number of unknown cases and estimated case fatality rate. Finally, the period under observation was limited. It was only after several weeks that the virus could be seen and recorded throughout Germany, althought far from systematic at the start. The analysis thus begins in December 2020 and ends in March 2023. This results in ten time periods available for comparison, of which eight comprise six-month blocks.

2.2 Comparison by district

The selected districts of Ansbach, Bad Kissingen and Wunsiedel involve rather sparsely populated, rural regions in northern Bavaria. This similarity and comparability are

highlighted in Table 1 and Fig. 2, right. For the regions observed, the population density lies at 40 – 50% of the state average. This density is used as an indicator for a similar type of building development and air pollution. Among other things, fine dust pollution in cities is a known risk for lung disease [22]. This factor can be equally omitted in the three selected districts to improve comparability. In addition, there is a smaller proportion of high-rise buildings which is relevant for the exposure of the population to radon: ground-level rooms are typically affected to a greater degree, meaning that a high proportion of residents in high-rise buildings distorts comparison figures.

Another factor that influences the case fatality rate is sunlight hours. This is relevant due to the presumed strong link between vitamin D deficiency and severe cases of Covid-19 [23]. The so-called Bavaria Energy Atlas ["Energie-Atlas Bayern"] presents similar figures for the three districts [24]. However, the districts vary slightly in terms of their elderly population. In Bad Kissingen and Wunsiedel, the 80+ age group is equally above 8 % while in Ansbach it is just 6.4 % of inhabitants [25]. Conversely, it concerns the 20 years and under age group. In Ansbach, this proportion is 19.4 % whereas in Bad Kissingen and Wunsiedel this figure lies at around 17 % [25]. Thus, if "age" were the significant difference, similar death rates would be seen in the two aforementioned districts.

The offspring of inter-family relationships are far more likely to have a weaker immune system [26]. This is particularly relevant in the case of Covid-19 as children who are the product of an incestuous relationship typically have a smaller lung capacity [27], too. Both are with high probability significant factors for an investigation into the Covid-19 case fatality rate. Among certain parts of Germany's population, up to 25 or 30 % of marriages are kept within families [28]. In the author's view, it is insufficient to only use the population of foreigners as a benchmark here. Within the scope of this publication however, it is difficult to ascertain which proportion of inhabitants in the three compared districts originate from inter-family marriages. Nevertheless, the three rural and largely similar districts also might have a comparable population share in this regard.

Table 1. Area, number of inhabitants and population density in Germany, Bavaria and the districts of Ansbach, Bad Kissingen and Wunsiedel according to [29-33].

state / district	**area** [km²]	**inhabitants** [quantity]	**population density** [inhabitants / km²]
Germany	357,588	84,358,845	236
Bavaria	70,541	13,369,393	190
Ansbach	1,971	188,623	96
Bad Kissingen	1,136	104,567	92
Wunsiedel	606	72,009	119

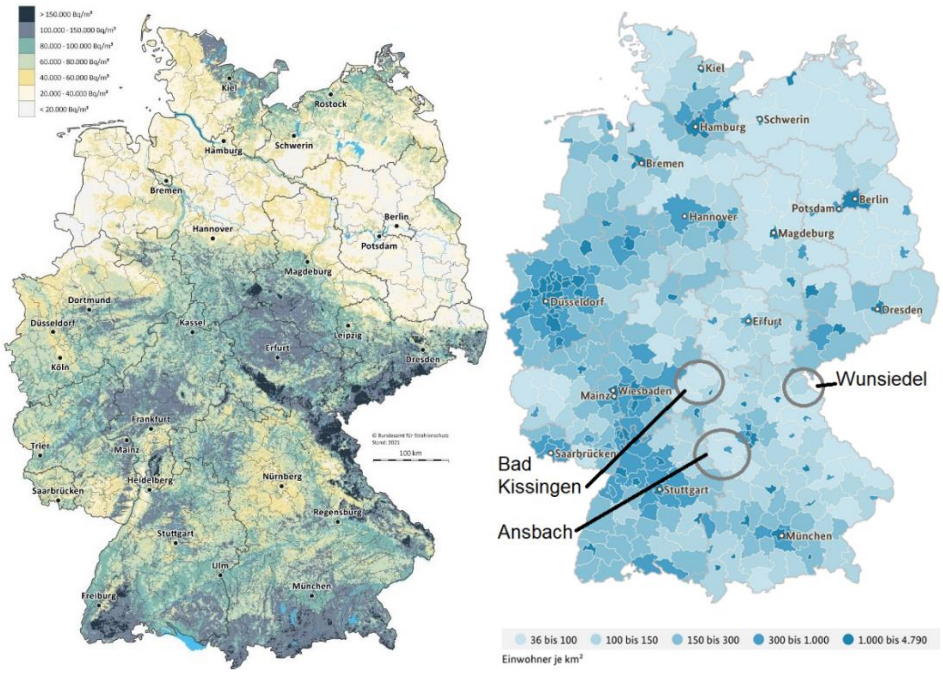

Fig. 2. Concentration of radon content in the soil air in Germany [16] (left, modified by the author) and population density in Germany according to [34] (right, version dated 2020) with the districts Ansbach, Bad Kissingen and Wunsiedel marked by the author.

The significant concentration of radon indoors is represented in Fig. 1 (left), even though with somewhat outdated information due to lack of recent data. It is dependent upon the building characteristics which are difficult to statistically record. On 11th of February 2021, the district of Wunsiedel was nonetheless declared a radon precautionary area based on statistical analyses from January 2021 [35]. The Free State of Bavaria thus implemented § 121 of the Radiation Protection Ordinance of 31/12/2018. So-called "radon precautionary areas" ["Radonvorsorgegebiete"] are regions with a higher geogenic radon concentration [11]. At least 10% of buildings exceed 300 Bq/m³ of air inside buildings, which is significant. Although the spa town of Bad Kissingen contains radon-based mineral springs [32], the population – statistically speaking – is less exposed to radon and so the district is not considered a radon precautionary area. Unlike the other two districts, Ansbach displays the lowest quantity of radon. Geological differences naturally exist within the districts, which in turn also applies to the occurrence of radon. However, the former is also plausible due to the concentration of radon in the soil air, which is represented in Fig. 3.

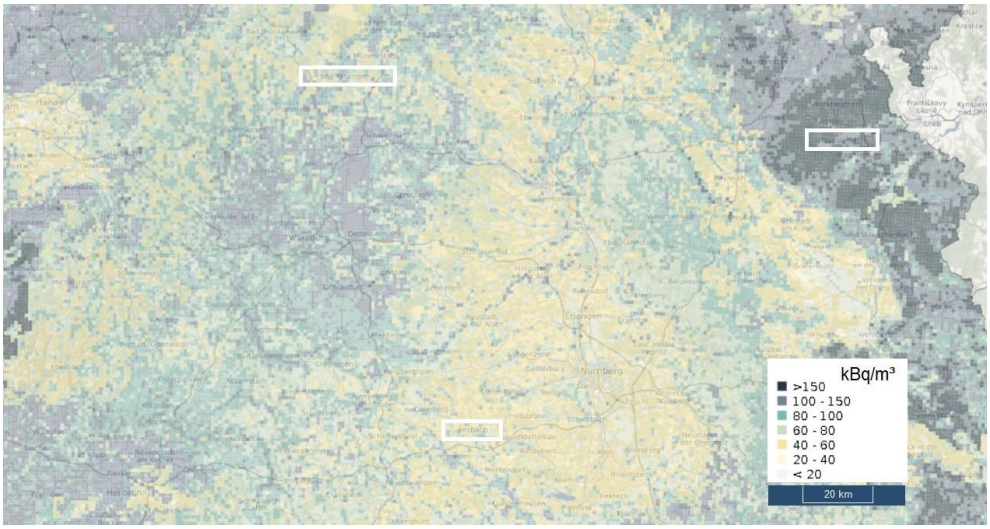

Fig. 3. Radon content in the soil air in Germany, extract from [36] modified and just for rough orientation marked with the administrative headquarters of the districts of Ansbach, Bad Kissingen and Wunsiedel by the author.

2.3 Comparison of case fatality rates

The first comparison of case fatality rates takes the period until 31/03/2023 into account. This scope has also been expanded: in addition to the regions named in Table 1, the case fatality rate for selected federal states is provided in Table 2. The result of these calculations is represented as a graphic in Fig. 4. This clearly shows that the federal states of Saxony and Thuringia, which are heavily exposed to radon, experienced a case fatality rate almost double the national average. The district of Wunsiedel also displays an above-average case fatality rate of 0.85 %.

Table 2. COVID-19 cases, COVID-related deaths and case fatality rate until 31/03/2023 for Germany, Bavaria, Lower Saxony, Saxony and Thuringia along with the districts of Ansbach, Bad Kissingen and Wunsiedel according to [37] and [19].

state / district	**cases** (per 31/03/2023)	**deaths** (per 31/03/2023)	**case fatality rate** (per 31/03/2023)
Germany	38,351,642	170,839	0.45 %
Bavaria	6,755,558	29,002	0.43 %
Lower Saxony	3,871,745	13,926	0.36 %
Saxony	1,961,832	16,893	0.86 %
Thuringia	886,579	8,352	0.94 %
Ansbach	96,749	302	0.31 %
Bad Kissingen	56,747	251	0.44 %
Wunsiedel	38,431	327	0.85 %

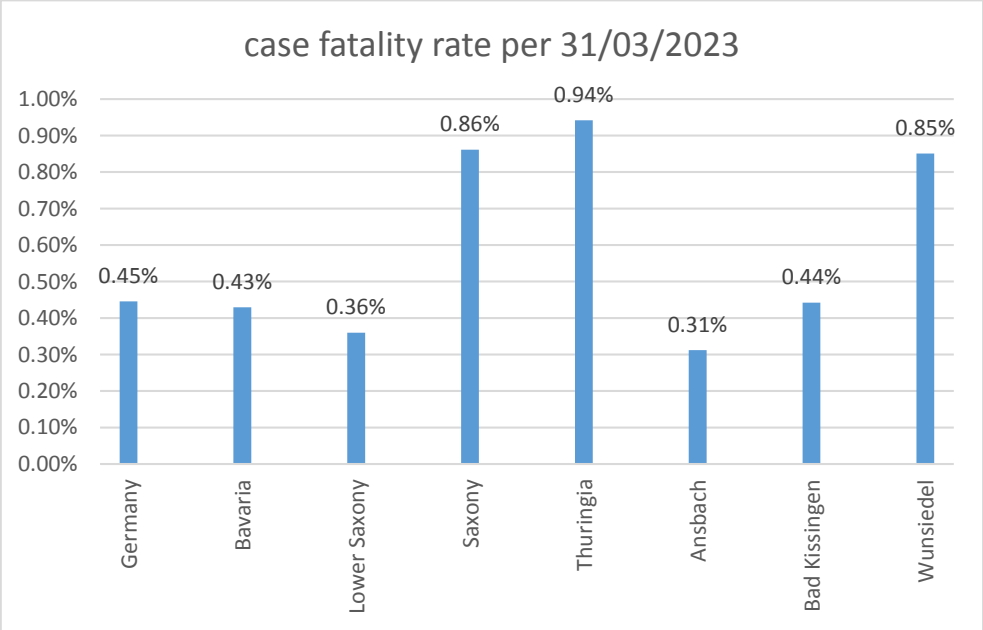

Fig. 4. Covid-19 case fatality rate until 31/03/2023 for Germany, Bavaria, Lower Saxony, Saxony and Thuringia along with the districts of Ansbach, Bad Kissingen and Wunsiedel according to [37] and [19] (own illustration).

The second comparison of case fatality rate refers to the ten time periods mentioned earlier. Change in testing availability and methods as well as the mutation of the virus were taken into account by that to create a more detailed overview. Here, only the three selected districts were compared with one another. The results are visible in Table 3 and Fig. 5.

Previously, the case fatality rate was always used as a benchmark for comparison. Finally the number of deaths per 100,000 inhabitants should now, in a third step, also be taken into account. This appears in Table 4, the results of which are represented in Fig. 6.

Table 3. Covid-19 cases, deaths and case fatality rate during different time periods for the districts of Ansbach, Bad Kissingen and Wunsiedel according to [19].

district	**cases** (until 31/12/2020)	**deaths** (until 31/12/2020)	**case fatality rate** (until 31/12/2020)	**cases** (01/01/2021 - 31/03/2021)	**deaths** (01/01/2021 - 31/03/2021)	**case fatality rate** (01/01/2021 - 31/03/2021)
Ansbach	3,415	76	2.23 %	2,552	77	3.02 %
Bad Kissingen	1,580	43	2.27 %	1,088	44	4.04 %
Wunsiedel	1,967	65	3.30 %	2,488	117	4.70 %

district	**cases** (01/04/2021 - 30/06/2021)	**deaths** (01/04/2021 - 30/06/2021)	**case fatality rate** (01/04/2021 - 30/06/2021)	**cases** (01/07/2021 - 30/09/2021)	**deaths** (01/07/2021 - 30/09/2021)	**case fatality rate** (01/07/2021 - 30/09/2021)
Ansbach	2,435	45	1.85 %	708	1	0.14 %
Bad Kissingen	972	17	1.75 %	299	1	0.33 %
Wunsiedel	569	16	2.81 %	205	3	1.46 %

district	**cases** (01/10/2021 - 31/12/2021)	**deaths** (01/10/2021 - 31/12/2021)	**case fatality rate** (01/10/2021 - 31/12/2021)	**cases** (01/01/2022 - 31/03/2022)	**deaths** (01/01/2022 - 31/03/2022)	**case fatality rate** (01/01/2022 - 31/03/2022)
Ansbach	11,785	34	0.29 %	36,396	22	0.06 %
Bad Kissingen	5,513	38	0.69 %	21,160	38	0.18 %
Wunsiedel	4,573	13	0.28 %	14,553	26	0.18 %

district	**cases** (01/04/2022 - 30/06/2022)	**deaths** (01/04/2022 - 30/06/2022)	**case fatality rate** (01/04/2022 - 30/06/2022)	**cases** (01/07/2022 - 30/09/2022)	**deaths** (01/07/2022 - 30/09/2022)	**case fatality rate** (01/07/2022 - 30/09/2022)
Ansbach	34,786	6	0.02 %	11,471	8	0.07 %
Bad Kissingen	17,948	21	0.12 %	8,603	16	0.19 %
Wunsiedel	10,450	29	0.28 %	6,633	19	0.29 %

district	**cases** (01/10/2022 - 31/12/2022)	**deaths** (01/10/2022 - 31/12/2022)	**case fatality rate** (01/10/2022 - 31/12/2022)	**cases** (01/01/2023 - 31/03/2023)	**deaths** (01/01/2023 - 31/03/2023)	**case fatality rate** (01/01/2023 - 31/03/2023)
Ansbach	34,414	17	0.05 %	4,158	16	0.38 %
Bad Kissingen	22,067	12	0.05 %	2,599	21	0.81 %
Wunsiedel	15,095	23	0.15 %	1,664	16	0.96 %

Table 4. Number of inhabitants, cumulated Covid-19 deaths and deaths per 100,000 inhabitants for Germany, Bavaria and the districts of Ansbach, Bad Kissingen and Wunsiedel according to Table 1 and 3.

state / district	**Inhabitants** [Quantity]	**Covid-19 deaths** [Figures until 31/03/23]	**proportion of Covid-19 deaths** [cases / 100,000 inhabitants]
Germany	84,358,845	161,321	191.2
Bavaria	13,369,393	27,538	216.9
Ansbach	188,623	302	160.1
Bad Kissingen	104,567	251	240.0
Wunsiedel	72,009	327	454.1

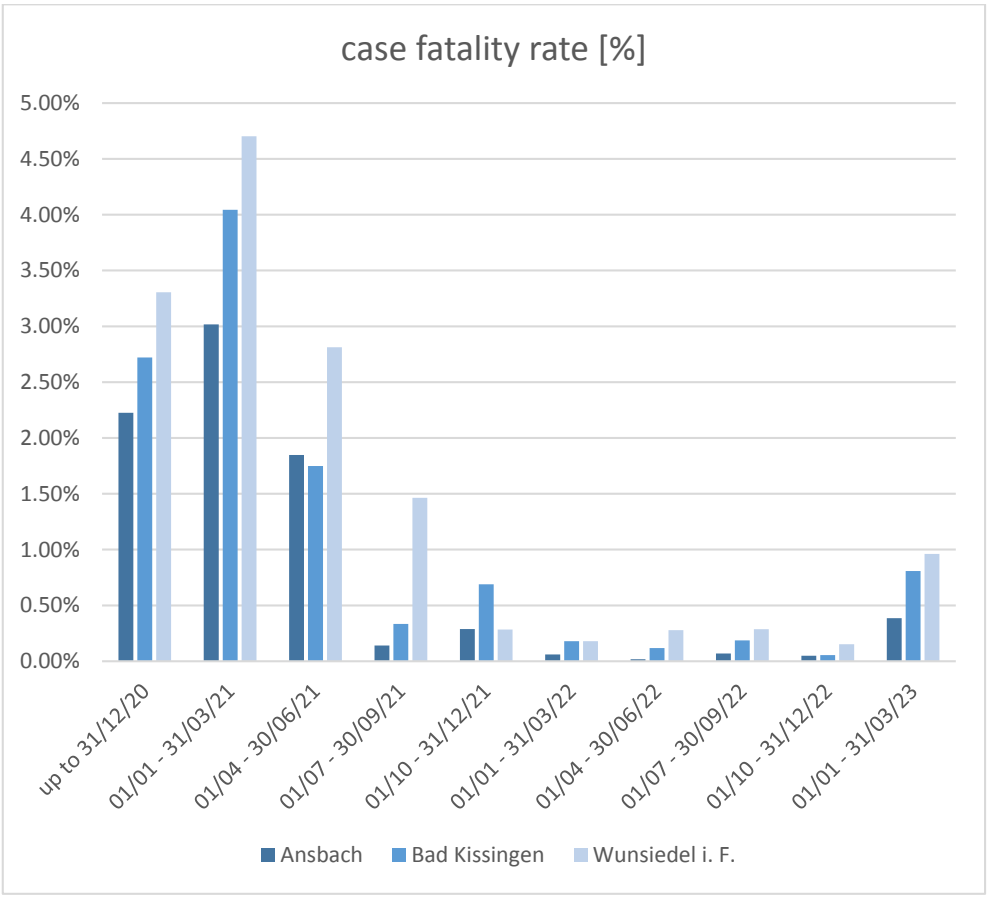

Fig. 5. Covid-19 case fatality rate according to Table 3 for the districts of Ansbach, Bad Kissingen and Wunsiedel according to [19] (own illustration).

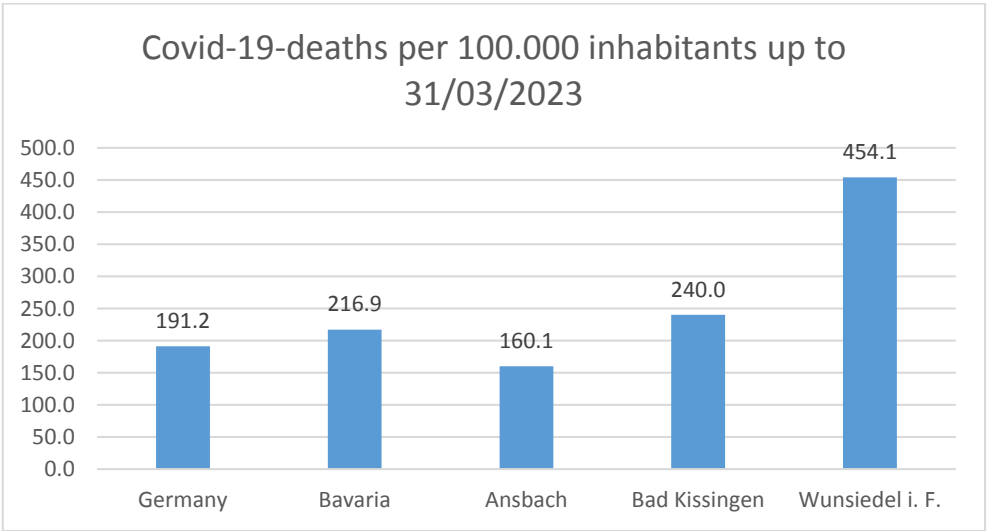

Fig. 6. Covid-19 deaths per 100,000 inhabitants in Germany, Bavaria and the districts of Ansbach, Bad Kissingen and Wunsiedel according to Table 4 (own illustration).

2.4 Analysis of the results

In Table 2 and Fig. 4, Wunsiedel displays a higher case fatality rate when compared to the two other districts. At 0.85 %, it was almost double the national average of 0.45 % for the entire duration, which corresponds to an average of 0.43 % for Bavaria. As already shown in [7], the case fatality rate in the more heavily radon-affected states of Saxony and Thuringia was far above average, too. The lesser radon-affected state of Lower Saxony, on the other hand, had a lower-than-average case fatality rate.

What Table 3 shows in figures is clearly represented in Fig. 5: the case fatality rate is almost always higher in the more heavily radon-affected district of Wunsiedel than in the two other districts. Only one exception exists for a given period: in the 4th quarter of 2021, the district of Bad Kissingen displayed the highest rate at 0.69 % whereas Ansbach and Wunsiedel experienced similar case fatality rates of 0.28 and 0.29 % respectively during this period.

Furthermore, the graphic and table also show that the case fatality rate is always lower in the district of Ansbach, which is least affected by radon, than in the two other regions compared. The only exception is in the 2nd quarter of 2021, in which Ansbach experienced a case fatality rate of 0.1 % higher than Bad Kissingen. Both of these exceptions to the rule are considered negligible: the number of deaths almost always lies in the middle to lower two-digit or even single-digit range. Lower values are therefore more likely to produce percentage-related deviations but may also be caused by the subsequent changes and deletions to the figures as mentioned at the beginning.

The comparison of Covid-19 deaths per 100,000 inhabitants in Fig. 6 provides a similar picture to the case fatality rate in Fig. 4: the district of Wunsiedel experienced more deaths relating to COVID-19 than the two other districts. In fact, this is almost double the Bavarian average and almost 2.4 times higher than the national average.

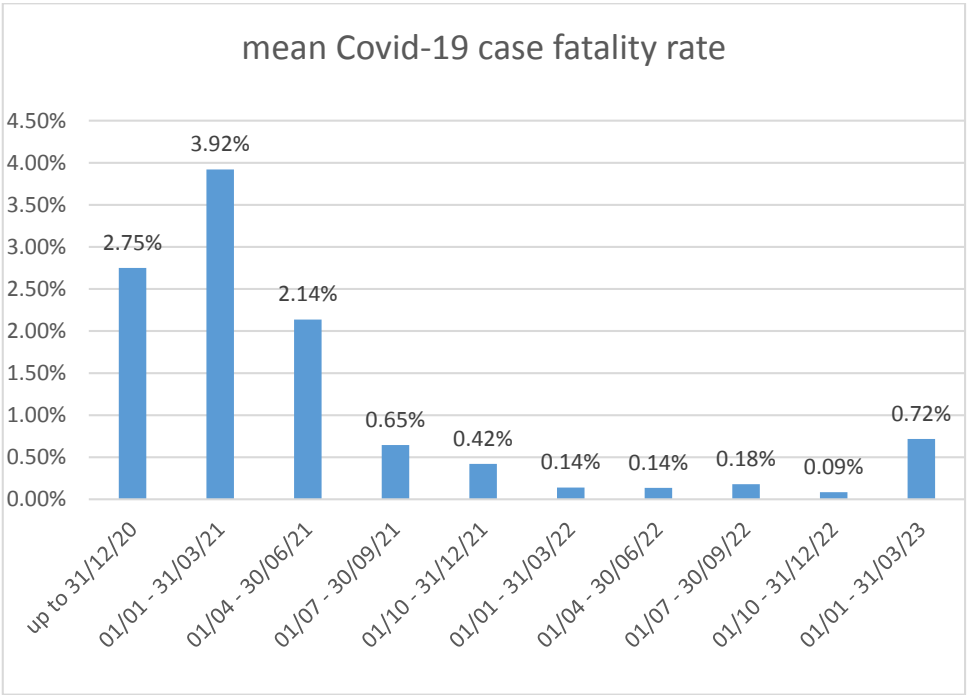

Fig. 7. Mean Covid-19 case fatality rate according to Table 3 for the districts of Ansbach, Bad Kissingen and Wunsiedel according to [19] (own illustration).

An interesting chronological sequence in terms of Covid-19 case fatality rate can be seen in Fig. 5 and even more clearly in Fig. 7 (mean value from Fig. 5). In general, the vast majority of deaths from and in connection with Covid-19 occurred among elderly people. The median age throughout the entire period was around 83 - 85 years. 85 % of deaths affected people over 70, whereby only around 8 % of all cases were attributed to this age group [38]. It was merely logical to prioritise these high-risk individuals when Germany finally began its vaccination campaign against SARS-CoV-2 at the end of 2020. However, contrary to expectations, this vaccination in the elderly population did not reduce the death rate and even increased it by more than + 40 % in the 1st quarter of 2021.

Only from July 2021 could a significant decrease in deaths be seen. From this point on, rapid testing was largely available. The introduction of the "3G" (vaccinated against, recently recovered from or negative tested for Covid-19) and "2G" (vaccinated or recovered) rule in Germany saw primarily unvaccinated children and teenagers being tested who were largely presumed to be asymptomatically positive. The case fatality rate temporarily fell to less than 0.2 % on average as a result. Only after the booster injection and the end of mandatory testing across almost all areas excluding care homes did the number of cases fall in early 2023. At the same time, the case fatality rate exceeded the figures in 2022 several-fold. This interpretation of the results requires additional research but is less critical to the question raised in this text.

3 Summary

Based on the comparisons in the previous chapters, a relatively clear picture can be concluded. In essence, the hypothesis presented in [7] is confirmed, whereby regions more heavily affected by radon also experienced a higher case fatality rate from Covid-19. However, in the author's view, a basic correlation cannot be concluded based on the four federal states and three Bavarian districts. The current state of findings is still too insufficient to determine a causality.

Nonetheless, the results of this publication indicate that it is worth examining this further in order to ascertain a general finding from the correlations between different regions. Who knows, perhaps - as with lung cancer - no causality will be found but one day severe and fatal instances of Covid-19 will be considered a general consequence of radon exposure. Regions with a higher concentration of radon would then also be linked with a higher occurrence probability of deaths related to Covid-19 and that illness contributed to the "stochastic radiation effects" [11] (p. 33).

This retrospective finding would not change anything for those who died but may help to improve Germany's currently rather poor approach to taking building measures that prevent high concentrations of radon indoors. For future research (or future epidemics), it is worth looking at the situation oversees where long-standing measures to protect against radon may also have been effective in preventing high Covid-19 case fatality rates.

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