

Nitrate in Drinking Water and Colorectal Cancer in Germany: A Population Attributable Fraction Analysis with Health-Economic Valuation

Thomas Krisch · ORCID: 0009-0008-9722-0339

zeitform Internet Dienste OHG / wassertipps.de, Darmstadt, Germany

Correspondence: krisch@wassertipps.de

Working Paper · October 2026

Abstract

Background: Nitrate in drinking water is suspected of increasing the risk of colorectal cancer (CRC). Drawing on the Danish national cohort study (Schullehner et al., 2018; $n = 1.74$ million) and the subsequent health-economic study (Jacobsen et al., 2024), this paper estimates the population attributable fraction (PAF) of nitrate-related CRC cases for Germany and assigns a monetary value to it. **Methods:** Two exposure categories are defined from the Wassertipps database (>10 mg/L: 32.5 million people; >25 mg/L: 3.0 million people; reference population: 71 million). The exposure-response function derived after error correction within the EU MARCHES project ($RR = 1.06$ per 10 mg/L) is applied continuously across the exposure distribution. Case numbers are based on 47,570 scaled CRC cases (ZfKD/RKI 2025, diagnosis year 2022). Direct treatment costs (mean €40,685 per case) are derived from phase-specific statutory health insurance claims data (Heisser et al., 2022). The health-economic valuation uses two VOLY scenarios: EU CAFE (€40,000) and Schlander et al. (2017, DKFZ; Germany-specific: €173,868, taken directly from empirical willingness-to-pay studies). **Results:** Assuming a causal relationship, the main scenario yields a PAF of 6.44%, corresponding to 3,063 nitrate-attributable CRC cases per year. Were the limit of 6 mg/L recommended by an international expert group to be met, approximately 1,821 of these cases would be avoidable annually; at 10 mg/L the figure would be 1,248 and at 25 mg/L only 147. Annual total damage is estimated at €908 million (EU CAFE) to €3,300 million (Schlander VOLY). The benefit-cost ratio is 1.8 to 17.6 for the benefit attainable at 6 mg/L (preventive fertiliser-ordinance costs, range €112–292 million per year) and 3.1 to 29.5 for the total attributable damage. **Conclusions:** The health-economic burden of nitrate-related colorectal cancer in Germany substantially exceeds the cost of remediation under both VOLY scenarios. At sites where the hydrogeology leaves little capacity for natural denitrification, such as well-aerated gravel aquifers, treatment at the water utility is a necessary complement to prevention. The repeal of the German nutrient-flow balance ordinance (Stoffstrombilanzverordnung) in 2025 is likely to increase this burden further over the medium term. One open question deserves mention: the rise in colorectal cancer among younger adults observed over roughly the past two decades coincides temporally with those birth cohorts exposed from early life to elevated nitrate levels resulting from the expansion of nitrogen fertilisation. Given the long latency of colorectal cancer, an investigation of this possible birth-cohort effect would be of interest; given the strong confounding with lifestyle factors that changed over the same period, however, no association can be inferred from this coincidence.¹

AI disclosure: Claude (Anthropic) was used to support the calculations, literature search, drafting and consistency checking of this paper. The author specified all methods and parameters, verified all results and sources against the originals, and takes full responsibility for the content (see Declarations).

1 Introduction

Nitrate (NO_3^-) enters groundwater in considerable quantities through the over-fertilisation of agricultural land, and from there the public drinking water supply. In Germany an estimated 45% of the population receives drinking water with nitrate concentrations above 10 mg/L — a level which, according to current epidemiological evidence, may already be associated with an elevated risk of colorectal cancer^{2 3}.

At the same time, a number of studies compare the costs that would arise from lowering the limit value with the savings this would bring to society^{4 5 6}.

The most comprehensive cohort study on this relationship to date (Schullehner et al., 2018)³ followed 1.74 million Danish adults over 33 years and identified statistically significant increases in CRC risk from nitrate concentrations of 3.87 mg/L upwards — far below the applicable EU limit of 50 mg/L. The health-economic study building on it (Jacobsen et al., 2024) quantified the economic damage from nitrate-related CRC cases in Denmark at approximately USD 317 million per year.

The present working paper transfers this methodology to Germany and calculates a population-based estimate of the annual nitrate-attributable CRC damage for the German population.

2 Methods

2.1 Data basis for Germany

Germany still lacks an official, supra-regional database that could serve as a data basis. An overview of all drinking water testing laboratories of the federal states does exist⁷, but a publicly accessible database listing individual monitoring points could be found only for Rhineland-Palatinate⁸. A direct assignment of a monitoring point to a supply zone is not possible there, and only a few selected parameters from the analyses are displayed.

In 2016 we began searching the internet for the analyses published by public water utilities and recording individual parameters, together with the corresponding supply zones, in a database of our own design.

We first combined the geographical information of postcode areas with the drinking water analyses of the public utilities in our Wassertipps database. Having quickly established that utilities in many regions operate several supply zones within a single postcode area, we additionally recorded these supply zones in the database using GIS software.

We also incorporated population data for the postcode areas from the first European census of 2011, later updating these with the most recent German census of 2022⁹.

This allows at least an approximate estimate of how many people are affected by the various nitrate concentrations in their drinking water.

We consistently used the mean values reported by the water utility. Where an analysis stated only minimum and maximum values, we calculated a mean from these and used it for our evaluation.

One source of uncertainty is that data coverage is not complete: drinking water data are available for approximately 80 million people in Germany, and for around 6 million of these the available analyses contain no nitrate values.

This leaves data for approximately 74.2 million people in Germany for whom nitrate values are available. The data were extracted from the published analyses of the water utilities between November 2024 and May 2026¹⁰.

Table 1 — Exposure categories in the Wassertipps database

Parameter	Population	Share
< 5 mg/l	28,376,879	35.31 %
5-10 mg/l	11,686,649	14.54 %
10-25 mg/l	29,449,950	36.64 %
25-35 mg/l	3,598,458	4.48 %
35-50 mg/l	1,108,930	1.38 %
> 50 mg/l	23,258	0.03 %
No data	6,127,374	7.62 %

One potential source of error lies in the supply zones we delineated ourselves, which have differing drinking water values and lie within a single postcode area. No direct population figures are available for these zones, so we examined the postcode areas concerned, together with the smaller supply zones within them, in greater detail ¹¹.

This concerns 2,475 records covering approximately 1,000 postcode areas (around 20% of all postcode areas we recorded) for which our research identified differing drinking water values. Of these, however, only 124 records (for a limit of 10 mg/L) and 109 records (for a limit of 25 mg/L), covering 1.57 million and 1.43 million inhabitants respectively, are relevant to the present analysis, because only in these cases do the nitrate values of the postcode area and of the sub-zone fall on opposite sides of the relevant threshold. These two groups were therefore likewise excluded from our calculations ¹².

According to our data, 32,538,291 people are supplied with water above 10 mg/L and 2,985,085 above 25 mg/L.

2.2 Population and exposure data

The reference population comprises 71 million inhabitants (scaled from the total population of 84 million on the basis of complete drinking water quality data; scaling factor $71/84 = 0.845$). Two exposure categories are defined: (1) >10 mg/L NO_3^- : 32,538,291 people (45.8%); (2) >25 mg/L NO_3^- : 2,985,085 people (4.2%).

The Centre for Cancer Registry Data at the Robert Koch Institute reported 56,280 new cases of colorectal cancer for 2022 (25,400 women, 30,880 men) ¹³. The same edition reports 55,320 cases for 2023; using this more recent figure would lower all case and cost estimates by 1.7% without affecting the conclusions. Since only a subset of the total population can be assessed, the CRC case numbers were scaled down accordingly.

Table 2 — Population structure and exposure categories

Parameter	Value	Share	Source	Note
Total population (observed)	71,000,000	100 %	Destatis 2023	Scaled from 84 million
Not exposed (<10 mg/L)	38,461,709	54.2 %	Wassertipps 2026	Reference category
Exposed 10–25 mg/L	29,553,206	41.6 %	Wassertipps 2026	RR = 1.06 per 10 mg/L, applied continuously (see 2.3)

Exposed >25 mg/L	2,985,085	4.2 %	Wassertipps 2026	RR = 1.06 per 10 mg/L, applied continuously (see 2.3)
CRC cases (scaled)	47,570	—	ZfKD/RKI 2025 (2022)	56,280 × (71/84)

2.3 Epidemiological basis and exposure-response function

The primary basis is the meta-analysis prepared within the EU MARCHES project (Deliverable D2.2).¹⁴ Its authors systematically reviewed seven existing meta-analyses on the association between nitrate in drinking water and colorectal cancer, together with the eleven underlying primary studies, and uncovered substantial errors: two meta-analyses contained data extraction errors that understated the true effect sizes and pulled the confidence intervals across the null hypothesis; several double-counted the same cohort. Once these errors are corrected, the meta-analyses consistently show statistically significant positive associations. The corrected exposure-response function is $RR = 1.06$ (95% CI: 1.00–1.11) per 10 mg/L increase in nitrate concentration. The authors themselves describe this value as conservative, since up to roughly half of the applicable limit of 50 mg/L the relationship is steeper, at approximately $RR = 1.15$ (95% CI: 1.08–1.26) per 10 mg/L. A separate examination of the linearity assumption found that the non-linear estimate initially follows the linear course and only flattens in the upper concentration range — there, however, with sharply increasing uncertainty, as few data points above 50 mg/L are available. A parallel calculation using the hazard ratios of the Danish cohort study (Schullehner et al. 2018) is deliberately omitted. That study is one of the eleven primary works entering the meta-analysis, and its risk estimates lie close to the meta-coefficients, so that a parallel calculation would yield no independent insight but merely create an appearance of precision.

2.4 Calculation of the population attributable fraction

The method used is a population attributable fraction (PAF) approach, as applied by Temkin et al. (2019) to US data and by Jacobsen et al. (2024) to Denmark. In the main scenario the continuous exposure-response function is applied across all exposure categories: $PAF = \sum p_i (RR_i - 1) / [\sum p_i (RR_i - 1) + 1]$, with $RR_i = ERF^((c_i - c_{ref})/10)$ and c_i as the category midpoint. For the open-ended top category (>50 mg/L) the upper bound was estimated in line with the MARCHES methodology as the lower bound plus 1.5 times the width of the preceding category (72.5 mg/L, midpoint 61.25 mg/L). The reference is $c_{ref} = 0$ mg/L. Three counterfactual scenarios are additionally considered, each answering the question of how many cases would be avoidable if a given limit were met: 6 mg/L (the recommendation of the international expert group), 10 mg/L (the threshold from which the epidemiological evidence suggests an elevated risk) and 25 mg/L (half the applicable EU limit). The calculation assumes that all persons supplied above the respective target value would be brought down to that value. The population-weighted mean nitrate concentration is 11.19 mg/L. The number of nitrate-attributable CRC cases is in each case obtained as $PAF \times 47,570$.

2.5 Direct treatment costs (Heisser et al., 2022)

Direct treatment costs are derived from the statutory health insurance claims study by Heisser et al. (2022, Cancers)¹⁵, which reports phase-specific annual costs for more than 2,800 German CRC patients (Vilva Healthcare database, 2012–2016). Cumulative costs per case are calculated from three phases (initial phase year 1, follow-up years 2–5, terminal phase), weighted by the five-year relative survival rate (64%: women 66%, men 63%, weighted by 2022 case numbers; ZfKD/RKI 2025). Table 2b sets out the derivation of the mean value of €40,685 per case.

An earlier study by Haug et al. from 2014¹⁶ arrived at €61,520 per case, which is why the more recent study was used for the present analysis.

An independent excess-cost analysis of AOK Niedersachsen claims data (Krüger et al., 2024; incident diagnoses 2017, matched controls without CRC) reports €12,289 in the first year after diagnosis and €4,949 per year in years 2–3, closely matching the follow-up assumption used here (€4,913 per year), and €8,429 in the final year of life¹⁷. Using these values would lower the mean treatment cost to about €35,100 per case and the total damage by about 2%, without affecting any of the conclusions. The lower terminal-phase value probably reflects the excess-cost design, which deducts the costs incurred in the last year of life irrespective of the cause of death. Since this analysis is so far available only as a conference abstract and covers a single regional health insurer, Heisser et al. (2022) is retained as the main basis.

Table 2b — Direct treatment costs after Heisser et al. (2022)

Cost component	Value	Weighted	Source / method
Initial phase, year 1 (mean men/women)	10.071–16.450 €	14.037 €	Heisser et al. 2022, Tab. 2
Years 2–5 (35% of year 1, four years)	~€4,913/year	19.651 €	Conservative estimate ("steep drop")
Terminal phase, final year of life	9.930–34.351 €	19.437 €	Heisser et al. 2022; 65% aged ≥70
Five-year relative survival (2021–2023)	64 %	—	ZfKD/RKI 2025; women 66 %, men 63 %, weighted by 2022 cases
Mean treatment cost per case (weighted)	—	40.685 €	$0.64 \times 33,688 + 0.36 \times 53,125$

2.6 VOLY scenarios

The health-economic valuation uses two VOLY scenarios:

(1) EU CAFE / UBA (€40,000): The standard value for air quality cost-benefit analyses (the European Commission's CAFE programme and the ExternE studies)¹⁸.

(2) Schlander et al. 2017, DKFZ (€173,868): A Germany-specific VSLY based on a comprehensive meta-analysis of willingness-to-pay studies conducted at the German Cancer Research Center (DKFZ). The VSLY determined for Germany directly from the empirical WTP studies is €173,868 (international median: €164,409; European median: €158,448). This is currently the methodologically most robust Germany-specific VOLY estimate¹⁹.

Total cost per case comprises: direct treatment costs (€40,685) + YLL costs ($\text{CFR} \times 14.3 \text{ years} \times \text{VOLY}$) + indirect costs (€22,247). The case fatality ratio ($\text{CFR} = 0.408$) is the ratio of colorectal cancer deaths to new cases in Germany in 2022 (22,959 / 56,280; ZfKD/RKI 2025). It is stable across 2021–2023 (0.406–0.410) and consistent with a sex-weighted 10-year relative survival of about 59%; unlike the complement of 5-year survival, it therefore also captures cancer deaths occurring more than five years after diagnosis.

Adding productivity-based indirect costs to a VOLY-based valuation of life years lost may partly double-count the loss from premature mortality, since willingness-to-pay values can already reflect expected income. The indirect costs account for only 2–8% of the total per case, however; omitting them would lower the cost per case to €274,061 (EU CAFE) or €1,055,100 (Schlander) and would not affect any of the conclusions.

3 Results

3.1 PAF and nitrate-attributable CRC cases

In the main scenario, which applies the conservative MARCHES function ($RR = 1.06$ per 10 mg/L) continuously across the German exposure distribution, the PAF is 6.44%, corresponding to 3,063 nitrate-attributable CRC cases per year. The 95% confidence interval of the underlying function (1.00–1.11) marginally includes the null hypothesis and translates into a range of 0 to 5,429 cases. A breakdown by exposure category shows what the estimate essentially rests on: 61.9% of the effect falls in the 10–25 mg/L category, which supplies 29.4 million people. Concentrations above 25 mg/L account for 19.8% in total, and the category above 50 mg/L for only 0.2%. The uncertainty about the course of the exposure-response relationship in the upper concentration range discussed in Section 4.5 therefore concerns roughly one fifth of the estimate, not its core. Table 3 summarises the results. The three counterfactual scenarios show how strongly the avoidable share depends on the chosen target value: a reduction to 25 mg/L — that is, halving the applicable EU limit — would affect 4.7 million people and would avert only 147 cases per year. A target of 10 mg/L would affect 34.2 million people and avert 1,248 cases; a target of 6 mg/L would affect 45.9 million people and avert 1,821 cases. The reason for this pronounced difference lies in the population distribution: only 4.2% of the population is supplied above 25 mg/L, but 45.8% above 10 mg/L. Measures directed solely at the most heavily burdened areas therefore reach only a small part of the avoidable damage. Table 3 additionally reports a sensitivity analysis: if the steeper relationship determined by MARCHES for the lower concentration range is applied ($RR \approx 1.15$ per 10 mg/L up to about 25 mg/L, flattening above), the estimate doubles to 6,826 cases. This value is not presented as an equally ranked scenario, as it depends strongly on the dose assigned to the top exposure category (Section 4.5, point 7); it does, however, indicate that the estimate used here is rather conservative.

Table 3 — PAF results, counterfactual scenarios and sensitivity analysis

Scenario	ERF	Approach	PAF	Attr. cases	95% CI	95% CI of the ERF
Main scenario (reference 0 mg/L)	1.06 per 10 mg/L	continuous	6.44 %	3,063	0–5,429	1.00–1.11
Counterfactual: limit 6 mg/L	1.06 per 10 mg/L	continuous	3.83 %	1,821	—	—
Counterfactual: limit 9.25 mg/L	1.06 per 10 mg/L	continuous	2.82 %	1,344	—	—
Counterfactual: limit 10 mg/L	1.06 per 10 mg/L	continuous	2.62 %	1,248	—	—
Counterfactual: limit 25 mg/L	1.06 per 10 mg/L	continuous	0.31 %	147	—	—
Sensitivity: steeper function below 25 mg/L	1.15 per 10 mg/L up to 25 mg/L	continuous	14.35 %	6,826	3,827–10,980	1.08–1.26

3.2 Cost per attributable case

Table 4 shows total costs per attributable case by VOLY scenario. The Schlander VOLY (€173,868) yields the highest value at €1,077,347 per case and reflects societal willingness to pay for a statistical life year in Germany — considerably above the established EU reference values, but consistent with international comparative studies.

Table 4 — Cost per attributable case by VOLY scenario

VOLY scenario	VOLY	Treatment	YLL cost	Indirect	Total per case
EU CAFE / German Environment Agency	40.000 €	40.685 €	233.376 €	22.247 €	296.308 €
Schlander et al. 2017, Germany	173.868 €	40.685 €	1.014.415 €	22.247 €	1.077.347 €

3.3 Annual total damage

For the main scenario (3,063 cases) the annual total damage amounts to €908 million (EU CAFE) to €3,300 million (Schlander et al. 2017). Table 5 additionally shows what share of this damage would be avoidable if the various target values were met.

Table 5 — Annual total damage and avoidable share (€ million)

Scenario	Attr. cases	EU CAFE (€40k)	Schlander 2017 (€174k)
Main scenario (reference 0 mg/L)	3,063	€908 million	€3,300 million
Counterfactual: limit 6 mg/L	1,821	€540 million	€1,962 million
Counterfactual: limit 9.25 mg/L	1,344	€398 million	€1,448 million
Counterfactual: limit 10 mg/L	1,248	€370 million	€1,345 million
Counterfactual: limit 25 mg/L	147	€44 million	€158 million

3.4 Benefit-cost ratio

The benefit-cost ratio of nitrate reduction depends decisively on the cost basis applied (Table 6). A range is used for the preventive costs: the lower bound of €111.7 million per year captures only the immediately effective compliance costs of the 2017 Fertiliser Ordinance, while the more realistic upper bound of some €292 million per year additionally includes the yield losses quantified in the 2020 amendment (Section 4.2). For the total attributable damage this gives a preventive BCR of between 3.1 and 29.5, and between 1.2 and 5.7 under reactive treatment costs. More informative for policy assessment, however, is the BCR of the counterfactual scenarios, since it sets the benefit actually attainable through a reduction in the limit value against the costs. At a target of 6 mg/L it lies between 1.8 and 17.6 (preventive costs), and at 10 mg/L between 1.3 and 12.0. For a target of 25 mg/L, by contrast, it remains below 1.5 and falls below the threshold of economic viability under unfavourable cost assumptions — further evidence that regulation confined to the hotspots is economically of little value.

Table 6 — Benefit-cost ratio by cost basis and target value

Scenario / target value	VOLY basis	Annual benefit	BCR at €112 million ¹	BCR at €292 million ²	BCR at €580–767 million ³
Main scenario (3,063 cases)	EU CAFE (€40,000)	€908 million	8.1	3.1	1.2–1.6
Main scenario (3,063 cases)	Schlender et al. 2017 (€173,868)	€3,300 million	29.5	11.3	4.3–5.7
Target 6 mg/L (1,821 cases)	EU CAFE (€40,000)	€540 million	4.8	1.8	0.7–0.9
Target 6 mg/L (1,821 cases)	Schlender et al. 2017 (€173,868)	€1,962 million	17.6	6.7	2.6–3.4
Target 10 mg/L (1,248 cases)	EU CAFE (€40,000)	€370 million	3.3	1.3	0.5–0.6
Target 10 mg/L (1,248 cases)	Schlender et al. 2017 (€173,868)	€1,345 million	12.0	4.6	1.8–2.3
Target 25 mg/L (147 cases)	EU CAFE (€40,000)	€44 million	0.4	0.1	0.1–0.1
Target 25 mg/L (147 cases)	Schlender et al. 2017 (€173,868)	€158 million	1.4	0.5	0.2–0.3
¹ Lower cost bound: immediately effective compliance costs of the 2017 Fertiliser Ordinance (BMEL, €111.7 million/year) — excludes yield losses					
² Realistic cost basis: 2020 Fertiliser Ordinance — €84 million compliance costs + €208 million yield losses (BMEL); ³ Reactive technical drinking water treatment (UBA Texte 43/2017, €580–767 million/year)					

3.5 Comparison of Denmark and Germany

Table 7 sets the results for the two countries side by side. For Denmark the annual figures from Jacobsen et al. (2024) are used rather than the metrics of the underlying cohort study, as only these are comparable with the German annual figures. It should be noted that Jacobsen et al. report two exposure categories separately: 72 cases per year above 9.25 mg/L and a further 55 cases in the 3.87–9.25 mg/L band, giving 127 in total. Both figures answer the question of how many cases would be avoidable if a given target value were met; they are therefore not comparable with the total damage reported here (reference 0 mg/L) but with the corresponding German counterfactual scenarios. Table 7 accordingly compares the same question in each case: at a target of 9.25 mg/L, 72 cases per year would be avoidable in Denmark and 1,344 in Germany. The main driver of the higher PAF in Germany (6.44% against 1.4%) is the considerably higher share of exposed population: in Denmark fewer than 10% of the population is supplied above 10 mg/L, in Germany 45.8%.

Table 7 — Methodological comparison: Denmark vs. Germany

Parameter	Denmark	Germany	Method
Reference population	5,800,000	71,000,000	Annual figures, total population in each case
CRC cases	5,153	47,570	Jacobsen 2024 / ZfKD/RKI 2025 (2022)
Exposed (>10 mg/L)	< 10 %	45.8 %	Jacobsen 2024 / Wassertipps
Treatment cost per case	—	40.685 €	Heisser et al. 2022
VOLY (applied)	~€120,000 (implicit)	40.000–173.868 €	Jacobsen 2024 / Schlander 2017
PAF	1.4 %	2.82 %	DE: continuous ERF; DK: $Pe \times (HR-1) / [...]$
Avoidable at target 9.25 mg/L	72	1,344	same question: reduction to 9.25 mg/L
Damage avoided (Schlander VOLY)	—	€1,448 million	$VOLY \times YLL + \text{treatment}$

4 Discussion

4.1 Selection of the VOLY for Germany

This analysis relies primarily on the VOLY estimate of Schlander et al. (2017). It is based on a systematic evaluation of international willingness-to-pay (WTP) studies and represents the methodologically most robust estimate available for Germany. The value of €173,868 determined directly from the WTP studies lies well above the EU standard values used for environmental appraisal (EU CAFE: €40,000), but corresponds to the order of magnitude observed in international health economics for highly developed economies. It is also only slightly above the median values reported by Schlander et al. (international median: €164,409; European median: €158,448).

The strikingly high BCR under the Schlander VOLY (11.3–29.5 relative to preventive Fertiliser Ordinance costs) illustrates how substantially health damage is understated when only EU environmental reference values (€40,000) are used. From a health-economic perspective the Schlander value is the most relevant for policy decisions in the German context.

4.2 Remediation costs: a differentiated analysis (UBA Texte 43/2017)

Drawing on the German Environment Agency report 'Quantification of the agriculturally induced costs of securing drinking water supply', this study distinguishes for the first time ²⁰ between two fundamentally different cost categories for the BCR calculation:

(1) Preventive costs (agricultural measures): The figure of €111.7 million per year used by the German Environment Agency requires closer scrutiny, as it systematically understates the costs of prevention. It corresponds to the immediately effective portion of the compliance costs estimated by the Federal Ministry of Agriculture for the 2017 Fertiliser Ordinance (€191.2 million per year in total, of which €81.1 million took effect only from 2020). It therefore captures compliance and administrative costs alone — the largest single items being the expansion of storage capacity (€45.3 million), annual nitrate sampling (€39.1 million) and the addition of urease inhibitors (€29.6 million).

What it does not include are the economically most significant effects: yield losses and revenue shortfalls. The 2017 Fertiliser Ordinance officially assumed that no further costs for businesses and consumers were to be expected. In the 2020 amendment, however, this item was explicitly quantified: the ministry calculated that reducing the fertilisation requirement by 20 per cent in nitrate-polluted areas results in costs of €208 million per year, in addition to recurring compliance costs of some €84 million²¹. The realistic total burden is therefore approximately €292 million per year — around two and a half times the value originally used. In addition, the ministerial estimates are politically contested: at an earlier stage of the procedure the National Regulatory Control Council considered a multiple of the amount assumed by the ministry to be possible for the administrative burden alone. Moreover, the €208 million yield-loss item relates precisely to the 20% reduction requirement in the nitrate-polluted ("red") areas. Following the rulings of the Federal Administrative Court of 24 October 2025, which declared the Bavarian implementing ordinance, and with it the designation of red areas, invalid for want of a sufficiently determinate statutory basis, these area-specific requirements are currently suspended in most federal states²²; a revised Fertiliser Ordinance is pending. The largest cost item on the prevention side thus describes a requirement that is not being applied at present.

For this reason Table 6 reports the preventive BCR as a range spanning both cost assumptions (€112 and €292 million per year). It thus lies between 3.1 and 29.5 rather than between 8.1 and 29.5 — the core finding holds under either variant. A countervailing effect should also be borne in mind: the costs of the Fertiliser Ordinance purchase not only lower nitrate levels in drinking water but at the same time cleaner surface waters, less eutrophication, reduced ammonia and nitrous oxide emissions, and the protection of biodiversity. The colorectal cancer benefit valued here is therefore only one of several benefit streams; setting the full costs of the ordinance against this single benefit understates the true overall economic BCR.

(2) Reactive costs (technical water treatment): Where water utilities no longer have alternatives and must remove nitrate from the raw water by technical means, the UBA study puts the additional annual costs at €580

to €767 million. In the affected regions drinking water prices would rise by 55 to 76 cents per cubic metre (+32% to +45%). For a household of four this amounts to up to €134 more per year.

Background: according to the 2024 German Nitrate Report, 25.6% of the monitoring points in the EU nitrate monitoring network exceeded the limit of 50 mg/L in the 2020–2022 reporting period; this network deliberately covers sites influenced by agriculture. In the considerably larger AVV designation network (more than 8,000 monitoring points) the share is 15%, rising to 21.2% at predominantly agriculturally influenced points compared with 7.1% at points influenced by settlement or forest. The UBA study draws on primary data from five model regions (OOWV: southern Oldenburg and East Frisia; RheinEnergie: left and right of the Rhine; RWW: Holsterhausen/Üfter Mark) and on a nationwide survey of water utilities. Around 74% of the costs incurred are attributable to preventive measures. Since its 1991 study the UBA has drawn the same conclusion: 'Prevention is cheaper than repair.'

The €580 to €767 million figure is a pure model calculation: none of the five UBA model regions operated technical nitrate treatment at the time of the study; the costs were calculated for hypothetical treatment processes applied to representative raw waters and then scaled up to Germany as a whole via a nationwide utility survey. This does not rule out technical nitrate removal in Germany altogether: in Aschaffenburg a biological denitrification plant has been in operation since December 2000, reducing the nitrate content from around 52 to about 25 mg/L²³. In recent years, moreover, new technical approaches have been advanced: Veolia Water Technologies' CARIX ion-exchange process now runs in more than 20 German waterworks²⁴, and the TZW: DVGW Water Technology Centre has, together with the town of Groß-Umstadt, developed a reverse-osmosis concept for nitrate removal that has been in routine operation since 2021²⁵. An update of the UBA's 2017 cost estimate based on plants actually built today is not yet available.

Site-specific hydrogeology can, moreover, limit what prevention alone can achieve. In well-aerated, highly permeable aquifers such as coarse sand and gravel, nitrification proceeds readily, while natural denitrification, which requires oxygen-poor conditions and electron donors such as organic carbon or reduced sulphur compounds, is largely absent; seepage water reaches the groundwater quickly, and where the denitrification capacity of an aquifer has been exhausted, nitrate concentrations can rise sharply (nitrate breakthrough)²⁶. Such sites pass nitrogen surpluses almost unattenuated to the groundwater. Where these conditions prevail, treatment at the utility is not an alternative to prevention but a necessary complement to it. Denmark provides an example: despite comparatively strict fertilisation rules, Aalborg Forsyning decided in December 2025, as the first Danish utility, to invest several hundred million kroner in nitrate removal, because it does not expect to comply even with the current limit of 50 mg/L by 2032, and a 2026 case study identified biological denitrification as the most suitable full-scale option for Aalborg²⁷. At the same time, the Aschaffenburg plant shows the limits of treatment: it lowers the nitrate content to about 25 mg/L, sufficient for the current limit but well above a target value of 6 or 10 mg/L. Sites of this kind would therefore need additional treatment capacity if the limit were tightened.

The BCR analysis (Table 6) shows that, relative to the total attributable damage, the ratio is 3.1 to 29.5 under preventive costs and 1.2 to 5.7 under reactive treatment costs. Taking the realistically attainable benefit of lowering the limit to 6 mg/L as the basis, the preventive BCR is 1.8 to 17.6 and the reactive BCR 0.7 to 3.4 (Table 6). At the national level, prevention thus remains the more economical option under every configuration; at individual sites with unfavourable hydrogeology, however, the economically optimal strategy may combine source control with targeted treatment. In interpreting these ratios, however, it must be borne in mind that the quantities compared derive from different logics of intervention. The costs of the Fertiliser Ordinance quantify an existing body of rules whose stricter requirements apply only in the designated nitrate-polluted areas and whose effect on groundwater nitrate concentrations has not so far been quantified. The effectiveness monitoring initiated for this purpose in 2019 is still being established; a monitoring ordinance to provide the legal basis is as yet only planned. The benefit reported here, by contrast, relates to attaining defined target values, which would require stricter and correspondingly more expensive measures. The benefit-cost ratio should therefore not be read as an evaluation of the Fertiliser Ordinance but as a comparison of orders of magnitude: it shows that the avoidable health damage exceeds the cost of the most expensive agricultural measures currently under discussion many times over.

4.3 Combined treatment strategies: PFAS and nitrate removal

The amendment to the German Drinking Water Ordinance that entered into force on 12 January 2026 obliges affected water utilities for the first time to comply with binding PFAS limits (PFAS-20: 100 ng/L from 2026; PFAS-4: 20 ng/L from 2028). Since PFAS are already present in groundwater and can be reduced at source only through production-side restrictions (EU-wide PFAS regulation), the utilities concerned are in practice compelled to adopt reactive treatment measures. This raises the question of whether such PFAS investments can be chosen so as to address the nitrate problem at the same time — thereby avoiding a second, technologically different retrofit should nitrate regulation be tightened in future.

Technically, such dual use is possible only with membrane processes (reverse osmosis and nanofiltration). These are the established state of the art for PFAS — including short-chain compounds — and simultaneously remove nitrate, sulfate, chloride and hardness constituents. A utility that is building a membrane plant for PFAS removal in any case thereby solves the nitrate problem as a side effect (a no-regret investment). The CARIX ion exchange process widely used in Germany, which is capable of removing nitrate, is by contrast unsuitable for this dual use: it is optimised for the exchange of inorganic anions and is unsuitable for PFAS, because the anions present at millions of times higher concentration (nitrate, sulfate, chloride) occupy the exchange sites, and short-chain PFAS as well as TFA are generally not retained. Three qualifications limit the reach of this argument, however. First, membrane processes entail higher energy and operating costs than CARIX and produce a concentrate (10–25% of throughput) whose disposal is demanding, particularly in the case of PFAS. Second, the affected regions overlap only partially: PFAS hotspots cluster around industrial sites, airports and locations where firefighting foam was used, whereas nitrate hotspots cluster around intensive agriculture. A utility facing a PFAS problem alone would over-invest by designing precautionarily for nitrate removal. Third — and this is the overriding point — even the most astute reactive combined solution does not overturn the economic superiority of nitrate prevention demonstrated in Section 4.2: source control via the Fertiliser Ordinance (€112–292 million per year) remains considerably cheaper than any technical treatment.

For policy assessment a differentiated picture emerges: the PFAS amendment may act as a catalyst prompting membrane investments that also address the nitrate problem regionally. This effect merely shifts reactive costs, however, and does not replace the economically preferable prevention of nitrate at source.

4.4 Regional differences within Germany

The distribution of nitrate concentrations within Germany differs considerably by region and federal state (mean values of 1–15 mg/L nitrate), but this was not taken into account in the present analysis (Figure 1).

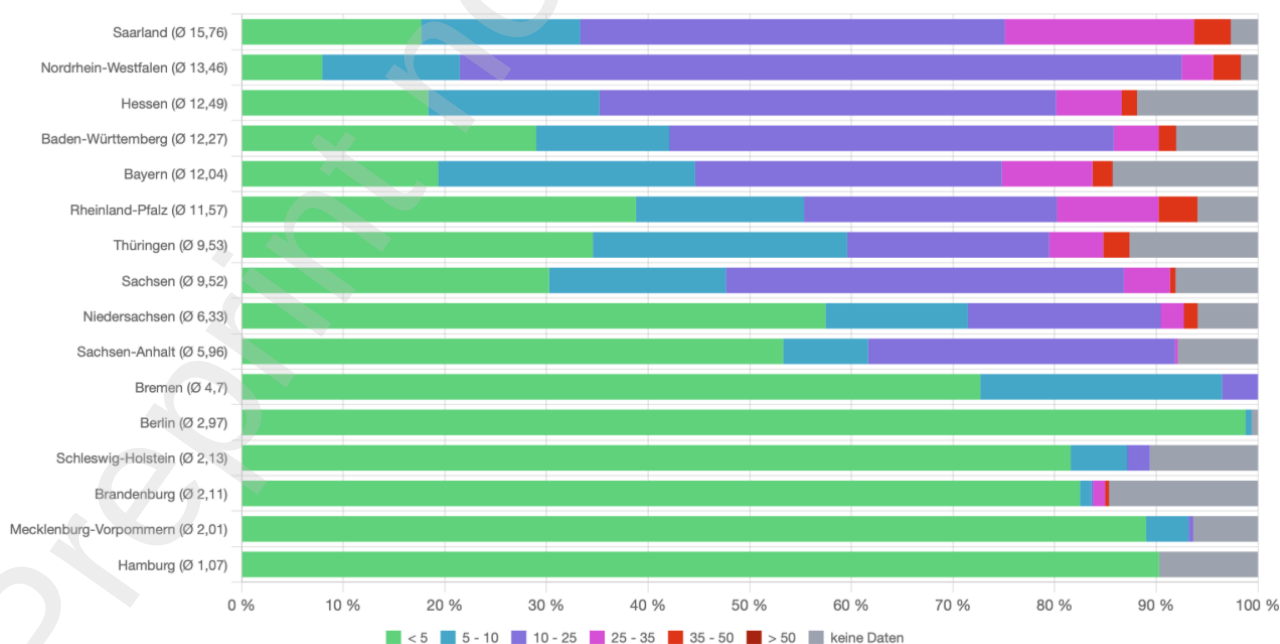


Figure 1 — Nitrate distribution by federal state; Ø = population-weighted mean (mg/L), “keine Daten” = no data. Source: nitratdatenbank.de (operated by the author), as published in German²⁸

4.5 Further limitations

(1) Transfer of the exposure-response relationship: This is the weightiest limitation of the present work. Schullehner et al. (2018) provide the exposure-response relationship from a Danish cohort of 1.74 million people over 33 years. No comparable epidemiological study exists for Germany, which is why the same relationship is assumed here. Whether it is transferable to the German population cannot be tested empirically — a difficulty compounded by the fact that the exposure distribution differs considerably: in Denmark fewer than 10% of the population is supplied above 10 mg/L, in Germany 45.8%. The shape of the exposure-response relationship in the higher exposure range can therefore be estimated only to a limited extent from the Danish data. This objection is addressed in the present version by basing the main scenario no longer on a single study but on the corrected European meta-analysis. Its separate examination of the linearity assumption confirms a saturation effect: the non-linear curve initially follows the linear one and flattens only in the upper concentration range, there however with sharply increasing uncertainty owing to the small number of data points above 50 mg/L. Since only 4.2% of the German population is supplied above 25 mg/L, this uncertainty affects only a small part of the estimate.

(2) Temporal basis of the exposure data: The exposure figures from the Wassertipps database represent a snapshot of the period 2024–2026. Individual lifetime exposure histories of the kind underlying the Danish cohort cannot be reconstructed from them (see also point 5).

(3) Treatment costs: The Heisser data (2012–2016) capture more recent high-cost therapies incompletely; the true value probably lies between €40,685 and €61,520. The excess-cost analysis of Krüger et al. (2024), which yields about €35,100 per case, widens the plausible range downwards to €35,100–61,520; at about 2% of total damage, the effect on the results is minor.

(4) Currency of the VOLY estimate: The Schlender VSLY is based on empirical WTP studies (1995–2015); at current German GDP per capita (~€45,000 in 2024) it would rise to approximately €210,000 — the published value of €173,868 is used here.

(5) Latency: Colorectal cancer develops over a long latency: initiation is followed by roughly 5–10 years until adenoma formation and a further 5–15 years until invasive carcinoma, giving a total of some 10–25 years²⁹. Schullehner et al. (2018) accommodate this through an exposure window averaging 20–35 years before diagnosis. The current exposure shares used here (Wassertipps database, 2024–2026) do not capture this aetiologically relevant historical exposure and therefore systematically understate it — which tends to make the estimated attributable case numbers conservative.

(6) Restriction to a single health endpoint: Only colorectal cancer is valued — according to the MARCHES review currently the sole endpoint for which the epidemiological evidence supports a robust exposure-response function. For further endpoints, however, there are indications of elevated risks that cannot yet be quantified for want of a sufficient number of studies: preterm birth, low birth weight, birth defects and childhood cancers, as well as gastric cancer, for which a systematic review reports a relative risk of 1.91 per 10 mg/L. Since these endpoints are not included, the total damage determined here should be understood as a lower bound on the actual health-economic burden.

(7) Inadequate characterisation of the upper exposure categories: The available epidemiological studies mostly report their highest exposure category as an open-ended class — for example as ">9.25 mg/L" — without stating a mean, median or distribution within that category. It therefore encompasses both people just above the threshold and those at 50 mg/L. For a meta-analysis, however, a dose value must be assigned to this category, and this necessarily arbitrary choice has a considerable influence on the slope of the resulting function at the upper end. The shape of the exposure-response relationship above 10 mg/L therefore cannot be determined robustly from the available data. For this reason the present work refrains from reporting the steeper function additionally given by MARCHES (RR ≈ 1.15 per 10 mg/L) as a separate result scenario; it is taken merely as an indication that the true effect is more likely to lie above than below the conservative estimate used here.

(8) Unknown effect of the preventive measures: For the measures of the Fertiliser Ordinance entered on the cost side there is no robust forecast of the extent to which they will lower nitrate concentrations in groundwater. The stricter requirements apply only in the designated polluted areas, whose delineation was considerably

reduced in several federal states when the areas were redesignated. The effectiveness monitoring initiated in 2019 to avert EU penalty payments, which is intended to document the success of these measures, is still being established. In addition there are long residence times in groundwater, so that changes in fertilisation practice take effect only over decades; the resulting discounting effects remain unaccounted for, as they did in the underlying UBA study. The cost and benefit sides of the ratios reported here should therefore not be understood as the balance sheet of a single package of measures.

(9) Systematic under-representation of small supply zones: The exposure data derive from the published analyses of water utilities. Small supply zones publish less often and less completely; the 6.1 million people for whom no nitrate values are available are therefore likely to be disproportionately attributable to small supplies. This matters because small supply zones across Europe exceed the nitrate limit considerably more often than large ones — the compliance rate is 99.7% for large supply zones but around 95% for small ones — and are typically located in rural, agriculturally shaped areas with the highest nitrate burden. The exposure share reported here is therefore more likely to understate than to overstate the actual burden.

4.6 Comparison with a parallel German estimate

In October 2026 the Forum Ökologisch-Soziale Marktwirtschaft (FÖS), commissioned by Greenpeace, published an independent estimate of the health costs of nitrate-related colorectal cancer in Germany³⁰. Its approach differs from the present one in one fundamental respect: rather than deriving an attributable fraction from the German exposure distribution, it applies the Danish attributable fraction of 2.5% (Jacobsen et al. 2024) directly to German totals, explicitly as a conservative assumption, since mean nitrate concentrations in German drinking water are higher than in Denmark. On this basis FÖS reports direct health-care costs of €74.75 million and indirect costs of €65.59 million per year (together about €140 million, or €1.65 per inhabitant) and, as a separately reported welfare measure, €1.16 billion per year from disability-adjusted life years valued at about €99,000 each. FÖS reports no case numbers; the 2.5% applied to 54,610 cases implies roughly 1,365 cases per year.

The two estimates are consistent in order of magnitude. The implied FÖS case number lies close to the counterfactual scenario of a 9.25 mg/L limit in the present work (1,344 cases), which is plausible, since the Danish 2.5% likewise describes the effect of lowering exposure to a low target value rather than to a reference of 0 mg/L. The FÖS welfare valuation of €1.16 billion lies between the two VOLY scenarios of the present main estimate (€908 million to €3,300 million), and the direct costs per attributable case implied by the FÖS top-down approach (some €55,000) fall within the range of €40,685–61,520 given in Section 4.5, point 3. Where FÖS treats the transfer of the Danish fraction as an assumption, the present work replaces it with an explicit calculation from German exposure data, and confirms the FÖS expectation that the attributable share in Germany is higher than in Denmark (main scenario: 6.44%).

The studies differ markedly on the cost side of prevention. FÖS values a nationwide reduction of nitrogen fertilisation by 10% or 20% at about €505 million or €774 million per year, based on compensation rates paid in Lower Saxony for selected arable crops. This is two to seven times the range of €112–292 million used here. Applying the FÖS costs, the BCR for the total attributable damage would be 1.2–1.8 (EU CAFE) and 4.3–6.5 (Schlander), and for the benefit attainable at 6 mg/L 0.7–1.1 (EU CAFE) and 2.5–3.9 (Schlander). Under the Germany-specific VOLY the benefit thus still clearly exceeds the costs; under the EU reference value the result for the 6 mg/L target is roughly balanced. Two points qualify this comparison: the FÖS cost estimate describes a flat-rate cut in fertilisation whose effect on drinking water concentrations is not quantified, and FÖS itself sets the prevention costs only against the direct and indirect health costs (€140 million), not against the value of lost life years, and expressly refrains from drawing up a cost-benefit balance.

A further difference concerns the policy conclusion. FÖS regards technical treatment at the waterworks essentially as combating symptoms that is unaffordable in the long run, and derives its recommendations exclusively from source control. The present work arrives at the same priority for prevention at the national level, but points out with reference to unfavourable hydrogeology and the case of Aalborg (Section 4.2) that

there are sites where prevention alone cannot reach low target values within a reasonable period, and where targeted treatment is therefore part of the solution.

4.7 Public health implications

The repeal of the nutrient-flow balance ordinance (June 2025) removes a central instrument of nutrient control. At European level developments point in the same direction: a Commission Directive of 9 February 2026 permits the use of so-called RENURE fertilisers derived from processed manure above the previously applicable ceiling of 170 kg nitrogen per hectare. The Federal Constitutional Court heard the Organstreit proceedings brought against the repeal on 16 June 2026 (2 BvE 15/25); at the time of writing no decision had been announced³¹. In addition, the stricter requirements for the nitrate-polluted areas are currently suspended in most federal states following the rulings of the Federal Administrative Court of October 2025 (Section 4.2). Given a BCR of 1.8 to 17.6 for the benefit attainable at a target of 6 mg/L alone — and of 3.1 to 29.5 relative to the total attributable damage — this policy decision cannot be justified in health-economic terms, whichever of the two VOLY scenarios is applied³².

A recent development in Denmark illustrates where robust national evidence can lead. In 2024 the Danish Ministry of Environment — expressly with reference to the study by Jacobsen et al. — appointed an international expert group to review the nitrate limit set out in the EU Drinking Water Directive (2020/2184). Its report, submitted in November 2025 (Halldorsson et al.), concludes that a slightly elevated colorectal cancer risk exists well below the applicable limit of 50 mg/L, and recommends on precautionary grounds that the limit be lowered to **6 mg/L NO₃ (1.35 mg/L NO₃-N)**. In December 2025 the Danish Minister of Environment commissioned an investigation into what lowering the limit would require; according to preliminary figures, around 300 of some 2,500 active public waterworks have measured nitrate above 6 mg/L³³. The programme of the four-party coalition government of June 2026 subsequently committed to lowering the nitrate limit to the values recommended by the authorities (the programme names no figure, but the only recommendation available to date is the 6 mg/L of the expert group) and to examining further restrictions in nitrate-sensitive drinking water areas³⁴; the regulatory implementation was still pending at the time of writing. For Denmark the group estimates that meeting this value would avert 57 to 90 colorectal cancer cases per year. The recommendation is supported among other things by a more recent Danish cohort analysis spanning 27 years and more than 2,200 CRC cases, which found no association between dietary nitrate intake and cancer risk but did find one between nitrate in drinking water and colon cancer above about 9 mg/L — a finding that counters the obvious objection that the observed association in fact reflects dietary factors³⁵. The context is notable: in Denmark around 90 per cent of the drinking water supplied in 2024 was below 5 mg/L — the pressure to act therefore arises there at a level of contamination that only a minority of the German population experiences. Applying the recommended value of 6 mg/L as a counterfactual to the German exposure distribution yields approximately 1,821 avoidable colorectal cancer cases per year (Table 3) — some twenty to thirty times the 57 to 90 cases estimated for Denmark. Two further target values are relevant to the German debate: lowering the limit to 10 mg/L — the threshold from which the epidemiological evidence suggests an elevated risk — would avert 1,248 cases per year, whereas halving the applicable EU limit to 25 mg/L would avert only 147. This gradation is relevant for the choice of a target value: because 45.8% of the German population is supplied above 10 mg/L but only 4.2% above 25 mg/L, only a target in the single digits has an appreciable effect. Regulation confined to the most heavily burdened areas reaches less than one tenth of the total avoidable damage. Within a few months, the expert group's report has attracted considerable attention across Europe³⁶.

The colorectal cancer damage quantified here should further be seen as one specific aspect of a far broader economic environmental damage caused by over-fertilisation. An expert report commissioned by the BDEW puts the avoidable environmental costs arising from the legally permitted surplus fertilisation of some 25 kg N/ha alone — for waters, air, health and climate combined — at approximately €3 billion per year³⁷. The same report sets out on technical grounds why the 2020 Fertiliser Ordinance fails to protect water bodies — in particular through excessive nitrogen requirement values, the abolition without replacement of the farm-level nutrient comparison, and a systematic overestimation of fertiliser requirements by 20–30 kg N/ha. The health costs calculated here should therefore be understood as a conservative lower bound within a considerably larger damage framework.

5 Conclusion

This analysis estimates approximately 3,063 nitrate-attributable colorectal cancer cases per year in Germany. Under the Germany-specific VSLY of Schlander et al. (2017) this corresponds to an annual total damage of some €3.30 billion. If a limit of 6 mg/L were met, around 1,821 of these cases would be avoidable each year; the benefit-cost ratio of this benefit relative to the preventive costs of the Fertiliser Ordinance is 1.8 to 17.6.

These figures must, however, be read with one fundamental caveat. They all rest on the assumption that the exposure-response relationship determined in Denmark is transferable to the German population. This assumption cannot currently be tested, and three circumstances counsel caution. First, the exposure distributions differ fundamentally: in Denmark around 90 per cent of drinking water was below 5 mg/L in 2024 and fewer than 10 per cent of the population above 10 mg/L, whereas in Germany 45.8 per cent are supplied above this threshold. The German analysis therefore extrapolates into an exposure range that is only sparsely populated in the Danish cohort. Second, and for precisely that reason, the shape of the exposure-response relationship at higher concentrations is uncertain; a saturation effect appears plausible but could not be distinguished empirically from a linear course. Third, the transfer rests on a single — albeit the largest available — epidemiological study. For transfers to populations without their own data basis, coefficients obtained from meta-analysis are methodologically regarded as more robust.

The estimates presented here should therefore not be understood as a robust national quantification but as an order-of-magnitude assessment. **Their actual purpose is a different one: to show that the question is large enough to warrant a German study of its own.** What Germany lacks is an epidemiological study on the Danish model — a linkage of individual drinking water exposures reconstructed over the lifetime with cancer registry data. Only such a study could provide a national risk estimator and thereby resolve the central uncertainty of this work. Its value would not, however, be confined to Germany. The internationally available evidence is thin precisely in the range above 10 mg/L, because in most study populations only few people are exposed to such high concentrations (Section 4.5, point 7). This is exactly the gap Germany could close: with 32.5 million people above 10 mg/L and 3.0 million above 25 mg/L, it has a population that covers the internationally missing exposure range in large numbers. A German study would therefore be of European as well as national value — it could determine the course of the exposure-response relationship where it is currently most uncertain. The necessary building blocks are in principle available: comprehensive cancer registry data, a dense network of drinking water analyses from the utilities, and — as this work shows — the ability to assign supply zones spatially. What is missing is the systematic linkage of these datasets.

The Danish sequence demonstrates the effect such evidence can have: a national cohort study gave rise to a health-economic valuation, this to the appointment of an international expert group, and its report finally to the recommendation that the limit be lowered from 50 to 6 mg/L. For Germany — with a considerably more heavily exposed population — this first step is still outstanding. Whatever the outcome of such a study, the need for action established here remains: strengthening groundwater protection through binding fertilisation rules and the designation of larger drinking water protection areas. For even under the most cautious assumptions of this work, the health damage avoided exceeds the cost of prevention, and under the Germany-specific VOLY this holds even for the considerably higher prevention costs estimated by FÖS (Section 4.6). Where unfavourable hydrogeology, such as well-aerated gravel aquifers, limits what source control can achieve, targeted treatment at the utility is a necessary complement; the Aschaffenburg plant and the plans in Aalborg show that biological denitrification is a proven option for this. The model costs of technical nitrate removal discussed in Section 4.2 likewise deserve an update based on plants actually built today.

Declarations

Acknowledgements

The author thanks Dr Jörg Schullehner (Aarhus University) for helpful comments on the methodology of an earlier version of this manuscript. He was not involved in the final analysis; the author alone is responsible for the content and conclusions.

Competing interests

The author operates the drinking water information platform wassertipps.de through zeitform Internet Dienste OHG. The exposure data used in this analysis originate from the Wassertipps database maintained by the author. Zeitform Internet Dienste OHG licenses drinking water data to commercial clients, including manufacturers of water filters, household appliances and heat pumps; none of these clients funded or had any role in this work. The company also publishes the app “Wassertipps Baby&Familie”, which provides drinking water nitrate and sodium values for families; the app is currently free of charge, a version with optional in-app purchases is in preparation, and voluntary donations towards its development are solicited on wassertipps.de. The author declares no other competing interests.

Funding

This work received no external funding.

Ethics statement

This study uses exclusively aggregated, publicly available data: published drinking water analyses of public water utilities, official population statistics and published cancer registry figures. No individual-level human data were collected or analysed; ethical approval and patient consent were therefore not required. The study involves no clinical trial, case report or animal experiments.

Data availability

The postcode-level and sub-zone exposure data underlying this analysis are publicly available for download from wassertipps.de (nitratesexposition_de_0926.zip, nitratesexposition_de_teilgebiete_0926.zip, nitratesexposition_de_ausnahmen_0926.zip; see Section 2.1). All other inputs are taken from the published sources cited.

AI-based tools used

Claude (Anthropic) was used as a tool in preparing this working paper. Responsibility for the selection, verification and factual accuracy of all statements rests with the author. All calculations were reproduced against the primary sources cited; all cited sources were checked in the original.

Type of use	Sections affected	Remarks
Performing and checking the calculations (PAF, cost model, BCR)	Sections 2.4–2.6, 3.1–3.5	Calculation methods and parameters specified by the author; results verified against primary sources
Literature search and source verification	entire document	All sources verified in the original; several suggested figures were rejected or corrected after checking
Drafting and structuring of text sections	Sections 2–5	Content specifications and expert judgement by the author
Consistency checking of figures, tables and cross-references	entire document	Checking for contradictions between body text and tables
Production of the document version (Word)	Document production	purely technical implementation

Tools: Claude (models Sonnet 5, Opus 4.8 and Opus 5), Anthropic PBC, <https://claude.ai> — period of use: June to October 2026.

Appendix: Zusammenfassung (German summary)

Hintergrund: Nitrat im Trinkwasser steht unter dem Verdacht, das Risiko für kolorektales Karzinom (CRC) zu erhöhen. Auf Basis der dänischen Nationalkohortenstudie (Schullehner et al., 2018; n = 1,74 Mio.) und der gesundheitsökonomischen Folgestudie (Jacobsen et al., 2024) wird die populationsattribuierbare Fraktion (PAF) nitrat-bedingter CRC-Fälle für Deutschland geschätzt und monetär bewertet. Methoden: Aus den Daten der Wassertipps Datenbank werden zwei Expositionskategorien definiert (>10 mg/L: 32,5 Mio. Personen; >25 mg/L: 3,0 Mio. Personen; Bezugspopulation: 71 Mio.). Verwendet wird die im EU-Projekt MARCHES nach Fehlerkorrektur abgeleitete Expositions-Wirkungs-Funktion (RR = 1,06 je 10 mg/L), die kontinuierlich auf die Expositionsverteilung angewandt wird. Die Fallzahl basiert auf 47.570 skalierten CRC-Fällen (ZfKD/RKI 2025, Diagnosejahr 2022). Direkte Behandlungskosten (Ø 40.685 €/Fall) werden aus phasenspezifischen GKV-Abrechnungsdaten abgeleitet (Heisser et al., 2022). Die gesundheitsökonomische Bewertung erfolgt über zwei VOLY-Szenarien: EU CAFE (40.000 €) und Schlander et al. (2017, DKFZ; Deutschland-spezifisch: 173.868 €, direkt aus empirischen WTP-Studien). Ergebnisse: Unter der Annahme eines kausalen Zusammenhangs ergibt das Hauptszenario einen PAF von 6,44 %, entsprechend 3.063 nitrat-attributablen CRC-Fällen pro Jahr. Bei Einhaltung des von einer internationalen Expertengruppe empfohlenen Grenzwerts von 6 mg/L wären davon rund 1.821 Fälle jährlich vermeidbar, bei 10 mg/L 1.248 und bei 25 mg/L lediglich 147. Der jährliche Gesamtschaden wird auf 908 Mio. € (EU CAFE) bis 3.300 Mio. € (Schlander VOLY) geschätzt. Das Nutzen-Kosten-Verhältnis beträgt für den bei 6 mg/L erreichbaren Nutzen 1,8 bis 17,6 (präventive Düngeverordnung-Kosten, Bandbreite 112–292 Mio. €/Jahr) und für den gesamten attributablen Schaden 3,1 bis 29,5. Schlussfolgerungen: Die gesundheitsökonomische Last nitratbedingter Darmkrebserkrankungen in Deutschland übersteigt die Kosten einer Sanierung erheblich — unter beiden VOLY-Szenarien. An Standorten, deren Untergrund kaum natürlichen Nitratabbau zulässt – etwa gut durchlüftete Kiesgrundwasserleiter –, ist die Aufbereitung beim Wasserversorger eine notwendige Ergänzung der Prävention. Die Abschaffung der Stoffstrombilanzverordnung (2025) dürfte diese Last mittelfristig weiter erhöhen. Ergänzend sei auf eine offene Frage hingewiesen: Der seit rund zwei Jahrzehnten beobachtete Anstieg von Darmkrebserkrankungen bei jüngeren Erwachsenen fällt zeitlich mit jenen Geburtsjahrgängen zusammen, die seit früher Lebensphase einer durch die Ausweitung der Stickstoffdüngung erhöhten Nitratexposition ausgesetzt waren. Angesichts der langen Latenz des kolorektalen Karzinoms wäre eine Untersuchung dieses möglichen Geburtskohorten-Effekts von Interesse; angesichts der starken Konfundierung mit gleichzeitig veränderten Lebensstilfaktoren lässt sich daraus jedoch kein Zusammenhang ableiten.³⁸

- 1 German Cancer Research Center (DKFZ) (2025). Rise in colorectal cancer among young adults in Germany as well — but well below US levels. Press release; analysis of ten German cancer registries, 2003–2023 (<https://www.dkfz.de/aktuelles/pressemitteilungen/detail/auch-in-deutschland-anstieg-von-darmkrebs-bei-jungen-erwachsenen-aber-deutlich-unter-us-niveau>)
- 2 Picetti R, Deeney M, Pastorino S et al. (2022). Nitrate and nitrite contamination in drinking water and cancer risk: A systematic review with meta-analysis. *Environmental Research*, 210, 112988 (<https://pubmed.ncbi.nlm.nih.gov/35217009/>)
- 3 Schullehner J, Hansen B, Thygesen M, Pedersen CB, Sigsgaard T (2018). Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. *International Journal of Cancer*, 143(1), 73–79 (<https://onlinelibrary.wiley.com/doi/abs/10.1002/ijc.31306>)
- 4 Temkin AM, Evans SR, Manidis T, Campbell C, Naidenko OV (2019). Exposure-based assessment and economic valuation of adverse birth outcomes and cancer risk due to nitrate in United States drinking water. *Environmental Research*, 176, 108442 (<https://www.sciencedirect.com/science/article/pii/S001393511930218X>)
- 5 van Grinsven HJM, Rabl A, de Kok TM (2010). Estimation of incidence and social cost of colon cancer due to nitrate in drinking water in the EU: a tentative cost-benefit assessment. *Environmental Health*, 9, 58 (<https://link.springer.com/article/10.1186/1476-069X-9-58>)
- 6 Jacobsen BH, Hansen B, Schullehner J (2024). Health-economic valuation of lowering nitrate standards in drinking water related to colorectal cancer in Denmark. *Science of the Total Environment*, 906, 167368. DOI: 10.1016/j.scitotenv.2023.167368 (<https://www.sciencedirect.com/science/article/pii/S0048969723059958?via%3Dihub>)
- 7 Online access provided by the federal states to the listed testing laboratories under the Drinking Water Ordinance (https://www.lgl.bayern.de/downloads/zqm/doc/internetzugang_untersuchungsstellen.pdf)
- 8 Rhineland-Palatinate drinking water information system (<https://wasserportal.rlp-umwelt.de/auskunftssysteme/trinkwasserinformationssystem>)
- 9 ArcGIS Hub Postleitzahlengebiete in Deutschland (<https://hub.arcgis.com/datasets/esri-de-content::postleitzahlengebiete-in-deutschland/explore>)
- 10 List of the postcode areas examined in Germany with their nitrate values (https://wassertipps.de/files/nitratexposition_de_0926.zip)
- 11 List of the examined sub-zones of postcode areas in Germany with their nitrate values (https://wassertipps.de/files/nitratexposition_de_teilgebiete_0926.zip)
- 12 List of sub-zones with differing nitrate values (https://wassertipps.de/files/nitratexposition_de_ausnahmen_0926.zip)
- 13 GEKID/RKI (2025). Cancer in Germany 2021–2023. Centre for Cancer Registry Data, Berlin. (https://www.krebsdaten.de/Krebs/DE/Content/Publikationen/Krebs_in_Deutschland/krebs_in_deutschland_2025.pdf)
- 14 Schullehner J, Donat-Vargas C, Villanueva CB (2025). Selected drinking water nitrate exposure-response functions with baseline incidences for EVA. MARCHES Deliverable D2.2, Horizon Europe Grant No. 101095430, 27.01.2025. Corrected exposure-response function: RR = 1.06 (95% CI 1.00–1.11) per 10 mg/L; steeper slope in the lower concentration range: RR ≈ 1.15 (1.08–1.26) (<https://cordis.europa.eu/project/id/101095430/results>)
- 15 Heisser T, Simon A, Hapfelmeier J, Hoffmeister M, Brenner H (2022). Treatment Costs of Colorectal Cancer by Sex and Age: Population-Based Study on Health Insurance Data from Germany. *Cancers (Basel)*, 14(15), 3836 (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9367511/#sec3-cancers-14-03836>)
- 16 Haug, Engel, Verheyen, Linder (2014). Estimating Colorectal Cancer Treatment Costs: A Pragmatic Approach Exemplified by Health Insurance Data from Germany (<https://pmc.ncbi.nlm.nih.gov/articles/PMC3929363/>)
- 17 Krüger K, Hemmerling M, Schaubert K, Brinkmann M, Krauth C et al. (2024). Die Kosten des kolorektalen Karzinoms in Deutschland: Eine Excess-Kosten-Analyse aus der Perspektive der gesetzlichen Krankenversicherung (GKV). Conference abstract, GMDS annual meeting 2024, Dresden. DOI: 10.3205/24gmds509. AOK Niedersachsen claims data; excess costs per case: €12,289 (first year), €4,949 per year (years 2–3), €8,429 (last year of life) (<https://www.researchgate.net/publication/384687721>)
- 18 Desaiques et al. (2011). Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY) (<https://www.sciencedirect.com/science/article/abs/pii/S1470160X10002116>)

- 19 Schlender M, Schaefer R, Schwarz O (2017). Empirical Studies On The Economic Value Of A Statistical Life Year (VSLY) In Europe: What Do They Tell US?
(https://www.researchgate.net/publication/320524786_Empirical_Studies_On_The_Economic_Value_Of_A_Statistical_Life_Year_VSLY_In_Europe_What_Do_They_Tell_US)
- 20 Oelmann M, Czichy C, Scheele U et al. (2017). Quantification of the agriculturally induced costs of securing drinking water supply. German Environment Agency, Texte 43/2017
(https://www.umweltbundesamt.de/system/files/medien/1410/publikationen/2017-05-24_texte-43-2017_kosten-trinkwasserversorgung.pdf)
- 21 Ordinance amending the Fertiliser Ordinance and other provisions (2020). Bundesrat printed paper 98/20. Recurring compliance costs approx. €84 million/year; further costs from yield losses due to the 20% reduction in fertilisation requirements in nitrate-polluted areas: €208 million/year
(<https://www.bundesrat.de/SharedDocs/drucksachen/2020/0001-0100/98-20.pdf>)
- 22 Federal Administrative Court (BVerwG), rulings of 24 October 2025 in four model proceedings on the Bavarian implementing ordinance to the Fertiliser Ordinance (AVDüV). top agrar (2025): Rote Gebiete – wie geht es weiter nach dem Urteil des Bundesverwaltungsgerichts?
(<https://www.topagrar.com/betriebsleitung/news/rote-gebiete-wie-geht-es-weiter-nach-dem-urteil-des-bundesverwaltungsgerichts-20020851.html>)
- 23 Stadtwerke Aschaffenburg (2022). Wasserwerk Aschaffenburg – treatment stages. Denitrification plant in operation since December 2000; nitrate concentration in drinking water approx. 25 mg/L
(<https://www.stwab.de/Energie-Wasser/Wasser/Wasser/Wasserwerk-Aufbereitung-Beschreibung-und-Schema-2022.pdf>)
- 24 Veolia Water Technologies Deutschland (2021). CARIX process (Carbon Dioxide Regenerated Ion Exchanger) for central softening and nitrate removal of drinking water; more than 20 plants operated by municipal water utilities in Germany since the early 2000s
(<https://newsroom.veolia.de/news/veolia-water-technologies-plant-erstmal-zwoelf-carix-anlagen-gleichzeitig-industrie-zeigt-interesse-423664>)
- 25 Mattheß B, Müller U (2023). Nitratentfernung mit Umkehrosmose: vom Konzept zur Umsetzung. DVGW energie | wasser-praxis 09/2023, 20–24. TZW: DVGW Water Technology Centre, practice partner town of Groß-Umstadt; plant in routine operation since 2021
(<https://tzw.de/projekte/projektetails/detail/umkehrosmose-nitratentfernung>)
- 26 Richter B, Patry A, Stein L, Oebel B, Gaugler T (2026). Nitrat – ein unterschätztes Gesundheitsrisiko. Eine Bestandsaufnahme der wissenschaftlichen Evidenz zu Wechselwirkungen von Düngung, Trinkwasser, Gesundheit und Ökonomie. Forum Ökologisch-Soziale Marktwirtschaft (FÖS), Berlin, study commissioned by Greenpeace e.V., October 2026, Section 2.1.1 and the literature cited there (e.g. Cremer 2015; UBA 2017)
(https://www.greenpeace.de/publikationen/Studie_Nitrat_ein_unterschaetztes_Gesundheitsrisiko.pdf)
- 27 LandbrugsAvisen (12 December 2025). I Aalborg Kommune skal de rense vandet for nitrat; Danish Ministry of Environment, press release of 9 December 2025 (see note on the Danish limit review); and: Aalborg University (2026). Udvidet vandbehandling til nitratfjernelse i drikkevand – et casestudie fra Aalborg Kommune. Master's thesis, submitted 4 June 2026
(<https://landbrugsavisen.dk/i-aalborg-kommune-skal-de-reNSE-vandet-for-nitrat-254046> ; <https://projekter.aau.dk/udvidet-vandbehandling-til-nitratfjernelse-i-drikkevand-et-casestudie-fra-aalborg-kommune-clcfc0aa.html>)
- 28 Distribution of nitrate concentrations by federal state, 2026 (<https://www.nitratdatenbank.de/trinkwasser/aktuelle-trinkwassersituation.html>)
- 29 Wan EYF, Yu EYT, Chin WY et al. (2023). The application of lag times in cancer pharmacoepidemiology: a narrative review. *Annals of Epidemiology*, available via ScienceDirect. Latency of colorectal cancer: 5–10 years from initiation to adenoma, 5–15 years from adenoma to invasive carcinoma
(<https://www.sciencedirect.com/science/article/pii/S104727972300090X>)
- 30 Richter B, Patry A, Stein L, Oebel B, Gaugler T (2026). Nitrat – ein unterschätztes Gesundheitsrisiko. Eine Bestandsaufnahme der wissenschaftlichen Evidenz zu Wechselwirkungen von Düngung, Trinkwasser, Gesundheit und Ökonomie. Forum Ökologisch-Soziale Marktwirtschaft (FÖS), Berlin, study commissioned by Greenpeace e.V., October 2026
(https://www.greenpeace.de/publikationen/Studie_Nitrat_ein_unterschaetztes_Gesundheitsrisiko.pdf)
- 31 Rath C (2026). Karlsruhe verhandelt über Grünen-Klage. taz, 17 June 2026 (Federal Constitutional Court, Organstreit 2 BvE 15/25 on the repeal of the nutrient-flow balance ordinance)
(<https://taz.de/Karlsruhe-verhandelt-ueber-Grünen-Klage/!6187957/>)

- 32 BUND (2025). Statement on the repeal of the nutrient-flow balance ordinance. German Federation for the Environment and Nature Conservation (https://www.bund.net/fileadmin/user_upload_bund/publikationen/landwirtschaft/Stellungnahme-Aufhebung-Stoffstrombilanzverordnung-BUND-2025.pdf)
- 33 Danish Ministry of Environment (Miljøministeriet) (9 December 2025). Miljøministeren igangsætter indsats efter ekspertvurdering af grænseværdien for nitrat i drikkevandet. Press release; the Danish EPA has asked DTU to assess the expert report and estimate the cost of reducing nitrate to 6 mg/L (<https://mim.dk/nyheder/pressemeddelelser/2025/december/miljoeministeren-igangsætter-indsats-efter-ekspertvurdering-af-grænsevaerdien-for-nitrat-i-drikkevandet>)
- 34 Danske Vandværker (2 June 2026). Beskyttelse af grundvandet: Historisk dag for vores drikkevand. On the government platform “Det politiske grundlag for firkloverregeringen” (June 2026, pp. 13–14): “Sænke grænseværdien for nitrat til myndighedernes anbefalede grænseværdier” (<https://danskvv.dk/nyheder/beskyttelse-af-grundvandet-historisk-dag-for-vores-drikkevand/>)
- 35 Halldorsson TI et al. (2025). Evaluation of the parametric value for Nitrate in drinking Water. Report commissioned by the Danish Ministry of Environment, submitted 24 November 2025. Recommendation: lowering the nitrate limit from 50 mg/L to 6 mg/L (<https://mim.dk/publikationer/2025/december/evaluation-of-the-parametric-value-for-nitrate-in-drinking-water>)
- 36 MARCHES project, Aarhus University (2025). International experts recommend lower limit value for nitrate in drinking water. News item of 18 December 2025 on the appointment and findings of the expert group (<https://projects.au.dk/marches/news/international-experts-recommend-lower-limit-value-for-nitrate-in-drinking-water>)
- 37 Taube F (2021). Expert assessment of the new German fertiliser law (DüngeG, DüV, AVV GeA) of 2020 from the perspective of drinking water protection. Report commissioned by BDEW — German Association of Energy and Water Industries (https://www.bdew.de/media/documents/PI_20210707_Expertise-Prof-Taube-Bewertung-Düngerecht-2020.pdf)
- 38 Deutsches Krebsforschungszentrum (DKFZ) (2025). Auch in Deutschland Anstieg von Darmkrebs bei jungen Erwachsenen – aber deutlich unter US-Niveau. Pressemitteilung; Auswertung aus zehn deutschen Krebsregistern, Zeitraum 2003–2023 (<https://www.dkfz.de/aktuelles/pressemitteilungen/detail/auch-in-deutschland-anstieg-von-darmkrebs-bei-jungen-erwachsenen-aber-deutlich-unter-us-niveau>)