Ground Water Monitoring

1989 - 2024

Summary

GEUS

The Nationale Geological Survey of
Denmark and Greenland

Groundwater monitoring

Status and trends 1989–2024

Summary

GEUS 2025

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G E U S

1 Summary

This report is part of the national, annual reporting of the results of the national monitoring program for water and nature (NOVANA). The report has a nationwide focus and does not contain assessments of the state of groundwater bodies, and in no way covers the state assessments of groundwater bodies in relation to the Water Framework Directive.

The target groups for this reporting are the Danish Parliament and the Government, authorities and the public, as well as the actors involved in the monitoring, including the Danish Agency for Green Land transistion and Water Environment (SGAV), the Danish Environmental Protection Agency (MST), municipalities, water supplies and Aarhus University (DCE).

This reporting of the status and trend of groundwater is based on data collected in the period 1989-2024 as part of the National Groundwater Monitoring (GRUMO) and Land Monitoring (LOOP). The groundwater water quality in the water supply boreholes from the public water supplies is presented based on the borehole monitoring, which is part of the self-monitoring. Information on the size of water abstraction is based on information from abstractions of groundwater and surface water, i.e. water supplies, industries, field irrigators, etc.

The collected data is presented in a number of figures and tables that are included each year. Based on this, supplementary results and conclusions are presented. In addition, there may be a more detailed data presentation to varying extents, typically in the form of a theme. Not all topics are reported every year. This year's report includes organic micropollutants, while trace elements, phosphorus and redox drilling are not reported. This year, for the first time in the history of the monitoring program, data for fluoride is reported, for which a thematic chapter has been prepared.

The report is published electronically only on the GEUS website www.geus.dk.

The report's professional chapters have been prepared by employees at GEUS, who have the relevant disciplines as their area of work:

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The national monitoring program	*Jacob Kidmose*
Nitrate	*Birgitte Hansen*
Pesticides	*Anders R. Johnsen*
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Fluoride	*Denitza Voutchkova and Birgitte Hansen*
Appendix 1: Data basis and methods	*Lærke Thorling*
Appendix 2: Monitoring network	*Mette Hilleke Mortensen*
Appendix 3: Background knowledge	*Lærke Thorling and Christian Nyrop Albers*

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1.1 Groundwater resources and their utilization

Introduction

Over the past 100 years, the annual precipitation in Denmark has increased. The Danish Meteorological Institute (DMI) compiles statistics on precipitation in Denmark and has found that, for the most recent climate normal period 1991-2020, there has been an increase in average annual precipitation of approximately 7% compared to the previous climate normal period 1961-1990 (DMI, 2023). In absolute terms, this sums up to 47 mm/year more precipitation in the 1991-2020 climate normal, which may have led to higher groundwater levels in parts of the country. Higher groundwater levels are particularly likely to occur in areas that are not artificially drained. In drained areas, higher precipitation will increase drainage water runoff to wetlands and watercourses.

The drinking water supply in Denmark is based on groundwater abstraction, with the very small island Christiansø as the only exception, where desalinated seawater is predominantly used as drinking water. Around 2,600 public waterworks account for the majority of groundwater abstraction for drinking water. In addition, groundwater is abstracted from several smaller non-public waterworks, each supplying fewer than 10 households.

Data basis

Groundwater levels are recorded as part of the national monitoring program with automatic data collection in monitoring wells in groundwater bodies. The assessment of groundwater level trends in 2024 is based on monitoring data collected and reported by the Danish Environmental Protection Agency to the national database Jupiter. Water abstraction volumes are reported annually by the municipalities to Jupiter when they receive and quality-assure data from waterworks and other water abstractors.

Status and trend

The status and trend of groundwater levels are assessed based on long time series. In 2024, the monitoring network comprised a total of 128 monitoring points distributed across 119 boreholes. Data for 40 monitoring points was missing for more than two months in 2024. The national monitoring network for groundwater level currently undergoes a review based on the strategy described in Ditlefsen, C. and Sivertsen, J. (2022), which affects the monitoring in such a way that currently some monitoring points are discontinued and time series terminated, while new are planned.

2023 was the most extreme wet year ever observed and also the first half of 2024 was particularly rainy. Therefore, the measurements for 2024 also show a generally high or very high groundwater level during 2024. 2024 ends with a higher ground water level than normal, though more observations than in previous very wet season are within the normal range compared to the climate normal period 1991-2020. The groundwater level in 2024 remains at a high level after 2023.

Groundwater resources are monitored so that the overall water balance can be continuously assessed to support the management of a sustainable use of the available water resources. Figure 1 shows total annual water abstractions, which in recent years has been between 600 and 850 million m³/year.

Public water supply accounts for the majority of abstraction. Abstraction of groundwater for agricultural irrigation, horticulture, and fish farming (the commercial irrigation category) varies greatly from year to year and was around 140 million m³ in 2024. Excluding agricultural irrigation, the total groundwater abstraction was around 700 million m³/year in 1990 and declined towards 2000 whereafter it has gradually stabilized at around 500 million m³/year.

Surface water abstraction in Denmark is very limited and accounted for just over 3% of the total abstraction in 2024. Surface water is not part of the drinking water supply in Denmark. The use of surface water for fish farming is typically around 100 million m³, but this is not included in the resource assessment, as in practice the water simply flows through the fish farms and is then returns directly to the same watercourse.

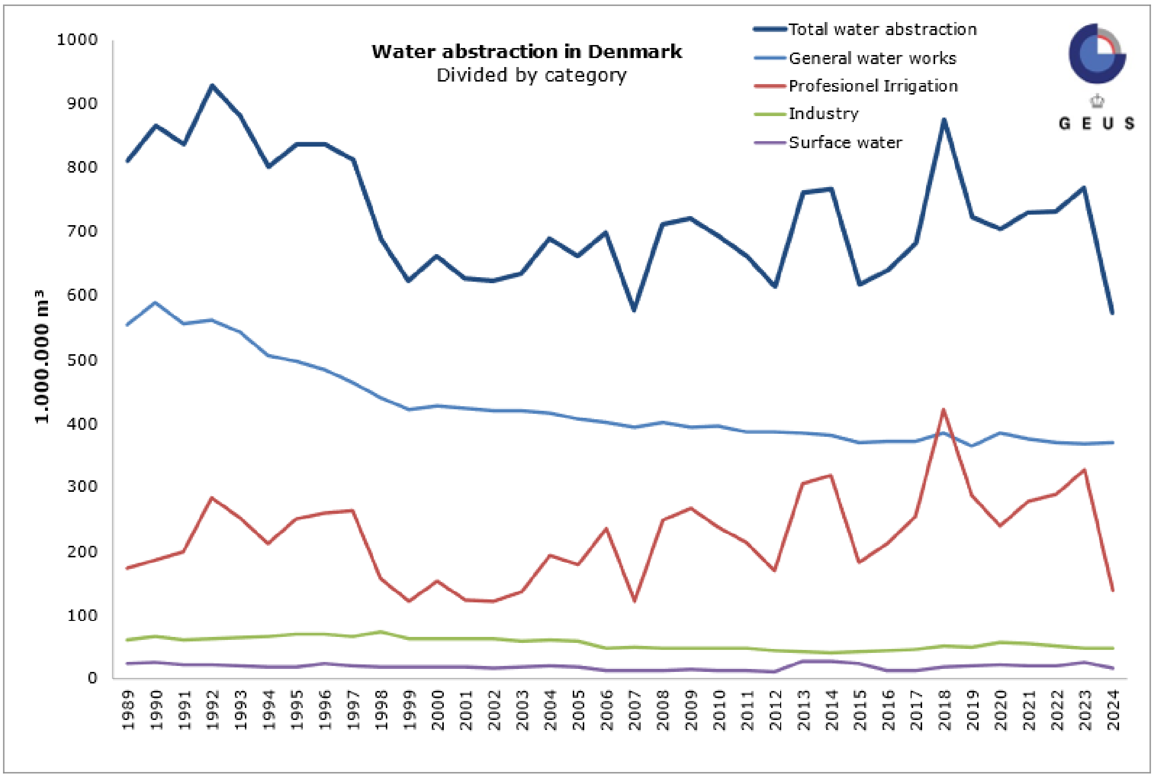


Figure 1. Water abstraction in Denmark in the period 1989-2024 broken down by public waterworks, commercial irrigation (agriculture, horticulture, and fish farming), industry, and surface water. The total reported abstraction is shown with a bold, dark blue line. Note how it varies with commercial irrigation, of which agricultural irrigation accounts for the vast majority. Data from 2024 has been adjusted with estimates for missing reportings.

1.2 Nitrate

Introduction

Elevated nitrate concentrations in groundwater are a problem both in terms of drinking water quality and because of the effect on the rest of the aquatic environment. This is because nitrate in drinking water can be harmful to health, and nitrate in groundwater can contribute to eutrophication of watercourses, lakes, and the marine environment when it enters surface water. The threshold value for nitrate in both groundwater and drinking water is set at 50 mg/l in EU. For the sake of groundwater protection, approximately 17% of Denmark's land area has been designated as nitrate-sensitive abstraction areas for drinking water in 2024.

Data basis

This report is based on groundwater samples taken for various purposes in GRUMO monitoring points, LOOP monitoring points, and water supply wells, respectively. The GRUMO and LOOP monitoring points cover the groundwater part of the national monitoring program NOVANA. The GRUMO monitoring points are situated in wells with depths up to more than 100 m below surface, while the LOOP monitoring points originate from the Agricultural Catchment Monitoring Program and are situated in short, shallow wells, typically less than 5 m below surface. Data from the water supply wells comes from the statutory well quality control, see chapter 2. Sampling in GRUMO alternates between surveillance monitoring, where all monitoring points are sampled, and operational monitoring where monitoring points affected by nitrate and pesticides are primarily sampled. In 2024, operational monitoring was carried out.

Status and trend, groundwater monitoring

Figure 2 shows the nitrate content in GRUMO and LOOP monitoring points and water supply wells sampled in 2024. In approximately 16% of GRUMO monitoring points and approximately 31% of LOOP monitoring points, the nitrate content exceeded 50 mg/l, while only approximately 1% of monitoring points in water supply wells had more than 50 mg/l nitrate. In the GRUMO and LOOP monitoring points, the nitrate concentration was between 25 and 50 mg/l in approximately 17% and 19% respectively, compared to approximately 5% in the water supply wells. Nitrate-free groundwater (nitrate ≤1 mg/l) occurred in approx. 42% of GRUMO monitoring points, approx. 27% of LOOP monitoring points, and approx. 81% of water supply wells.

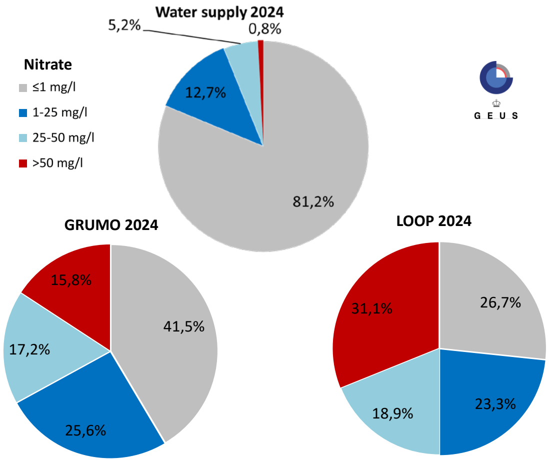


Figure 2. GRUMO, LOOP, and water supply. The distribution of the average nitrate content in 2024 in 931 GRUMO monitoring points, 89 LOOP monitoring points, and 1,658 water supply wells.

Figure 3 shows the geographical distribution of the nitrate concentrations in GRUMO monitoring points in 2024, which shows that nitrate concentrations above the threshold value of 50 mg/l were found in most parts of the country.

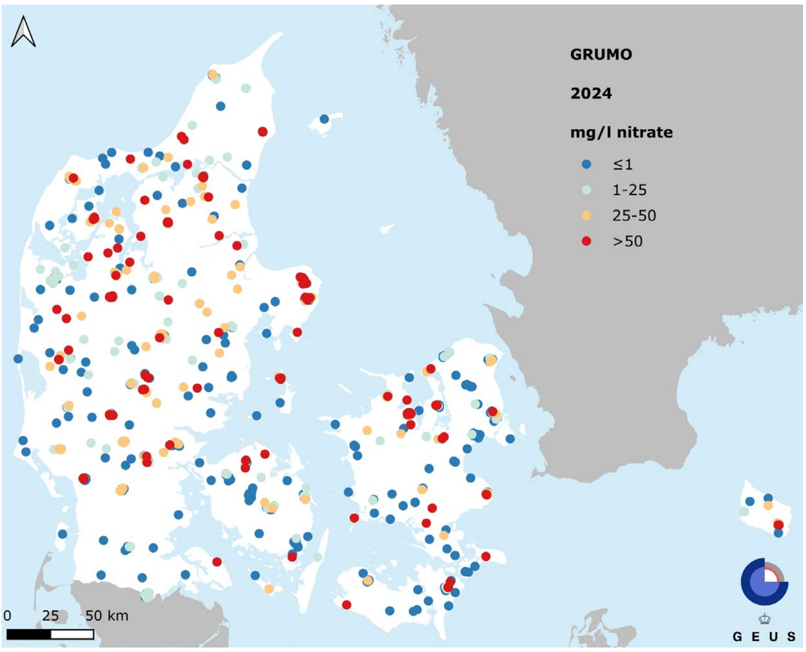


Figure 3. GRUMO. Nitrate concentrations in groundwater in 2024 in 931 GRUMO monitoring points. The nitrate content is divided into four concentration intervals. The highest concentrations are shown at the top.

Figure 4 shows the distribution of nitrate at different depths in GRUMO monitoring points sampled in 2024. The depth is divided into 10-meter intervals. Closest to the surface (0-10 m below surface), nitrate was present (>1 mg/l) in approximately 65% of the monitoring points. Here the concentration of nitrate was above 50 mg/l in about 17% of the monitoring points and above 25 mg/l in about 35% of the monitoring points. The nitrate content gradually decreases with depth, and the majority (approx. 97%) of the samples with >1 mg/l nitrate originates from monitoring points in the upper 50 meters. From 80 m below surface, the nitrate concentration is less than 1 mg/l in the relatively few monitoring points sampled.

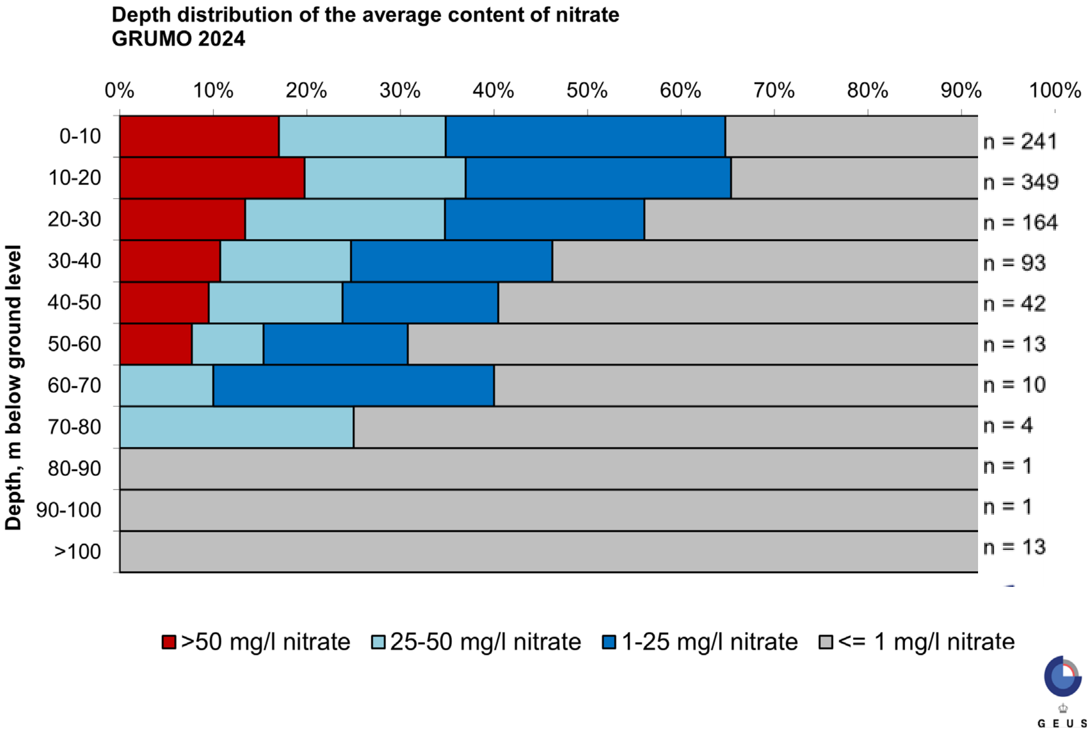


Figure 4. GRUMO. Depth distribution of the average nitrate content in 2024 in 931 GRUMO monitoring points. The red signature shows the percentage of monitoring points with concentrations above the threshold value of 50 mg/l. The depth indicates the distance from the surface to the top of the screen of the monitoring point. The number of monitoring points for each depth is indicated to the right. The nitrate content is divided into four concentration intervals.

Figure 5 shows the distribution of the nitrate content of oxic groundwater in GRUMO monitoring points for each year in the period 1990-2024. The figure is based on annual average nitrate concentrations for each of the monitoring points for each sampling year in question.

Figure 5 shows the nitrate content in the groundwater at the time of sampling and does not reflect the actual temporal trend of the impact of nitrate leaching. This is because the age of the oxic groundwater varies from a few years to approximately 50 years, as shown by the dating of the groundwater (Hansen et al., 2017).

In 2024, approximately 46% of the sampled GRUMO monitoring points were oxic with >1 mg/l oxygen, while approximately 59% of the GRUMO monitoring points contained nitrate disregarding the oxygen concentration. The nitrate content of the oxic groundwater is shown as box plots for each sampling year. The average value (mean) and the 10%, 25%, 50% (median), 75% and 90% fractiles are shown together with the threshold value.

The nitrate content in oxic groundwater shows a wide variation in all years. Throughout the monitoring period (1990-2024), the median value is somewhat below the average value, indicating that there are a few points with very high nitrate values. The highest median and average values were found in groundwater samples from the period 1996-1998. Over the last 11 years, the average value of nitrate concentrations in oxic groundwater has been below the threshold value of 50 mg/l, and there is a tendency towards decreasing concentrations for virtually all fractiles. In 2024, the average value for nitrate in oxic groundwater was approx. 41 mg/l and the median value approx. 36 mg/l, while approx. 31% (132 out of 430 monitoring points) of nitrate concentrations were higher than the threshold value of 50 mg/l.

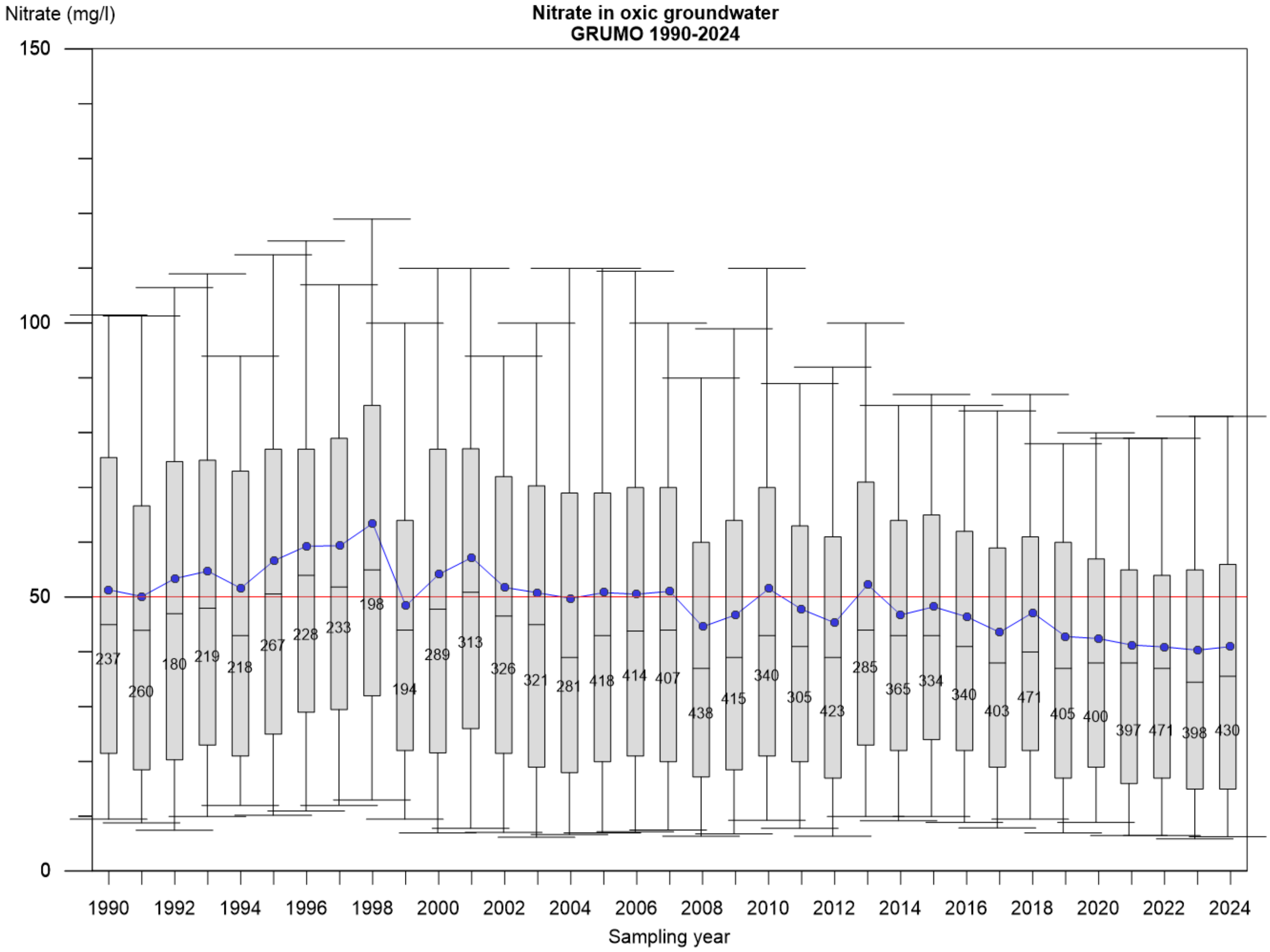


Figure 5. GRUMO. Time series for nitrate content in oxic groundwater in GRUMO monitoring points shown as box plots for each sampling year in the period 1990-2024. The figure is based on the average nitrate content per monitoring point per year. The number of sampled monitoring points with oxic groundwater is indicated for each year.

Figure 6 shows based on the recharge year of groundwater of monitoring points in oxic groundwater only a 5-year moving average of nitrate concentrations divided into four periods. Figure 6 also shows the N surplus in Danish agriculture calculated based on data from Statistics Denmark for the primary Danish agricultural sector (personal communication: Tommy Dalgaard, Department of Agroecology, AU). The N surplus is the amount of nitrogen that is not utilized in agricultural production, and which can therefore potentially be lost to the environment, e.g., in the form of nitrate leaching into groundwater.

There is a clear correlation between the annual trend in the agricultural N surplus and nitrate in oxic groundwater at the overall national level. There is a tendency towards stagnation in the N surplus in the period 2012-2015 at approx. 90-96 kg N/ha/year, roughly coinciding with a slight stagnation in the annual average nitrate content in oxic groundwater in the period 2008-2014 at approx. 43 mg/l. The trend towards stagnation in the nitrate content of oxic groundwater therefore appears slightly earlier than the N surplus, which may be due to uncertainty in the dating of the very young groundwater and the comparison with a 5-year moving average nitrate content in oxic groundwater.

Figure 6 shows a trend towards an increase in both the nitrate content in oxic groundwater and the N surplus in agriculture after the introduction of the Food and Agriculture Package in 2016. The increase in the nitrate content in oxic groundwater from 2010-2012 (annual average: approx. 43 mg/l) to 2016-2018 (annual average: approx. 45 mg/l) is approx. 5%. This observed increase is lower than earlier reported. However, the observed increase is still in line with the 2016 scientific forecast of the impact of nitrate on oxic groundwater as a consequence of the phasing out of the reduced nitrogen application standards after implementation of the Food and Agriculture Package (Hansen and Larsen, 2016). When compared with the nitrogen balance, calculated at field level based on data from LOOP (the Agricultural Catchment Monitoring Program, Blicher-Mathiesen, 2024), there is also a tendency towards an increase in the period 2016-2018, followed by a decline in the nitrogen surplus until 2023.

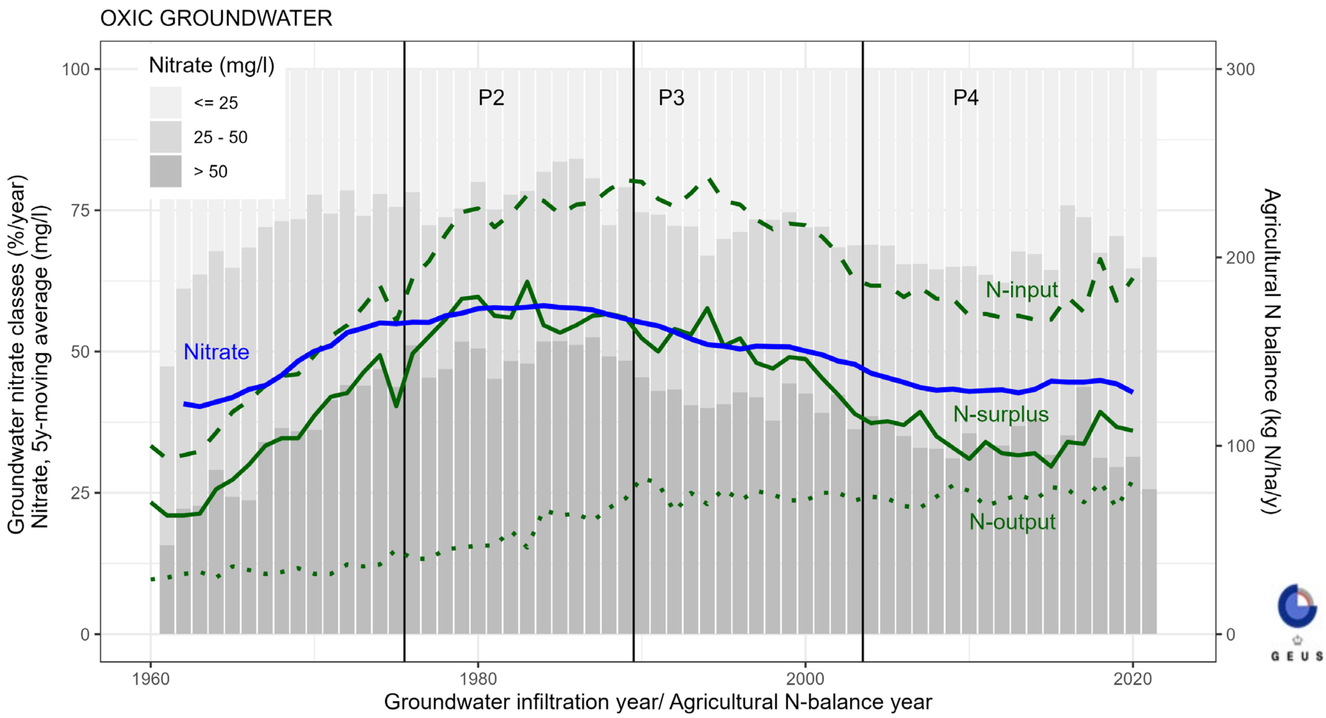


Figure 6. GRUMO. Trends in nitrate in oxic groundwater: 5-year moving average of nitrate concentration in oxic groundwater (blue line). Fraction of samples in three concentrations classes (>50 mg/l, 25-50 mg/l, and 1-25 mg/l) as a function of the year of groundwater formation. The figure is based on 9,229 nitrate samples from 458 oxic, dated monitoring points sampled in the period 1990-2024. Vertical dark lines mark the division into the four periods mentioned in the text. The annual nitrogen balances (N input, N output, and N surplus) for agriculture have been calculated for the primary Danish agricultural sector (personal communication: Tommy Dalgaard, Department of Agroecology, AU).

Trend analysis of nitrate in oxic groundwater in GRUMO shows that concentrations have generally been declining throughout the monitoring period, but a tendency is observed in the nitrate content of oxic groundwater from the third period (1990-2003) to the fourth period (2004-2022) towards more increasing nitrate trends and fewer decreasing nitrate trends. At the same time, the results show that the implemented mitigation measures have not been successful in reducing the nitrate content in groundwater everywhere in Denmark. Thus, for approximately 25% of the studied monitoring points, nitrate concentrations are above 50 mg/l in 2022, and at the same time either a statistically significant increase or no statistically significant trend in nitrate concentration are observed in the most recent period (2004-2022).

Similar nitrate trend analyses have been performed on oxic groundwater in LOOP with a slightly different period division than for GRUMO. The results show that the concentrations have initially been decreasing, but in the most recent period (2016-2024) there is a trend towards more intakes with increasing nitrate content and more intakes without significant trend. At the same time, the results for the most recent period (2016-2024) show that the implemented mitigation measures have not had the same effect on the trends of the nitrate content in oxic groundwater everywhere in the agricultural monitoring catchments. Thus, for approximately 83% of the monitoring points on sandy soils and approximately 25% of monitoring points on clay soils, nitrate concentrations above 50 mg/l are seen in 2024, and at the same time either no statistically significant effect or significantly increasing nitrate trends are observed in the most recent period (2016-2024).

Water supply wells

Figure 7 shows the geographical distribution of nitrate concentrations in groundwater in water supply wells over the last five years (2020-2024), calculated as the average for the period of the annual average for nitrate in the individual wells.

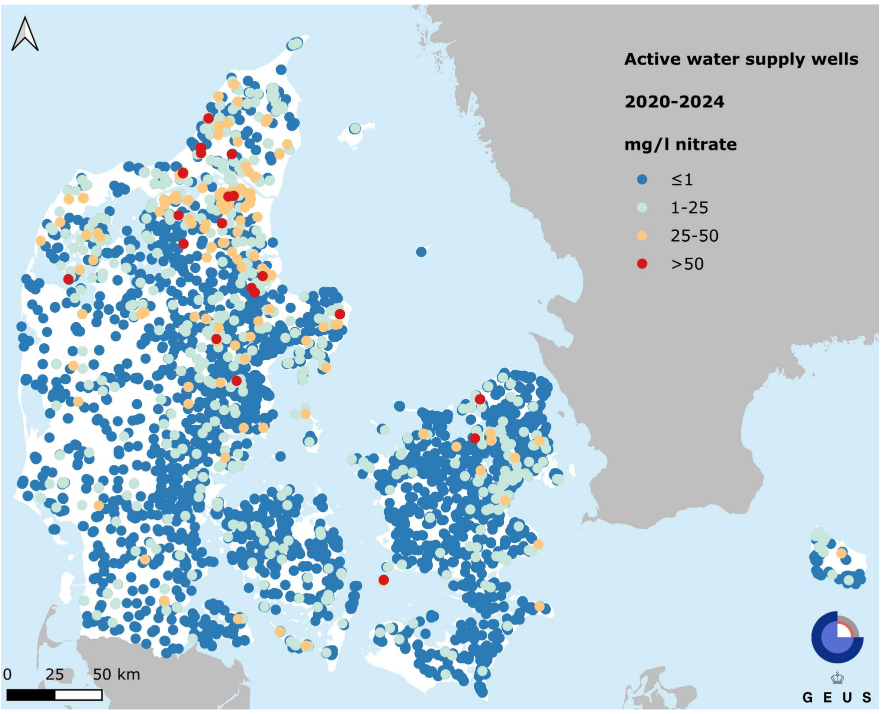


Figure 7. Water supply. Nitrate concentrations in groundwater in 6,019 water supply wells. The nitrate content is divided into four concentration intervals. Data shows average per well in the period 2020-2024. Wells that are no longer used for drinking water supply may be included. The highest concentrations are shown at the top.

The highest nitrate concentrations measured in groundwater samples from water supply wells occur mainly in North Jutland, Thy, Himmerland, and Djursland. This is because these areas have poor natural protection of the groundwater in the limestone aquifers, and because the limestone is found close to the surface in many places. There is a low natural turnover rate of nitrate in the limestone, and nitrate leaching from agricultural areas can therefore penetrate deep into these limestone aquifers (Aamand et al., 2025 & Voutchkova et al., 2025).

Figure 8 shows the depth distribution of nitrate in water supply wells in the period 2020-2024. There is a gradual decrease in the nitrate content with depth. Nitrate concentrations are significantly lower in water supply wells compared to GRUMO monitoring points (see Figure 4). However, in the water supply wells, nitrate concentrations above 50 mg/l were found down to 70-80 m below surface in individual wells in the period 2020-2024. Nitrate concentrations of up to 50 mg/l have also been found in water supply wells deeper than 100 m below surface.

The explanation for the higher frequency of nitrate findings in deep wells in water supply wells, compared to GRUMO monitoring points, may be that local abstraction draws nitrate deep into the groundwater aquifers. It addition it can also be explained by the fact that there is more data in the deeper parts of the groundwater for water supply wells than for GRUMO monitoring points. The generally lower nitrate content in water supply wells compared to the nitrate content in GRUMO monitoring points is related to the fact that water works avoid extraction from wells where the water quality does not meet the threshold values for nitrate (Schullehner and Hansen, 2014).

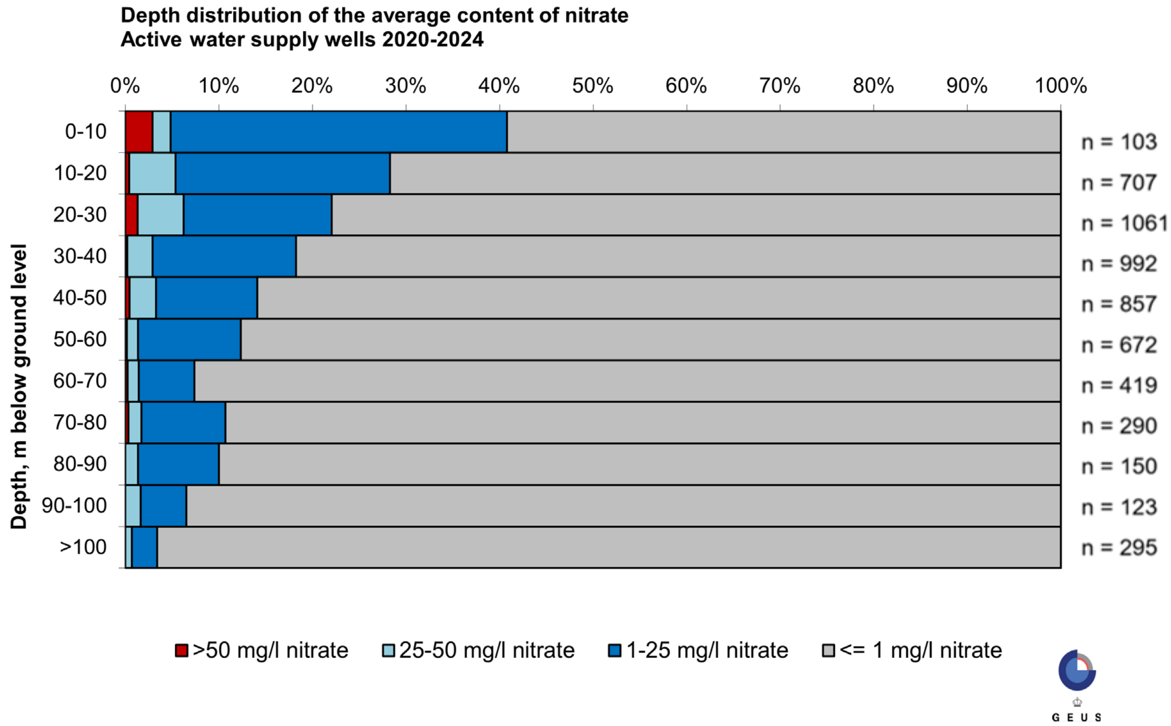


Figure 8. Water supply. Depth distribution of the average nitrate content in 2020-2024 in relation to the top of the well screen in m below surface in 5,669 wells in water supply wells. The red signature shows the percentage of wells above the threshold value for nitrate of 50 mg/l. The number of wells in each depth interval is shown to the right of the figure. The nitrate content is divided into four concentration intervals.

1.3 Pesticides

Introduction

Pesticides and their degradation products may occur in groundwater as a result of commercial or private use of pesticides in forestry and agriculture, parks, gardens, etc. According to Annex 1 of the Groundwater Directive (EU, 2006), the term pesticide also covers substances with biocidal use, e.g., disinfectants, preservatives, and biocides in paint and wood protection. Groundwater is monitored for its pesticide content, among other things, to assess whether the regulation of pesticide consumption is having the desired effects.

Data basis

This report discusses pesticide analyses from the period 2015-2024 from groundwater monitoring points and water supply wells. The substances are presented with a brief explanation in chapter 5 of the main report (in Danish). Sampling in groundwater monitoring alternates between surveillance monitoring, where all monitoring points in pesticide monitoring are sampled, and operational monitoring, where monitoring points with previous pesticide findings are primarily sampled. 2024 was a year of operational monitoring. Over the years, a varying number of substances have been included in the analysis programs. For individual pesticides and degradation products, the threshold value in groundwater is set at 0.1 µg/l, while the threshold value for the sum of all individual substances detected is 0.5 µg/l. The threshold value applies to both pesticide and biocide use. The calculation of the impact from pesticides is based on a method that calculates the share of monitoring points in which, at least once during a period (typically one, three, or five years), there has been at least one substance above the detection limit, at least one substance exceeding the threshold value of 0.1 µg/l, or at least one sample where the sum of detections exceeded the threshold value of 0.5 µg/l.

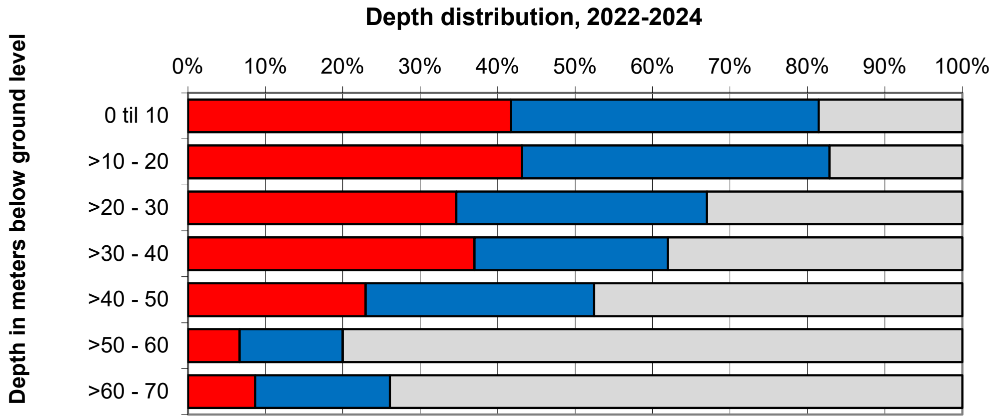
Status, groundwater monitoring

2024 was a year of operational monitoring, and the detection rates for 2024 are therefore not representative of the entire monitoring network. In the period 2022-2024, however, all scheduled GRUMO monitoring points were analysed for pesticides. Table 1 shows that pesticides were found in 69.8% of the monitoring points examined during the period. The threshold value for individual substances (0.1 µg/l) was exceeded at least once in 35.8% of the monitoring points, and the threshold value for the sum of detected substances (0.5 µg/l) was exceeded in 15.9%, where in all cases the threshold value for individual substances had already been exceeded. Findings and exceedances of the threshold value were evenly distributed throughout the country.

Table 1. GRUMO. Pesticide findings in GRUMO monitoring points shown as number and percentage of monitoring points. The monitoring points are divided into monitoring points with at least one finding and monitoring points with at least one exceedance of the threshold value (>0.1 µg/l for individual substances and >0.5 µg/l for the sum) for the period 2022-2024, where all monitoring points have been analysed at least once.

GRUMO	**Intake Number**				**Intake share**		
	Total	**With find-**	**Single substance**	**Sum >0.5 µg/l**	**With findings**	**Single substance**	**Total >0.5 µg/l**
2022	1050	733	376	167	69.8	35.8	15

Figure 9 shows the distribution of pesticides at different depths for the period 2022-2024. The share of findings generally decreases with depth.



	>60 - 70	>50 - 60	>40 - 50	>30 - 40	>20 - 30	>10 - 20	0 til 10
>0,1µg/l	2	2	14	37	61	151	108
Detected ≤0,1 µg/l	4	4	18	25	57	139	103
Not detected	17	24	29	38	58	60	48

Number of intakes

Figure 9. GRUMO. Depth distribution of pesticides for GRUMO monitoring points sampled in the period 2022-2024. The monitoring points are divided into three concentration intervals: >0.1 µg/l, detected ≤0.1 µg/l, and not detected (below the detection limit, typically <0.01 µg/l). The depth indicates the distance from the surface to the top of the screen of the monitoring point. Intakes with a top deeper than 70 m below surface are not shown.

Trends in the fixed group of monitoring points in groundwater monitoring

The trend for 11 individual substances found has been monitored for a fixed core of 409 monitoring points, which have been sampled regularly since 2005. As these are selected monitoring points, the detection rates are not necessarily representative of the monitoring network as a whole. **DMS** was the most frequently detected of the selected substances in the fixed core of monitoring points. DMS has only been monitored since 2018, but in recent years the share of findings has been increasing, while the share of exceedances of the threshold value has been declining slightly. **DPC** is the second most frequently detected of the selected substances and is the pesticide with the highest share of monitoring points exceeding the threshold value. The prevalence of DPC in the fixed group of monitoring points has been largely constant since the first analyses in 2017, albeit with a slight upward trend in exceedances of the threshold value. The share of **BAM** findings has been steadily declining since 1998. The share of exceedances for BAM declined until 2013 and has since remained largely constant at around 5%. The detection rates for desethylatrazine and desisopropylatrazine peaked around 2009 with detections in approximately 15% of monitoring points, followed by sharp declines, so that the prevalence is now 3% and 6%, respectively. **DEIA** shows the same trend, but with less significant declines, probably because desethylatrazine and desisopropylatrazine are converted to DEIA.

Pesticides in water supply wells

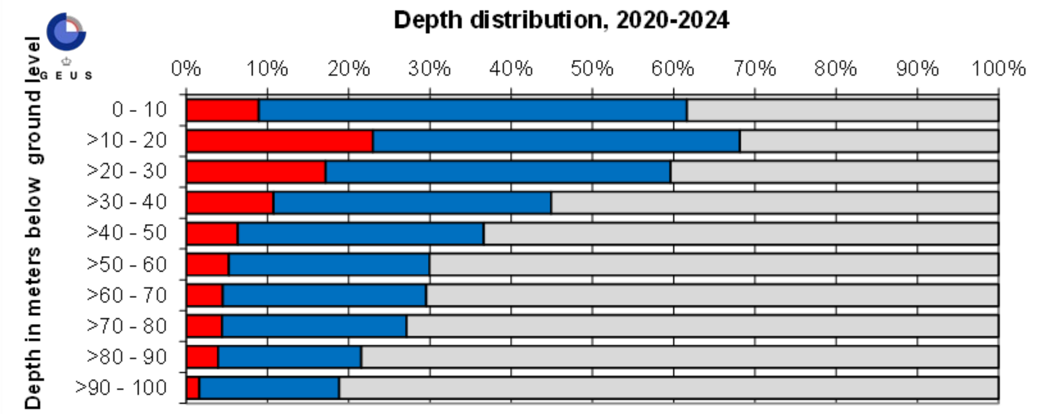
Table 2 shows that in 2024, at least one pesticide substance was found in 55.1% of the water supply wells examined, with 13.8% of the wells having at least one exceedance of the threshold value, and where 2.4% of the wells had at least one exceedance of the threshold value for the sum of pesticides.

In the period 2020-2024, pesticide substances were found at least once in 43.4% of the supply wells, with 10.7% of the wells exceeding the threshold value at least once. The threshold value for the sum of pesticides was exceeded at least once in 2.2% of the wells. Pesticide findings above and below the threshold value are widespread throughout the country, except for an area in West Jutland where many abstractions wells are deep and therefor show only few exceedances of the threshold value.

Table 2. Water supply. Pesticide findings in water supply wells shown as number and percentage of wells. The wells are divided into wells with at least one finding and wells with at least one exceedance of the threshold value (>0.1 µg/l for individual substances and 0.5 µg/l for the sum) for individual years and for the period 2020-2024. Each year is based on data from year-specific downloads from the national database Jupiter.

Water supply	Number				Water supply wells Share (%)		
	Total	With findings	Single substance >0.1 µg/l	Sum >0.5 µg/l	With findings	Single substance >0.1 µg/l	Sum >0.5 µg/l
2024	2175	1198	30	52	55.1	13.8	2
2023	2272	1156	277	44	50.9	12.2	1.9
2022	2405	1208	317	41	50.2	13.2	1.7
2021	2393	1198	321	56	50.1	13.4	2.3
2020	2219	1131	323	51	51.0	14.6	2
2020	6175	2679	659	138	43.4	10.7	2

Figure 10 shows the depth distribution of pesticide findings in 2024 in water supply wells. The share of findings and exceedances of the threshold value is generally highest in the upper groundwater and decreases with depth, but there are a few findings and exceedances of the threshold value in boreholes with filter tops deeper than 100 m below surface.



	>90 - 100	>80 - 90	>70 - 80	>60 - 70	>50 - 60	>40 - 50	>30 - 40	>20 - 30	>10 - 20	0 - 10
>0,1µg/l	2	6	13	19	36	56	109	189	169	10
Påvist ≤0,1 µg/l	21	27	67	106	169	267	346	468	332	59
Not detected	99	120	215	298	480	559	558	445	234	43

Number of intakes

Figure 10. Water supply. Depth distribution of pesticide substances for supply wells sampled in the period 2020-2024. The wells are divided into three concentration intervals: >0.1 µg/l, detected ≤0.1 µg/l, and not detected (below the detection limit, typically <0.01 µg/l). The depth indicates the distance from the surface to the top of the screen. Wells with screen tops deeper than 100 m are not shown.

DMSA, DEET, and 2,6-dimethylacetanilide were added to the pesticide list in the Drinking Water Order in 2024. DMSA is a degradation product of the fungicide cyazofamid and was found in 1.4% of the wells examined in the water supply drilling control, exceeding the threshold value in 0.5% of the wells. 2023 was the last year of sale for cyazofamid. DEET is an active ingredient in repellents against mosquitoes, flies, ticks, etc. and was found in 0.3% of the water supply wells examined. 2,6-dimethylacetanilide is a degradation product of the fungicide metalaxyl/metalaxyl-M, which had its last year of sale in 2013 but is still imported in treated seeds. 2,6-dimethylacetanilide was not detected.

The most frequently found pesticides

Table 3 shows the five most frequently found pesticide substances in the last 10 years (2015-2024) in GRUMO monitoring points and water supply wells. The 25 most frequently found pesticide substances are shown in Table 12 in Chapter 5 in the main report (in Danish).

In 2015-2024, **DMS** (***N,*N-dimethylsulfamid)** was the most frequently detected pesticide in groundwater monitoring, found in 35.6% (5.8% above the threshold value) of the monitoring points examined, and in water supply wells, found in 24.9% (5.5% above the threshold value) of the wells examined. DMS is a degradation product of the fungicides tolylfluanid, dichlofluanid, and cyazofamid.

DPC (desphenylchloridazon). In 2015-2024, DPC was detected in 30.9% of the groundwater monitoring points (17.8% above the threshold value) and 16.3% of the water supply wells examined (4.4% above the threshold value). DPC is the only pesticide substance in groundwater monitoring that is more often detected above the threshold value than below. DPC is a degradation product of the herbicide chloridazon, which was mainly used in beets (sugar beet and fodder beet).

1,2,4-triazole was the second most common substance in groundwater monitoring in the period 2015-2024, found in 34.8% (9.2% above the threshold value) of the monitoring points examined. There may have been false positives in the groundwater monitoring in 2022, which may have contributed to the high detection rate. In water supply wells, 1,2,4-triazole was detected in 1.7% of the wells examined in 2015-2024 without exceeding the threshold value. 1,2,4-triazole is a degradation product from several triazole fungicides used in agriculture and as a biocide in paint and wood protection.

Table 3. GRUMO & Water supply. The five most frequently found pesticides in the period 2015-2024 in GRUMO monitoring points and water supply wells. The table shows the share of monitoring points broken down by at least one finding or at least one exceedance of the threshold value (>0.1 µg/l). See also Appendices 6.2 and 6.4, which show all analysed substances.

GRUMO monitoring points 2015-2024			**Water supply wells 2015**		
Substance name	**With findings (%)**	**>0.1 µg/l (**	**Substance name**	**With findings (%)**	**>0.1 µg/l (%)**
DMS (N,N-dimethylsulfamide)	3	5.8	DMS (N,N-dimethylsulfamide)	24.9	5
1,2,4-Triazole	34	9	DPC (desphenyl chloridazon)	16	4
DPC (desphenyl chloridazon)	30.9	17	R471811 (4-bis-amido-3,5,6-trichlorobenzenesulfonate)	16	1
R471811 (4-bis-amido-3,5,6-trichlorobenzenesulfonate)	29.1	4	BAM (2,6-dichlorobenzamide)	12.7	1
LM3 (6-hydroxy-7,7-dimethyl-6,8-dihydroimidazo[1,2-a][1,3,5]triazine-2,4-dione)[a]	21.7	2	LM3 (6-hydroxy-7,7-dimethyl-6,8-dihydroimidazo[1,2-a][1,3,5]triazin-2,4-dion)	6.1	0

[a] Data from screening of 249 monitoring points in 2022.

R471811 (4-bis-amido-3,5,6-trichlorobenzenesulfonate) was analysed in water supply wells in the period 2022-2024 and detected in 16.2% of the wells examined (1.4% above the threshold value). R471811 was included for the first time in the general analysis program for groundwater monitoring in 2023, but the data was flawed and is not included in the report, which is why some GRUMO monitoring points have not yet been tested for R471811. R471811 was found in 29.1% of the GRUMO monitoring points examined (4.2% above the threshold value). R471811 is a degradation product of the fungicide chlorothalonil, which has been used as a plant protection product and biocide.

BAM (2,6-dichlorobenzamide). In 2015-2024, BAM was detected in 15.8% of the groundwater monitoring points (4.5% above the threshold value) and 12.7% of the water supply wells examined (1.5% above the threshold value). BAM is a degradation product of the herbicides dichlobenil and chlorthiamid and of the seed treatment agent fluopicolid. BAM has historically been one of the most frequently detected degradation products in GRUMO monitoring points and water supply wells, but its impact is declining.

LM3 (2,6-dihydroxy-7,7-dimethyl-6,8-dihydroimidazo[1,2a][1,3,5]triazine-4(6H)-one) was screened in 249 GRUMO monitoring points in 2022 and was the most frequently found triazine (21.7% of screened monitoring points, 2.0% above the threshold value). LM3 was not included in the groundwater monitoring analysis program in 2023 or 2024. In water supply wells, LM3 was found in 6.1% of wells examined in 2023-2024, exceeding the threshold value in 0.5%. LM3 is a degradation product of the herbicide terbuthylazine and probably also of the biocide terbutryn.

1.4 PFAS and Organic Micropollutants

Introduction

Organic micropollutants are a very diverse group of substances with many different detection limits and quality criteria, as well as very different sources and behaviour in the environment. This year's report only includes substances belonging to the PFAS group. However, two screenings were carried out in 2024 as part of the groundwater monitoring, covering substances belonging to the groups of pharmaceuticals and nitrification inhibitors, respectively. Data for these two screenings are therefore also reported.

Data basis

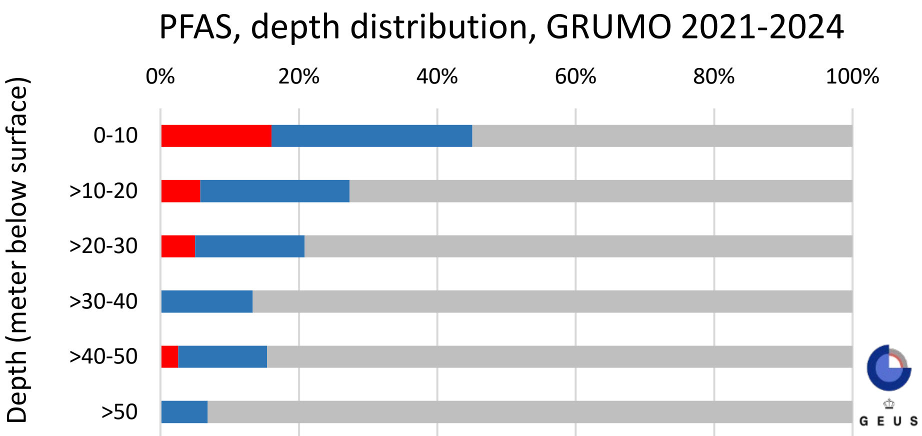
There are differences in sampling frequency for the various organic micropollutants. In order to achieve the best possible representativeness, combined with the most recent data available, the following has been selected for this year's report: For groundwater monitoring, PFAS is reported for 2021-2024, as the use of low detection limits and the expansion to 22 substances began in 2021 and the data set for 2021-2024 can therefore be expected to be relatively homogeneous. For the monitoring of water utility wells, PFAS is only reported for the period 2022-2024 for the same reasons.

For groundwater monitoring, TFA will be reported for the period 2020-2024. For the monitoring of water utility wells TFA analyses will be reported for the period 2021-2024, covering the entire period during which this substance has been analysed.

Groundwater monitoring

Seventeen of 22 PFAS compounds were found, with PFOA being the most frequently found, followed by PFOS, PFBS, and PFHxS. Overall, one or more PFAS compounds were found in 212 out of 672 monitoring points, corresponding to 32%. Slightly more monitoring points were analysed for the four PFAS compounds included in the sum of 4 PFAS, with findings in 171 out of 716, corresponding to 24%. The share of findings is slightly higher than in last year's report, but there are also slightly more indications of false positives.

The concentration was below the threshold value of 0.1 µg/l for the sum of 22 PFAS in all monitoring points, except for three, two of which are likely to be false positives. This means that the threshold value for the sum of detections for 22 PFAS is probably only exceeded in a single monitoring point. On the other hand, the sum of detections for 4 PFAS was above the threshold value of 0.002 µg/l in 53 out of 716 sampled monitoring points, corresponding to 7%. The highest concentration was 0.043 µg/l, i.e. approximately 20 times the threshold value. In five monitoring points, concentrations 10 times the threshold value or more were found.

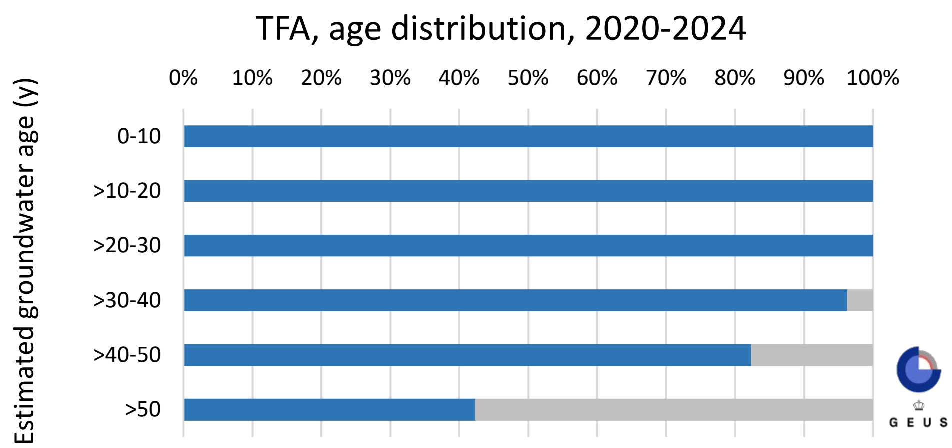


	>50	>40-50	>30-40	>20-30	>10-20	0-10
> Qual. criter.	0	1	0	6	15	31
Detected	3	5	8	19	56	56
Not detected	41	33	52	95	189	106

Figure 11. GRUMO. Depth distribution of 716 GRUMO monitoring points analysed for PFAS substances (excluding TFA) in the period 2021-2024. The monitoring points are divided into three concentration intervals. Red indicates findings above the threshold value for the sum of four PFAS substances: PFOS, PFOA, PFHxS, and PFNA. Blue (>DG) indicates findings of at least one PFAS compound below the threshold value for the sum of four PFAS substances: PFOS, PFOA, PFHxS, and PFNA or the sum of 22 PFAS substances. Gray (not detected) indicates no detected PFAS compounds. The depth indicates the distance from the surface to the top of the screen of the monitoring point. The table below the figure shows the number of monitoring points investigated at different depths, broken down by concentration intervals.

Figure 11 shows the depth distribution for PFAS findings. Both the share of findings and the share of monitoring points with concentrations above the threshold value decrease with depth. There are no exceedances of the threshold value below 30 m, apart from a single monitoring point where the exceedance is most likely due to a false positive. The PFAS compounds that account for the majority of the findings and exceedances are considered persistent and thus not expected to degrade once they have reached the groundwater, so it must be expected that PFAS concentrations above the current threshold value will also be found at greater depths in the coming years.

Trifluoroacetic acid (TFA) belongs to the so-called ultra-short-chain PFAS compounds, and it has been shown that the concentration of TFA in groundwater is increasing and has been doing so for several years (Albers and Sültenfuss, 2024). In the period 2020-2024, a total of 529 GRUMO monitoring points were analysed for TFA, with findings in 466, corresponding to 88%. TFA is detected throughout the country where analysed, at depths of more than 40 meters and in all groundwater formed within the last approx. 40 years, see Figure 12. The highest concentration measured was 2.3 µg/l, which is well below the current threshold value for drinking water of 9 µg/l. TFA comes from both diffuse atmospheric deposition and local sources such as pesticide use. A recent study showed that the TFA content in young groundwater under forest areas, where diffuse atmospheric deposition is the only presumed source of TFA, always contains TFA, typically from 0.2-0.7 µg/l (Albers, 2024). Approximately 25% of the 529 GRUMO monitoring points studied contained TFA above 0.7 µg/l.



	>50	>40-50	>30-40	>20-30	>10-20	0-10
> Qual. criter.	0	0	0	0	0	0
Detected	11	14	26	30	42	95
Not detected	15	3	1	0	0	0

Figure 12. GRUMO. Age distribution of groundwater in 237 GRUMO monitoring points analysed for TFA in the period 2020-2024, where the age of the groundwater has been assessed using tritium-helium dating (see Appendix 3.2). The monitoring points are divided into two concentration intervals: ≤ KV of 9 µg/l, or not detected (below the detection limit). There are no monitoring points with concentrations above the threshold value (>KV). The table below the figure shows the number of monitoring points examined in the different age intervals, divided by concentration intervals.

Overall, it must be concluded that PFAS compounds are detected in a significant share of the GRUMO monitoring points examined. To the extent that TFA is included in calculations of PFAS compounds, based on its chemical structure, PFAS can be detected in the majority of GRUMO monitoring points. However, with the current threshold value for TFA at 9 µg/l, TFA does not contribute to values above the threshold value in drinking water. In the vast majority of cases, the concentration of the other PFAS is significantly below the threshold value for the sum of 22 PFAS (0.1 µg/l), but in some cases (7%) the sum value for the four substances PFOS, PFOA, PFHxS, and PFNA (0.002 µg/l) is exceeded. There are still suspected cases of false positives for PFAS in GRUMO monitoring points and false positives and negatives for TFA, but this does not appear to change the overall picture as long as the most obvious examples of this are omitted.

Screening for pharmaceuticals
In 2024, screening was carried out for 17 pharmaceutical substances (13 human, two veterinary and two used for both human and veterinary purposes) in 245 GRUMO monitoring points. The detection limit for the analysis of the 17 substances typically ranged from 0.01 to 0.05 µg/l, but with a single substance (doxycycline) having a higher detection limit of 0.5 µg/l(see Chapter 6). The two purely veterinary medicinal substances (clopidol and tylosin) were not detected, and there were only five findings of the other medicinal substances; two findings of sulfamethoxazole (sulfonamide antibiotic with both human and veterinary use) at 0.17 and 0.012 µg/l, respectively, one finding of sulfamethizole (sulfonamide antibiotic) at 0.0064 µg/l, one finding of carbamazepine (nerve pain and epilepsy medicine) at 0.028 µg/l and one finding of diatrizoate (X-ray contrast agent) at 0.015 µg/l. Apart from the single finding of sulfamethoxazole, the findings were close to the detection limit for the analysis method used.

Overall, the conclusion of the screening is that the selected pharmaceutical substances are not widespread in Danish groundwater outside built-up areas. With regard to human pharmaceuticals in general, it should be noted that relatively few monitoring points in urban areas have been investigated, and the number of substances investigated is low compared to how many pharmaceuticals are and have been in use. The two pharmaceutical substances that are most frequently mentioned internationally in relation to occurrence in groundwater (sulfamethoxazole and carbamazepine), and which have been proposed for inclusion in the Groundwater Directive, were included in the screening with a relatively low detection limit of 0.01 µg/l but were not found to be particularly widespread in the open countryside. However, sulfamethoxazole was found in two cases above 0.01 µg/l. Finally, it should be noted that pharmaceuticals are degraded into a wide range of substances both in the body of humans and animals as well as and in the environment, and whether these degradation products will be present in groundwater cannot be concluded from the screening, which focused solely on the parent substances.

Screening for synthetic nitrification inhibitors
Synthetic nitrification inhibitors are chemicals that have been used since the 1970s, particularly in North American agriculture, to reduce or delay the conversion of ammonium to nitrate, thereby reducing leaching and increasing the utilization rate of nitrogen from the fertilizer applied. There are no statistics on consumption in Denmark, but the use has probably been very limited, as there has been considerable uncertainty about the economic benefits of using nitrification inhibitors under Danish conditions. In recent years, however, nitrification inhibitors have been brought into play as a climate measure, as they can reduce nitrous oxide emissions from fertilized fields.

In Denmark, there are currently two synthetic nitrification inhibitors on the market, 3,4-dimethylpyrazole and nitrapyrin. In Germany, a mixture of three nitrification inhibitors (3-methylpyrazole, N-[(3-methyl-1H-pyrazol-1-yl)methyl]acetamide, and N-[(5-methyl-1H-pyrazol-1-yl)methyl]acetamide) is also available on the market and is relatively easy to import into Denmark. The presence of these five nitrification inhibitors and three degradation products (3-methylpyrazole-4-carboxylic acid from 3,4-dimethylpyrazole and 6-chloropicolinic acid, and 6-hydroxypicolinic acid from nitrapyrin) was investigated in 38 GRUMO monitoring points, mainly located in Jutland.

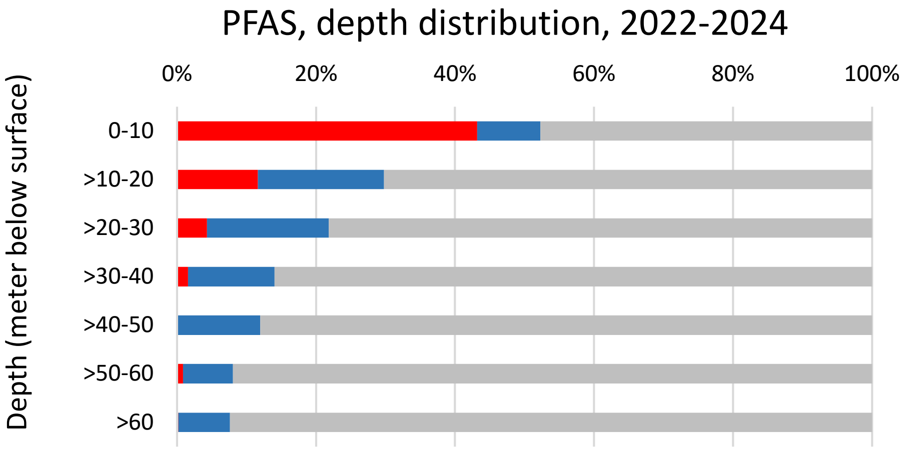
Only one substance, 3,4-dimethylpyrazole was detected, and only in one monitoring point in southern Jutland, where the concentration was 0.13 µg/l. This monitoring point is very close to the surface (2 meters below ground) and contains very young water (<5 years, as determined by tritium-helium dating in 2023), and the finding may thus reflect very recent use of nitrification inhibitors. Overall, there is therefore no evidence of widespread occurrence of the nitrification inhibitors investigated in Danish groundwater. However, it should be noted that 38 investigated monitoring points are not enough to draw conclusions, and that the detection limit in the screening was relatively high (0.05 µg/l) compared to the detection limit normally sought for pesticides (0.01 µg/l). It should also be noted that the use of nitrification inhibitors has probably not been particularly widespread to date, but that this may change in the future if nitrification inhibitors gain ground as a climate measure.

Water supply wells
In 2022-2024, PFAS were analysed in samples from 2,302 water supply wells, and at least one PFAS compound was found in 391 of these, corresponding to 17% of these wells. The sum of 22 PFAS was below the threshold value of 0.1 µg/l in all cases, whereas the sum of 4 PFAS (PFOS, PFOA, PFHxS, and

PFNA) was above the threshold value of 0.002 µg/l introduced in 2021 in 88 wells, corresponding to 3.8%. The highest measured value for the sum of 4 PFAS was 0.024 µg/l, corresponding to 12 times the threshold value for drinking water. In 11 wells, more than 5 times the threshold value was measured. As in groundwater monitoring, PFOA was the most frequently found PFAS compound in the monitoring of supply wells and the substance that was most frequently detected above the threshold value of 0.002 µg/l.

PFAS compounds can be found throughout the country, but findings of PFAS, and in particular concentrations above the threshold value for the sum of four PFAS, are concentrated around Copenhagen, although concentrations above the threshold value are also seen in other areas. In particular, there are also high PFAS concentrations in near-surface water supply wells near the North Sea (Fanø, Hanstholm, Skagen).

There is a clear pattern in the depth distribution of PFAS in the water supply wells, see Figure 13 , with a decrease in both findings and exceedances of the threshold value with depth. The depth distribution supports the conclusion from the groundwater monitoring that PFAS compounds are currently mainly found in groundwater close to the surface, which is consistent with the assumption that the main use of PFAS compounds has taken place within the last 40-50 years.



	>60	>50-60	>40-50	>30-40	>20-30	>10-20	0-10
> Qual. criter.	1	2	0	6	18	34	19
Detected	38	17	35	47	73	53	4
Not detected	475	217	257	325	326	205	21

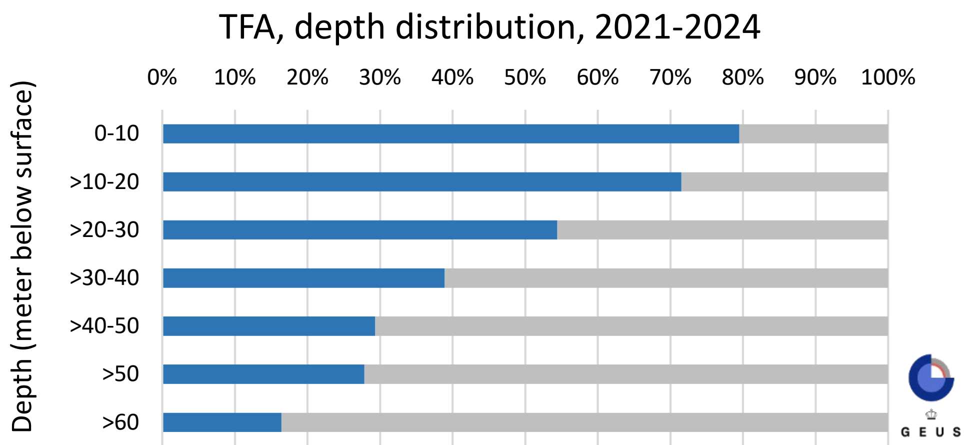
Figure 13. Water supply. Depth distribution for PFAS (excluding TFA) in 2022-2024 in 2,173 water supply wells with known screen depth. The wells are divided into three concentration intervals: Red (> KV) indicates findings above a threshold value (in this case exclusively >0.002 µg/l for 'Sum of PFOS, PFOA, PFHxS and PFNA'). Blue (≤ EQS) indicates findings below the threshold value for the sum of 4 or 22 PFAS. Gray (not detected) indicates wells with no detected PFAS compounds. The depth indicates the distance from the surface to the top of the well screen. The table below the figure shows the number of wells examined at different depths, divided into concentration intervals.

Many water suppliers began testing for TFA after the numerous findings in the GRUMO monitoring points in 2020. As a result, TFA was included in the drinking water a statutory decree with a threshold value of 9 µg/l. A total of 2,394 water supply wells were examined, and the TFA concentration was above the detection limit (typically 0.05 µg/l) in 965 of them, corresponding to 40% (see Chapter 6). There are a number of areas, particularly in West Jutland and on Lolland-Falster, where the number of boreholes analysed for TFA is very low, while the findings are generally spread across the areas where TFA has been analysed.

The highest TFA concentration was 4.8 µg/l, and only 10 wells contained more than 1 µg/l. However, there are various indications that several of the findings of more than 1 µg/l TFA are not real (see chapter 6), so that there is only certainty of TFA up to approx. 1 µg/l in Danish water supply wells.

Figure 14 shows the depth distribution of TFA in water supply wells with known screen depth. The share of findings decreases significantly with depth. As TFA, based on current knowledge, is not expected to degrade in the soil or groundwater, both concentrations and the number of TFA findings are expected to increase in the future, which is consistent with the fact that in recent years there has been a significant and increasing content of TFA in precipitation, which is also reflected in concentrations of typically around 0.5 µg/l in young groundwater under areas with nature (Albers, 2024; Albers and Sültenfuss, 2024). In relation to the analytical uncertainty for TFA, the clear depth dependence shows that most TFA findings in water supply wells are not random but represent actual findings.

Overall, there are one or more PFAS compounds in many water supply wells, especially in wells closer to the surface and especially when TFA is included. The PFAS compounds found in water supply wells are generally the same as those found in the groundwater monitoring, GRUMO, but the detection rates for both TFA and the longer-chained PFAS compounds are lower in water supply wells, which is probably mainly due to the greater average depth of water supply wells (see Appendix 2).



	>60	>50	>40-50	>30-40	>20-30	>10-20	0-10
> Qual. criter.	0	0	0	0	0	0	0
Detected	72	71	98	161	258	211	31
Not detected	367	184	236	253	216	84	8

Figure 14. Water supply. Depth distribution for TFA in the period 2021-2024 in 2,250 water supply wells. The wells are divided into two concentration intervals: ≤ KV of 9 µg/l or not detected (below the detection limit). There are no wells with concentrations above the threshold value (>KV). The depth indicates the distance from the surface to the top of the well screen. The table below the figure shows the number of wells examined at the various well depths, divided into concentration intervals.

1.5 Theme: Fluoride

In this year's report, fluoride has been selected as a special theme for reporting. Fluoride in groundwater has not previously been reported from the GRUMO groundwater monitoring. There is no groundwater quality criterion for fluoride in groundwater, while the threshold value for fluoride in drinking water at 1.5 mg/l. Fluoride in drinking water can have both negative and positive health effects. Small concentrations of fluoride in drinking water can prevent caries (cavities), while high concentrations of fluoride can lead to dental fluorosis (discoloration of the teeth) and skeletal fluorosis (deformities). Both too low and too high a content can therefore have adverse health effects, which is why the WHO recommends a level of around 0.5–1.5 mg/l (WHO, 2017). Conversely, recent research recommends that the fluoride content in drinking water should be below 0.3 mg/l due to concerns about negative cognitive development in children (Grandjean et al., 2024).

GRUMO

Figure 15 shows the depth distribution of fluoride in GRUMO monitoring points sampled in the period 2023-24. General, there is an increase in fluoride concentration with depth. This indicates that fluoride does not originate from seepage from the soil surface but is released by geochemical processes in the geological layers.

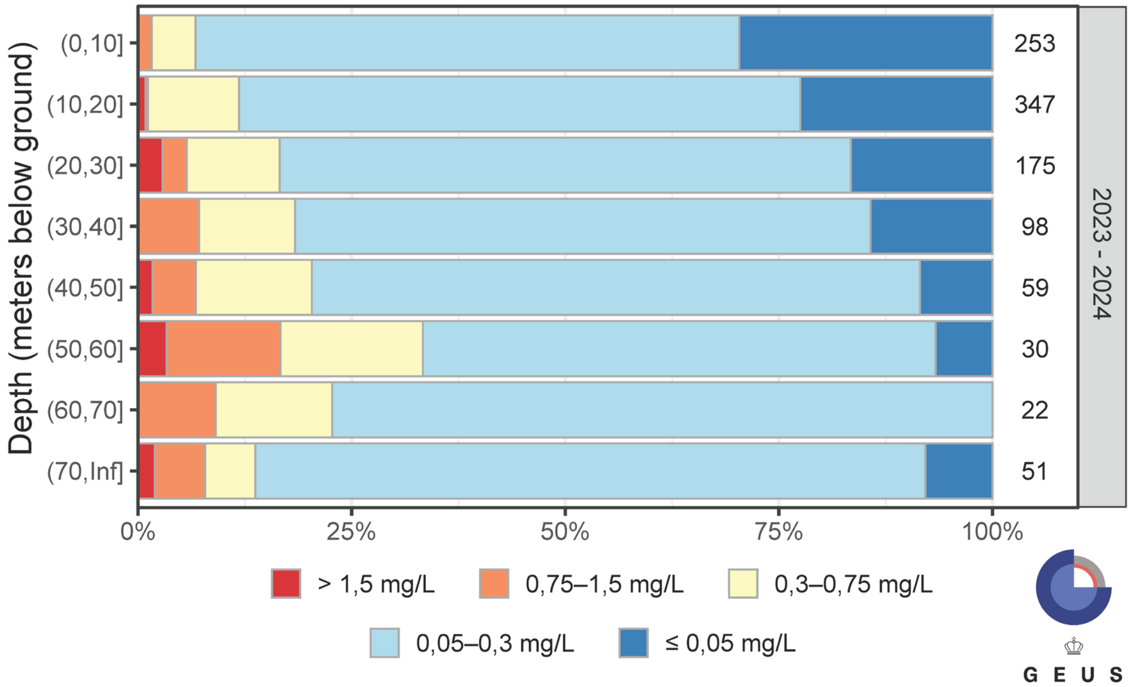


Figure 15. GRUMO. Depth distribution of the average fluoride content in GRUMO monitoring points for the most recent period (2023-2024), divided into five concentration classes. The depth indicates the distance from the surface to the top of the screen of the monitoring point. The number of monitoring points in each depth interval is shown on the right in the figure.

Figure 16 shows the geographical distribution of fluoride content in GRUMO monitoring points in the period 2023-24. The highest concentrations are mainly found in the eastern part of Denmark, where samples are primarily taken from limestone reservoirs overlaid with clay. Eleven monitoring points have concentrations higher than the threshold value (1.5 mg/l), while the highest concentration is 4.4 mg/l. It should be noted that although many GRUMO monitoring points are placed in limestone on Djursland and around Limfjorden, there are only a few monitoring points with fluoride concentrations above 0.3 mg/l in these areas. In these areas, the limestone is shallow and often overlaid by sandy deposits. The lower concentrations of fluoride are probably due to shorter residence times of the groundwater in the limestone compared to the eastern part of Denmark.

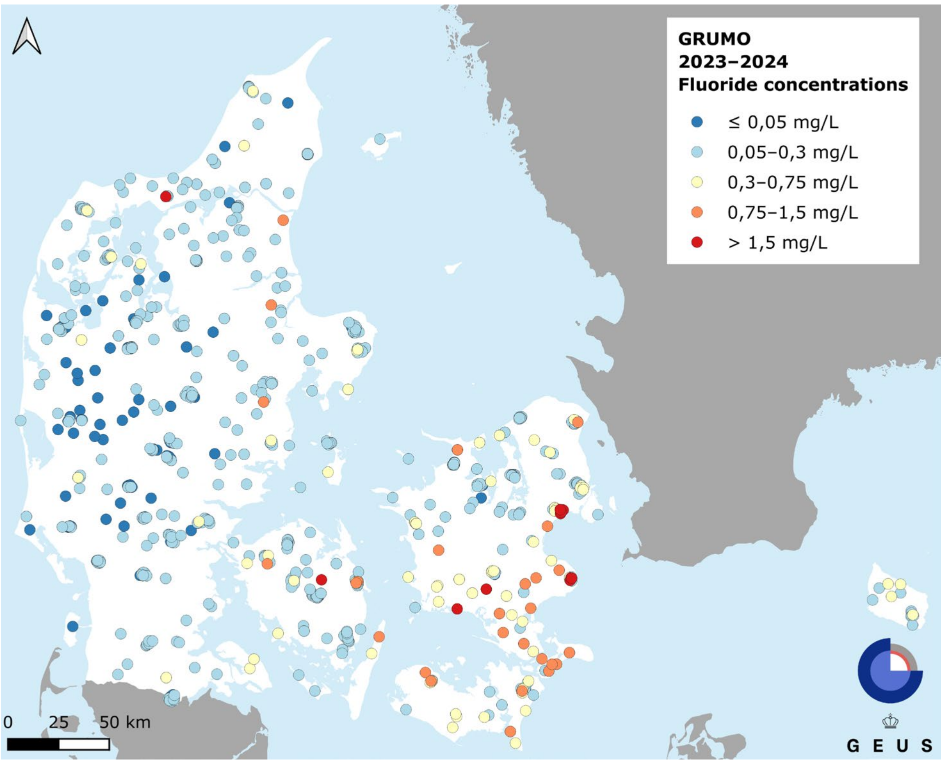


Figure 16. GRUMO. Average fluoride concentrations in 1,035 GRUMO monitoring points in the period 2023-24. The highest concentrations are shown at the top.

Water supply wells

Figure 17 shows the depth distribution of fluoride in water supply wells in the period 2020-2024. In general, there is a gradual decrease in fluoride content greater than 0.3 mg/l with depth. While the fraction above 0.75 mg/l is relatively constant.

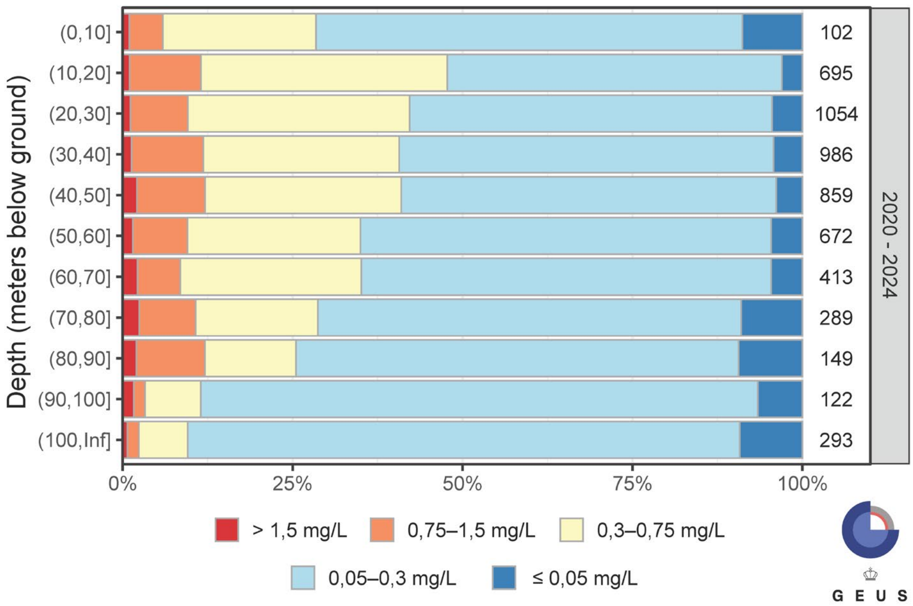


Figure 17. Water supply. Depth distribution of the average fluoride content in relation to the top of the well in m below surface in water supply wells for the period 2020-2024, divided into five concentration classes. The number of wells in each depth interval is shown on the right in the figure.

Figure 18 shows the geographical distribution of fluoride in water supply wells for the period 2020-2024. As with the analyses from GRUMO, the highest concentrations are mainly found in the eastern part of Denmark, where water is primarily extracted from limestone aquifers. Fluoride concentrations are also relatively high on Bornholm, with values above the threshold value. High values, but fewer exceedances of the threshold value, are seen in areas where water is extracted from limestone, on Funen, Djursland, and in the area around Aalborg. Ninety-six wells have average concentrations higher than the threshold value (1.5 mg/l), while the highest concentration is 4.2 mg/l.

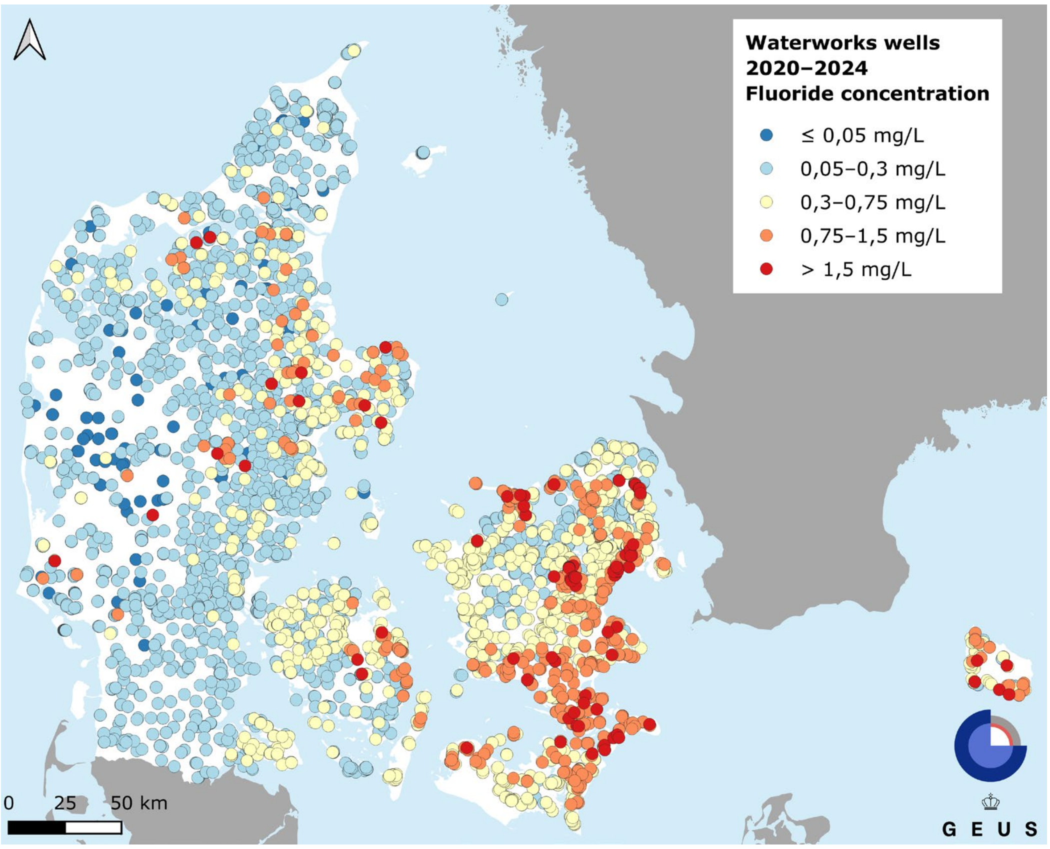


Figure 18. Water supply. Average fluoride concentrations at well level in 5,981 water supply wells in the period 2020-2024. The highest concentrations are shown at the top.

Geology and fluoride

Fluoride occurs in groundwater in varying concentrations depending on geochemical processes in the geological layers. Fluoride-containing groundwater may be due to the dissolution of fluoride-containing minerals such as fluorite/fluorspar, $CaF_{(2)}$ or phosphorite ($Ca_5(PO_4,CO_3,OH)3F$). Phosphorite can have a varying chemical composition. In limestone reservoirs, phosphorite is mainly found in so-called "hardgrounds" (limestone benches cemented as a result of sedimentation stoppage and erosion), while fluorite can be found scattered in the limestone, especially in chalk (Vangkilde-Pedersen et al., 2011).

Figure 19 shows the concentration distributions for fluoride in four different geological layers, where it appears that fluoride concentrations are highest in the limestone aquifers and in the aquifers on Bornholm and lowest in the pre-Quaternary sand aquifers. The median fluoride concentration in Denmark is 0.43 mg/l for limestone aquifers and aquifers on Bornholm, 0.18 mg/l for Quaternary sand aquifers, and 0.12 mg/l for Pre-Quaternary sand aquifers.

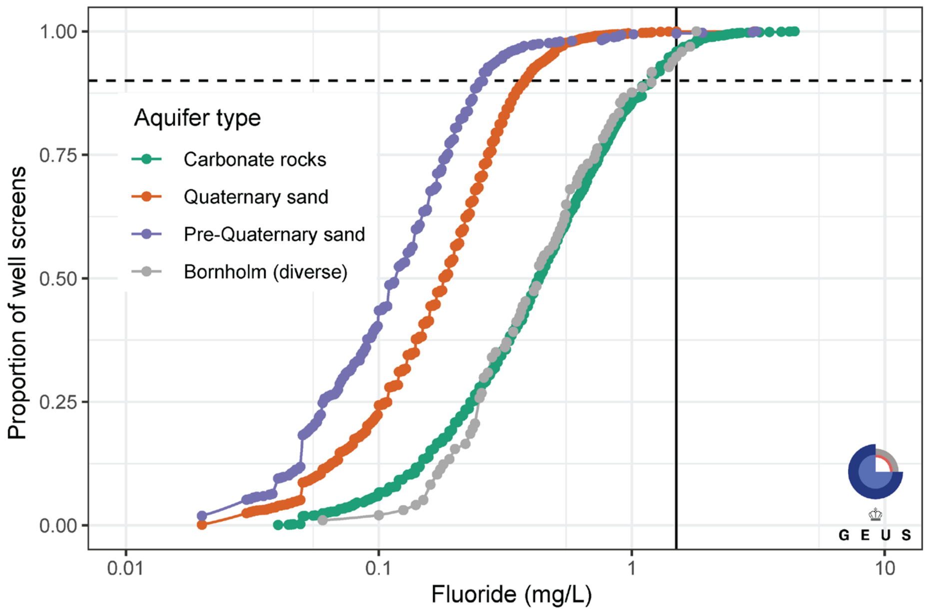


Figure 19. GRUMO monitoring points and water supply wells. Concentration distribution for fluoride in different types of aquifers (ks – carbonate, ps – Quaternary sand, uu – Bornholm). The figure shows average concentrations for the periods at monitoring point level. The vertical line shows the threshold value (1.5 mg/l). The horizontal line shows the 90% fractile (Q90), which can be used as a natural background value. Note the logarithmic x-axis. The figure is based on average concentrations at monitoring point level for the period 2023-2024 for GRUMO and for the period 2020-2024 for water supply wells.

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