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AT A GLANCE

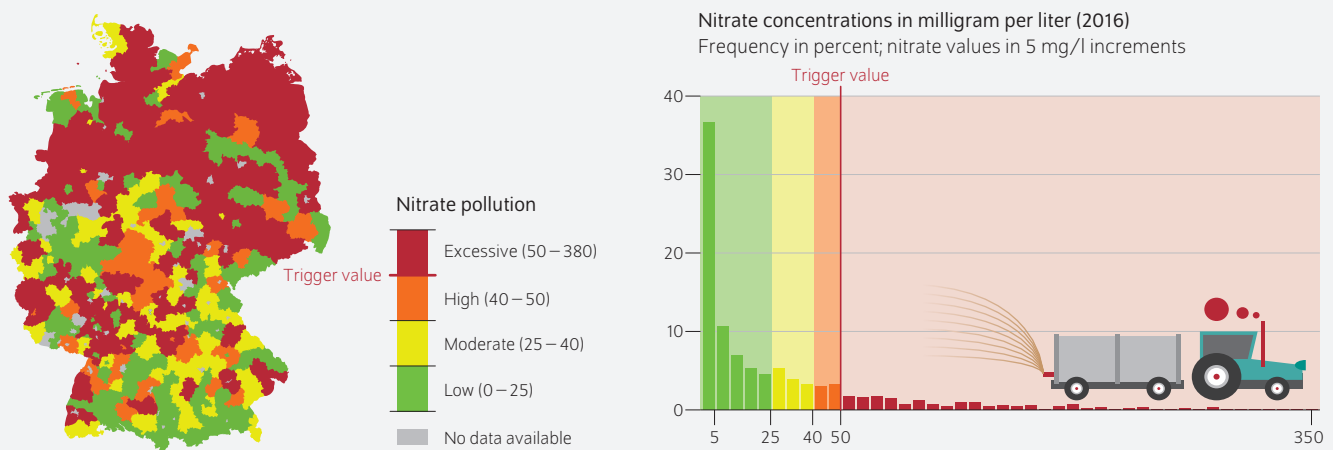
Nitrate pollution of groundwater long exceeding trigger value; fertilization practices require more transparency and oversight

By Greta Sundermann, Nicole Wagner, Astrid Cullmann, Christian von Hirschhausen, and Claudia Kemfert

- Current data on nitrate pollution of groundwater in Germany confirm the long-known exceedance of the trigger value of 50 milligrams per liter at about 18 percent of sampling sites
- Especially excessive nitrate concentrations are found in areas with intensive agriculture
- Possible short-term effects include fines in the millions to the EU; medium-term and long-term effects include ecological problems and increased water rates
- Effective regulation requires transparency and registration of nitrogen input
- Effectiveness of new fertilizer ordinance must be reviewed and, if necessary, supplemented with additional measures

Nitrate pollution is a problem throughout Germany; levels of nitrate concentration have been excessively over the trigger value for many years

Maximum nitrate pollution at district level in milligrams per liter



Source: Authors' own calculations based on data from the German Federal Environment Agency.

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FROM THE AUTHORS

“Combating excessive nitrate pollution of groundwater does not only require acute intervention to avoid fines; rather, structural reforms of intensive agriculture are needed to protect the environment and our health”

— Claudia Kemfert —

MEDIA



Audio Interview with G. Sundermann (in German)
www.diw.de/mediathek

Nitrate pollution of groundwater long exceeding trigger value; fertilization practices require more transparency and oversight

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ABSTRACT

For many years now, nitrate concentrations have exceeded the trigger value of 50 milligrams per liter at nearly one-fifth of the groundwater sampling sites in Germany. Apart from impairing the ecosystem by, for example, causing eutrophication of water bodies, nitrate-polluted drinking water also damages human health; it is suspected to cause cancer. Econometric calculations using current data confirm the correlation established in the literature between nitrate pollution and intensive agriculture. Federal states with intensive agriculture, such as Saxony, Lower Saxony, Schleswig-Holstein, Rhineland-Palatinate, and Saxony-Anhalt, are particularly affected by nitrate pollution. While the German federal and state governments revised the fertilizer ordinance in 2017, it remains insufficient to effectively combat nitrate pollution of groundwater. As a result, the European Union brought proceedings against Germany for non-compliance, threatening fines in the millions of euros. The Fertilizer Ordinance to be adopted in 2020 must ensure compliance with the trigger value for nitrate pollution. Progress has already been made by introducing state-specific regulations and increasing reporting obligations on nutrient inputs. Nevertheless, the effectiveness of these measures should be reviewed closely and, if necessary, supplemented with additional regulatory measures.

For over a decade, nitrate levels in groundwater in Germany and other Member States have exceeded the maximum permissible value set by European Union law. The Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources sets a trigger value of 50 mg/l for the amount of nitrate in groundwater.¹ However, almost a fifth of the 1,200 sampling sites in Germany have nitrate concentrations exceeding 50 mg/l. In areas with heavy agricultural activity, more than every fourth sampling site exceeds the trigger value, sometimes by as much as over 700 percent.

There is consensus in the literature that high nitrate concentrations correlate with the intensity of agriculture. Farmers spread nitrogenous fertilizer over the land to provide their crops with nutrients. If the amount of slurry or chemical fertilizers is too high, the nitrogen accumulates in the ground and biochemical processes convert it into nitrate. As a result, nitrate accumulates in groundwater and surface water. Similar to other nitrogen compounds, elevated nitrate concentrations in surface waters may have a negative impact on the ecosystem by causing excessive algae growth that can displace other plants and animals. In addition, nitrate-contaminated drinking water is harmful to humans, especially newborns, and is suspected to increase the risk of cancer (Box 1).

Due to elevated nitrate concentrations in Germany's groundwater bodies and insufficient countermeasures, the European Commission took the German Federal Government to the EU Court of Justice in 2016.² In response to the suit, the Federal Government reformed the German Fertilizer Ordinance

¹ Cf. European Commission, *Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources* (available online, accessed on February 5, 2020). This applies to all other online sources in this report unless stated otherwise). The Council Directive assumes a harmlessness threshold of 25 mg/l; when the nitrate levels are below this value, a region is no longer obligated to take initiative in regular nitrate measurements. According to the German Environment Agency (*Umweltbundesamt*, UBA), corrective measures must be taken when 75 percent of the trigger value of 50 mg/l has been reached, so at a nitrate level of at or over 37.5 mg/l.

² Cf. European Commission/Federal Republic of Germany, action brought on October 27, 2016, Case C-543/16 (available online).

Box 1

Information on nitrate contamination of groundwater

A little over half (51 percent) of German land area is used for agriculture.¹ Nitrogen fertilizer is an important and common component of agricultural cultivation. Fertilizer maintains soil fertility, delivers nutrients, and promotes the growth of plants, thus increasing agricultural yields. Whereas nitrogen, as the main component of air, is partly converted naturally into reactive nitrogen compounds, such as ammonia (NH₃), nitrogen oxides (NO and NO₂), and nitrate (NO₃), nitrogen in agricultural soils is limited. The biologically available nitrogen is removed from the soil by harvesting, outgassing, infiltration, or leaching. To maintain soil fertility and achieve consistent harvests, farmers regularly add nitrogen to the soil via fertilizer.²

However, excess nitrogen remains in the soil due to over-fertilization. According to the 2016 Nitrate Report, the plants do not absorb almost half of the fertilizers used, resulting in an average surplus of approximately 100 kilograms of nitrogen per hectare each year.³ Bacterial processes convert these excess nitrogen into nitrate, which then seeps into the groundwater or is washed out into the surrounding running and still waters by precipitation.

The excessive use of fertilizer leads to high concentrations of nitrate in water bodies and can have serious ecological and health-related consequences. In terms of ecological consequences, it can lead to the eutrophication of water bodies, which damages plants and animals and thus biodiversity.⁴

The danger posed to humans results from nitrate in food or in the human body. Nitrate can be converted to nitrite during digestion by bacteria or enzymatic processes, which inhibits the transport of oxygen in the blood. Newborns during the first few months of life are particularly at risk.⁵ If caretakers feed newborns baby food that was made using nitrate-contaminated drinking water, low blood oxygen can become a problem. Epidemiological studies indicate that newborns are particularly at risk of developing methemoglobinemia if the nitrate concentration of the water is over 44.3 mg/l.⁶ In addition to the risk posed to newborns, nitrate-contaminated water is also suspected to promote cancer, such as stomach cancer. However, a causal link to specific types of cancer has not yet been determined.⁷

1 Cf. Umweltbundesamt (UBA), *Struktur der Flächennutzung* (Dessau-Roßlau: 2018) (in German; available online).

2 Cf. Sachverständigen Rat für Umweltfragen, *Stickstoff: Lösungsstrategien für ein drängendes Umweltproblem*. Sondergutachten (Berlin: 2015) (in German; available online).

3 Cf. BMU and BMEL, *Nitratbericht 2016* (Berlin: 2016) (in German; available online).

4 Eutrophication describes a human-caused phenomenon in which a body of water becomes overly enriched with nutrients, inducing excessive growth of algae and other aquatic plants. This ultimately leads to a loss of biodiversity as the algae deprive other plants, small organisms, and animals of proper living conditions.

5 Cf. UBA, *FAQs zu Nitrat im Grund- und Trinkwasser* (Dessau-Roßlau: 2020) (in German; available online).

6 Cf. World Health Organization (WHO), *Guidelines for Drinking-Water Quality, 4th Edition* (Geneva: 2017) (available online); European Commission, *Less water pollution from agriculture, but worrying hotspots remain and need stronger action* (Brussels: 2018) (available online).

7 Cf. WHO, *Guidelines for Drinking-Water Quality*.

(*Düngeverordnung*, DüV) in 2017. Together with the German Fertilizer Law (*Düngegesetz*, DüngG), it transposes the European Nitrates Directive into national law.³ Central elements of the reform include pre-determining plant fertilizer needs with location-specific maximum levels of nitrogen⁴ as well as material flow balances (*Stoffstrombilanzen*),⁵ which

must be documented in writing for each plot of land.⁶ For the first time, the DüV was partly regionalized in recognition of the states' differences. The federal states were obligated to choose at least three options from a catalog of additional fertilization requirements, such as a precise analysis of the chemical composition of farm fertilizer or increased minimum storage capacities for slurry and digestate.⁷ Most of the federal states have implemented the additional requirements over the past year via state-specific ordinances.

As the reforms to the Fertilizer Ordinance of 2017 were insufficient to ensure compliance with the Nitrates Directive,⁸

3 DüngG and DüV supplement the Federal Water Act (*Wasserhaushaltsgesetz*, WHG) in protecting bodies of water from nitrate pollution from agricultural sources. Cf. BMU/UBA, *Wasserwirtschaft in Deutschland – Grundlagen, Belastungen, Maßnahmen* (Dessau-Roßlau: 2017) (in German; available online).

4 Before fertilization begins, the amount of nitrogen and phosphate required by field crops is determined. The requirements are based on the average crop yields of the last three years, from which the amount of nitrogen present in the soil before cultivation is deducted. In addition, the site-specific requirements also take into account preceding and intercropping effects, the humus content of the soil, and organic fertilizer quantities of the previous year. Cf. § 3, para. 2 of the DüV (2017) (in German; available online). Exceeding the requirement violates the regulations and is punishable with a fine of up to 50,000 euros. Cf. BMEL, *Die neue Düngeverordnung – Was ändert sich für Landwirtschaft und Gartenbau?* (2020) (in German; available online).

5 Since January 1, 2018, farms (initially only larger farms with higher livestock counts) have had to draw up an annual balance of nutrient inputs and outputs for nitrogen and phosphorus. All incoming and outgoing nutrient fluxes are recorded. Cf. *Verordnung über den Umgang mit Nährstoffen im Betrieb und betriebliche Stoffstrombilanzen* (2017) (in German; available online) and BMEL, *Stoffstrombilanz: Mehr Transparenz über Nährstoffe in landwirtschaftlichen Betrieben* (2019) (in German; available online).

6 An agricultural plot of land is a "uniformly cultivated area, spatially coherent and covered with the same plant species or with plant species with comparable nutrient requirements or intended for cultivation," cf. § 2 of the DüV.

7 Cf. § 13 of the DüV.

8 Cf. BMEL, "Nitratrichtlinie: Deutschland erhält Mahnschreiben," Press release no. 161 from July 25, 2019 (in German; available online). To review the effectiveness of the legislation, groundwater, surface waters, and coastal waters are reviewed regularly. Results are presented to the EU Commission every four years in the form of a nitrate report. Cf. BMU and BMEL, *Nitratbericht 2016, Gemeinsamer Bericht der Bundesministerien für Umwelt, Naturschutz, Bau und Reaktorsicherheit sowie für Ernährung und Landwirtschaft* (2017) (in German; available online).

the European Commission filed a second suit against the German Federal Government in 2019.⁹ A new guilty verdict could result in substantial fines of up to 850,000 euros per day.¹⁰ Currently, the Fertilizer Ordinance of 2020 is being drafted and should be issued soon. The current proposal for the Fertilizer Ordinance 2020 was in principle approved by the European Commission in mid-February.¹¹ In order to avert the lawsuit, the Bundesrat must now vote in favour of the draft on April 3, 2020.¹²

This Weekly Report contributes to the discussion on nitrate pollution of groundwater in Germany. Using new data, it empirically analyzes the relationship between agricultural land use and nitrate pollution as well as nitrate pollution and local water prices to reach economic and environmental policy conclusions.

Nitrate concentrations exceed the trigger value nationwide

The Federal Ministry for Environment, Nature Conservation, and Nuclear Safety (*Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit*, BMU) and the Federal Ministry of Food and Agriculture (*Bundesministerium für Ernährung und Landwirtschaft*, BMEL) are responsible for reporting on the status and development of groundwater nitrate pollution. Every four years, the results from the around 1,200 sampling sites in the European Environment Agency's groundwater monitoring network (EEA groundwater monitoring network) in Germany are summarized in a nitrate report, most recently for the period between 2008 and 2014.¹³ In addition, three interbranch associations, the German Association of Energy and Water Industries (*Bundesverband der Energie- und Wasserwirtschaft*, BDEW), the German Technical and Scientific Association for Gas and Water (*Deutscher Verein des Gas- und Wasserfaches*, DVGW), and the Association of Municipal Enterprises (*Verband kommunaler Unternehmen*, VKU), maintain a joint groundwater database on nitrate pollution in the catchment area of over one thousand drinking water abstraction sites.¹⁴

The most current data from the EEA groundwater monitoring network show an average level of nitrate contamination

of approximately 28 mg/l for the network in 2015 and 2016.¹⁵ The concentrations are, on average, particularly high in the federal states of Saxony (41.8 mg/l), Lower Saxony (40 mg/l), Schleswig-Holstein (37.3 mg/l), Rhineland-Palatinate (37.3 mg/l), and Saxony-Anhalt (35.4 mg/l). Overall, about a fifth of all sampling sites have had concentrations exceeding the trigger value of 50 mg/l for years.

At the district level, there is a clear heterogeneity in the average level of nitrate contamination of groundwater (Figure 1). The average reading in 42 districts—about 15 percent of all districts with a sampling site—exceeds the trigger value. These districts are primarily found in northwestern, eastern, and southwestern Germany. However, excessive nitrate levels in the groundwater is a nationwide problem. Looking at the highest readings from all sampling sites in districts between 2015 and 2016, nitrate levels in every federal state exceed the trigger value of 50 mg/l at at least one sampling site (Figure 2). Moreover, the readings from a large number of sampling sites are very close to the trigger value, around 40-50 mg/l.

Excessive nitrate contamination is particularly an issue at sampling sites in agriculture-heavy regions

Article 5 of the Nitrates Directive requires the German Federal Government to pay particular attention in its reporting to sampling sites in whose catchment area arable land, grasslands, and specialized crops dominate land use.¹⁶ This specialized agriculture monitoring network (*Teilmessnetz Landwirtschaft*) comprises about 680 sampling sites in the provided dataset. The readings in the agriculture monitoring network are 40 mg/l on average, significantly above the mean value of sampling sites without agricultural influences (13 mg/l) (Figure 3). The maximum permissible value is exceeded within this agriculture monitoring network not only to a more serious extent but also more frequently than in the rest of the entire network. For example, in 2015, readings from some sampling sites showed nitrate levels of about seven times the trigger value. Excessively high levels were found in the sampling sites in, for example, Haldensleben in the rural district of Börde in Saxony-Anhalt (370 mg/l) and in Laar in the rural district of Grafschaft Bentheim in Lower Saxony (347 mg/l).

Trigger value continually exceeded over many years

These findings are not one-off; nitrate readings have been consistently high for many years. The proportion of sampling sites where the nitrate levels exceed the trigger value remains relatively constant at around 18 percent for the entire

⁹ The guilty verdict in the first trial was handed down in June 2018. Cf. Verdict of the High Court (Ninth Chamber) from 21 June 2018 – European Commission / Federal Republic of Germany (Case C-543/16) (in German; available online).

¹⁰ As the lawsuit is ongoing, the warning letter from the European Commission is not yet publicly available, cf. European Ombudsman, *Decision in case 1082/2019/EWM on the European Commission's refusal to provide access to a letter to Germany in an infringement procedure for non-response of the Nitrates Directive* (2019) (available online). For information regarding the potential fines, see Tagesschau, "Für Deutschland könnte es teuer werden," July 27, 2019 (in German; available online).

¹¹ At the end of 2019, a first draft of the DüV was completed and presented to the European Commission, cf. Landwirtschaftskammer Schleswig-Holstein, *Diskussion Düngeverordnung 2020* (2020) (in German; available online).

¹² BMEL, "Sprechererklärung zur Düngeverordnung – fristgerechte Zuleitung an den Bundesrat ist erfolgt", press release, February 21, 2020, (available online).

¹³ Cf. BMU and BMEL: Nitratbericht 2016.

¹⁴ Cf. DVGW, BDEW, and VKU, *Bericht zur Nitratbelastung der Trinkwasserressourcen in Deutschland* (2019) (in German; available online).

¹⁵ The UBA provided the dataset, which, in addition to information on sampling sites (location, category within the monitoring network), contains individual nitrate readings during the year including the date the reading was taken. Since the readings taken during a year are performed with varying frequency and at different times, the readings taken during the year at each sampling site were aggregated to annual mean values.

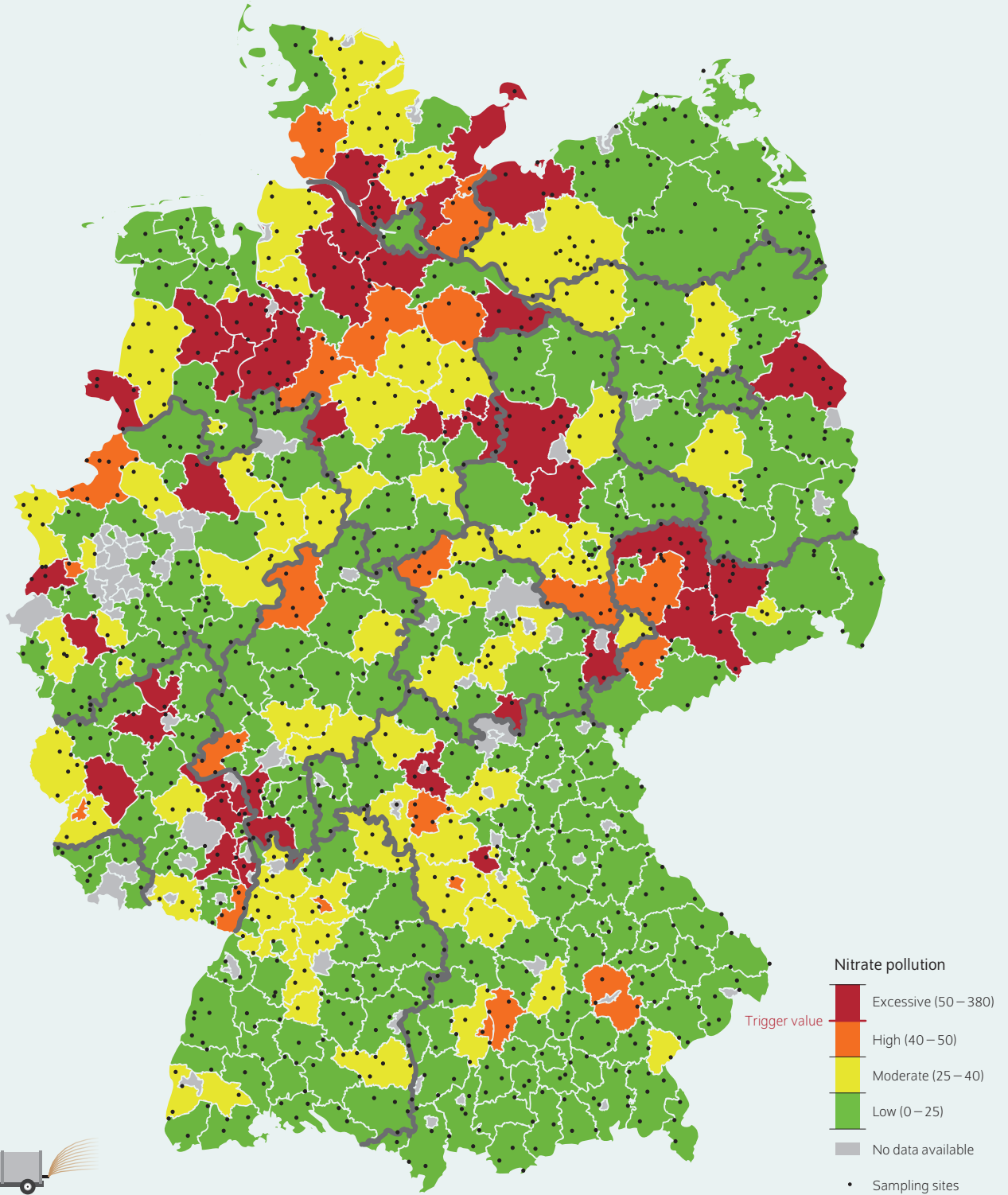
¹⁶ Cf. BMU and BMEL, *Nitratbericht 2016*.

NITRATE POLLUTION

Figure 1

Average nitrate groundwater concentration at district (*Landkreis*) level

Average nitrate concentration at all sampling sites in a district for the years 2015 and 2016 in milligrams per liter



Notes: the sampling sites are represented by individual dots. Districts without nitrate sampling sites are in grey.

Source: authors' own calculations based on data from the German Federal Environment Agency.

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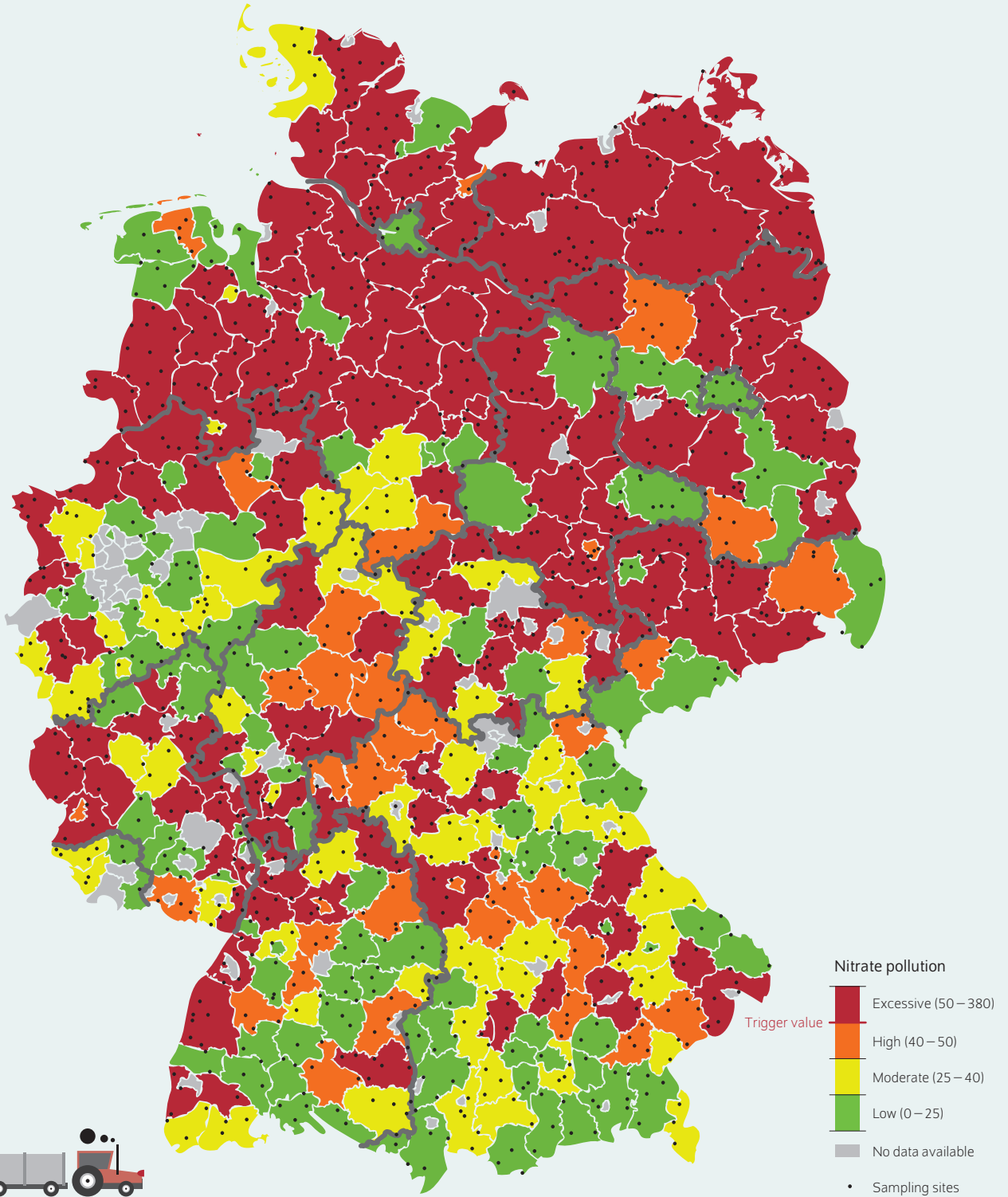
High average levels of nitrate concentration are particularly frequent in Lower Saxony, Saxony, Saxony-Anhalt, and Rhineland-Palatinate.

NITRATE POLLUTION

Figure 2

Maximum nitrate groundwater concentration at district (*Landkreis*) level

Maximum nitrate concentration at all sampling sites in a district for the years 2015 and 2016 in milligrams per liter



Notes: the sampling sites are represented by individual dots. Districts without nitrate sampling sites are shaded in grey.

Source: authors' own calculations based on data from the German Federal Environment Agency.

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Excessive nitrate pollution is a problem throughout Germany.

network and 28 percent for the agriculture monitoring network (Figure 4).

Intensive agriculture increases nitrate problem

The correlation between intensive agriculture and nitrate pollution is well established in the literature (Table 1). Studies show that there are higher nitrate concentrations in the groundwater in areas used for intensive agriculture and that forests and grasslands generally show a lower concentration of nitrate in the groundwater.¹⁷

However, there has not yet been a systematic, empirical study on the connection between land use and groundwater nitrate pollution in Germany. Therefore, DIW Berlin performed an econometric analysis using a multivariate linear regression (Box 2).

The results from the analysis confirm the internationally established correlation between agricultural land use and nitrate pollution for Germany. Sampling sites that belong to the agriculture monitoring network and are thus mainly comprised of arable land, grasslands, or specialized crops, have, on average, nitrate levels that are 16.7 mg/l higher than at sampling sites without any agricultural association (Table 2). In particular, nitrate levels are higher at sampling sites where the surrounding area is used for arable farming or wine growing.¹⁸ In contrast, the nitrate readings are significantly lower at sampling sites in areas comprised primarily of forests and grasslands (Table 2). These findings are in line with the results found in the international literature.

The effect of livestock density has been considered only scarcely in the literature,¹⁹ although theoretically a positive correlation with nitrate pollution of groundwater can be expected. The present analysis shows that higher pig density is associated with higher concentrations of nitrate in the groundwater, but no statistically significant correlation could be found between the density of cattle or sheep and nitrate levels. However, it is important to note that livestock density is calculated at the district level and is therefore only a rough approximation of the actual livestock count in the area surrounding the sampling site. Additionally, “manure tourism”—the purchase and sale of slurry and its transport over great distances—is not taken into account.

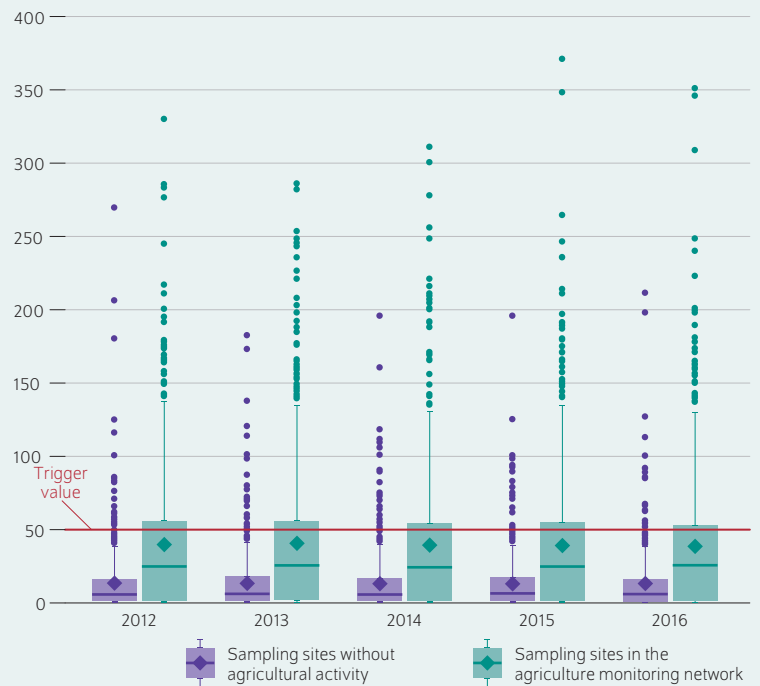
17 In addition to agricultural and forestry land use, weather affects the nitrate concentration of groundwater.

18 For example, an increase of one percentage point *ceteris paribus* in the cultivated area of adjacent arable land and fields is associated with an increase in nitrate levels of 0.1 mg/l. The estimated value is even higher for vineyards. However, in terms of area, wine production plays a subordinate role in Germany.

19 Some case studies have analyzed the correlation between livestock size and nitrate pollution of groundwater. However, the analysis is often limited to a specific type of body of water. Cf. Nicholas J.K. Howden et al., “Nitrate pollution in intensively farmed regions: What are the prospects for sustaining high-quality groundwater?” *Water Resources Research* 47, no. 6 (2011) (available online).

Figure 3

Distribution of nitrate concentration
In milligrams per liter



Notes: the figure displays boxplot diagrams illustrating the distribution of the nitrate groundwater concentration. The diamonds represent the arithmetic mean of the distribution, the lower and upper limits of the rectangular boxes indicate the lower and upper quartiles. The horizontal line within the boxes represents the median. The whiskers are 1.5 times the distance between the top and bottom quartile. The points above the whiskers are annual nitrate measurements classified as outliers.

Source: authors' own calculations based on data from the German Federal Environment Agency.

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The agriculture monitoring network has higher average nitrate concentrations and deviations from the trigger value are more pronounced.

High nitrate levels drive up cost of drinking water supply

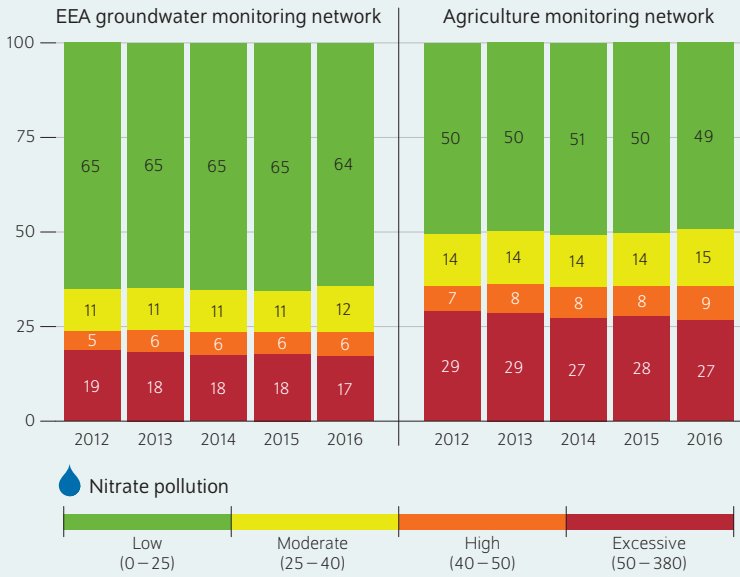
In the medium to long term, high nitrate levels lead to cost increases in the drinking water supply, which also have an indirect effect on water prices for consumers. Water distribution companies already take measures, both preventative and reactive, to reduce the nitrate levels in drinking water. Preventatively, water suppliers attempt to limit the amount of pollutants, and thus nitrate, that get into raw water in the first place.²⁰ Reactively, they treat the drinking water to ensure it is below the trigger value of 50 mg/l (“repair measures”).²¹

20 Raw water is untreated ground and surface water that will be turned into drinking water via treatment, cf. UBA, *Wasserwirtschaft in Deutschland*. Examples of preventative measures include payments to farmers for implementing more environmentally friendly cultivation methods, advising farmers on water-protecting cultivation methods, and purchasing or leasing land to prevent the use of fertilizers completely.

21 The nitrate limit for drinking water is established in the Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption (available online) and the Ordinance on Water for Human Consumption (Drinking Water Ordinance, *Trinkwasserverordnung*) (in German; available online).

Figure 4

Nitrate measurements according to pollution categories
In percent



Source: authors' own calculations based on data from the German Federal Environment Agency.

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The proportion of sampling sites where nitrate levels exceed the trigger value remains relatively constant over time.

Such reactive treatment measures include blending polluted and unpolluted raw water and relocating drinking water production to deeper, less polluted groundwater bodies.

If drinking water suppliers increasingly invest in measures to ensure compliance with the nitrate trigger value, this will result in additional costs. It is expected companies will pass on part of these costs to households by increasing the annual base fee. DIW Berlin studied this correlation for the years 2012 to 2015 (Box 3). The analysis only considers the possible effect on the base fee, which is independent of consumption. The consumption-based component of the water price could also be affected by increased nitrate pollution, but this aspect is not considered here.

The results of the regression analysis suggest that nitrate concentration in groundwater has a price-increasing effect on the base fee (Table 3). In communities with nitrate concentration above the trigger limit of 50 mg/l, households' annual base fee is, on average, over five euros more than the annual base fee in communities with nitrate concentrations below 25 mg/l. There is no statistically significant difference between communities with nitrate concentrations between 25 and 50 mg/l and communities with lower nitrate concentrations in the groundwater. The results indicate that water suppliers only enact measures to reduce nitrate levels in drinking water after the trigger value has been exceeded. If nitrate levels are elevated but remain below the trigger value, the suppliers do not seem to take action.

Box 2

Econometric estimation of the determinants of nitrate pollution

The multivariate regression analysis statistically investigates the relationship between nitrate contamination of groundwater at all sampling sites and the possible influencing factors (Table).

The readings from the entire nitrate monitoring network are explained by a number of regional factors selected from international specialized literature. These factors include the various land uses for agricultural and forestry purposes within 300 meters of a sampling site and the livestock density of the district the sampling site is located in. The type of sampling site is represented by a binary variable for the agriculture monitoring network, as higher nitrate concentrations are expected in said network. In addition, the estimated equation contains dummy variables for the federal states. This way, potential differences in nitrate concentration due to different geological conditions and institutional policies for water and land management are systematically included in the study. Dummy variables for the individual years in the dataset take potential year-specific effects, which could affect readings in the entire network, into consideration. Finally, the regression analysis also considers weather-related effects, such as temperature and precipitation. These factors can affect the build-up of nitrate in soil and its leaching into adjacent waters.

A report by the German Association of Energy and Water Industries (BDEW) estimates that, due to current fertilization practices and the resulting need for measures to reduce nitrate pollution, water prices will rise by up to 62 percent regionally in the future, mainly as a result of the facilities required to remove nitrate from drinking water.²² This means the yearly water bill for a three-person household with a daily average consumption of 122 liters of water per person would increase from 217 to 352 euros.²³

Nitrate can remain in the ground for a long time and cause problems for future generations

How quickly excess nitrogen from fertilization leads to measurable nitrate groundwater contamination depends on the physico-chemical processes in the soil, and can take anywhere

²² The price increase results from the additional costs for denitrification facilities. Cf. Bundesverband der Energie- und Wasserwirtschaft (BDEW), *Berechnung der Kosten der Nitratbelastung in Wasserkörpern für die Wasserwirtschaft* (Berlin: 2017) (in German; available online).

²³ Cf. BDEW, *Berechnung der Kosten der Nitratbelastung*.

Table

Variables and descriptive statistics for regression analysis on nitrate groundwater pollution

Variable	Definition	Unit	Mean	Standard deviation	Minimum	Maximum
German Federal Environmental Agency (2019)						
Nitrate	Annual mean of nitrate concentration at groundwater sampling site	Milligrams per liter	28	41	0	370
Agriculture monitoring network	Binary variable for the type of sampling site, indicates that site belongs to the agriculture monitoring network (Teilmessnetz Landwirtschaft)	1 = yes; 0 = no	0.574	0.495	0	1
CORINE Land Cover Database (2012)						
Farmland	Share of arable land in the measuring area	Percent	0.375	0.374	0	1
Wine growing	Proportion of wine-growing areas in the measuring area	Percent	0.006	0.062	0	0.995
Fruit cultivation	Proportion of fruit-growing cultivation in the measuring area	Percent	0.005	0.046	0	0.957
Grasslands	Proportion of meadows and pastures in the measuring area	Percent	0.200	0.272	0	1
Forest	Proportion of forest in the measuring area	Percent	0.272	0.361	0	1
Water	Share of water areas in the measuring area	Percent	0.002	0.022	0	0.356
Regional statistics of the statistical offices of the Federation and the Länder (2012 and 2016)						
Cattle density	Number of cattle relative to district area	Cattle per square kilometer	35	31	0	152
Pig density	Number of pigs relative to district area	Pigs per square kilometer	80	161	0	1633
Sheep density	Number of sheep relative to district area	Sheep per square kilometer	5	5	0	44
German Weather Service (2019)						
Precipitation	Average daily precipitation per year at the sampling site	Millimeters per year	1.937	0.533	0.978	5.888
Temperature	Average daily temperature per year at the sampling site	Degree Celsius	9.638	1.153	-3.893	12.561

Notes: the table lists all variables used, their sources, and descriptive statistics. The annual mean nitrate concentration and the categorization into the agriculture subnetwork are recorded for each sampling site. The land use shares refer to the measuring area of the sampling site. The measuring area describes the immediate area within a radius of 300 meters around the sampling site. For the measuring area of each sampling site, the shares of the respective land use form are shown as percentages. The data on the respective livestock density refer to the population of cattle, pigs, and sheep in the district of the sampling site. Information on precipitation and temperature correspond to the measured values of the weather station at the shortest distance from the respective nitrate sampling site.

Source: authors' own calculations based on data from the German Federal Environmental Agency, EEA-Groundwater Monitoring Network (2019).

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from a few months to multiple decades.²⁴ Therefore, it is expected that the levels of nitrate contamination will remain high in the coming years, partly due to nitrate inputs caused by past intensive agriculture.

It is unclear what a “fair” allocation of the external environmental costs of nitrate pollution might look like. What is certain is that the soil is currently being overloaded by the excessive use of fertilizers and the resulting additional nitrate input must be reduced (flow problem), for example through stricter nitrogen spreading regulations. However, the majority of nitrate contamination comes from past excessive nitrate input (stock problem).

This makes it more difficult to apply the polluter pays principle (PPP), as nitrate has accumulated over many decades in soils and groundwater. In many cases, the original polluter no longer exists. In terms of quantity, the existing stocks of

nitrate in the soil are likely well above the annual additional flow of nitrate and thus represent the greatest cost to drinking water suppliers. However, there are currently no practicable technologies available to solve the stock problem directly and remove nitrate from groundwater.

Experiences in other countries show regulations can reduce nitrate pollution

Other countries have shown that stringent regulations can reduce the nitrogen input in the soil and thus the nitrate contamination of groundwater in the medium term. Denmark is an example of a country that has successfully reversed the trend. Since the mid-1980s, Danish legislation has aimed at reducing nitrate pollution from agriculture; the implementation of the EU Nitrates Directive further tightened national legislation.²⁵ The Danish goals were two part: to comprehensively reuse slurry and manure as much as possible and to

²⁴ Cf. Christoph Gerber et al., “Using environmental tracers to determine the relative importance of travel times in the unsaturated and saturated zones for the delay of nitrate reduction measures,” *Journal of Hydrology* 561 (2018): 250–266 (available online); Lei Wang et al., “The nitrate time bomb: a numerical way to investigate nitrate storage and lag time in the unsaturated zone,” *Environmental Geochemistry and Health* 35, no. 5 (2013): 667–681 (available online); and Mathieu Sebilo et al., “Long-term fate of nitrate fertilizer in agricultural soils,” *Proceedings of the National Academy of Sciences* 110, no. 45 (2013): 18,185–18,189 (available online).

²⁵ Cf. Brigitte Hansen et al., “Groundwater nitrate response to sustainable nitrogen management,” *Nature Scientific Reports* 7, no. 1 (2017): 1–2 (available online) and Lisbeth Flindt Jørgensen, Karen G. Villholth, und Jens Christian Refsgaard, “Groundwater management and protection in Denmark: a review of pre-conditions, advances and challenges,” *International Journal of Water Resources Development* 33, no. 6 (2016): 868–889 (available online).

Table 1

International empirical literature on the factors determining the nitrate pollution in the groundwater

Authors	Region	Time period	Method	Examined variable	Influencing factors investigated	Central results on influencing factors of nitrate content in groundwater
Bawa and Dwivedi (2019)	Florida, USA	2008–2018	Multivariate linear regression	Nitrate, potassium	Land cover	Agriculture (+)
Sun et al. (2018)	China (Haihe River Basin)	2010	Multivariate linear regression	Nitrate, phosphorus	Precipitation-weighted land cover	Agriculture (+), forests (-), residential areas (+), grassland (-)
Gallagher and Gergel (2017)	USA und Canada (Abbotsford-Sumas-Aquifer)	2005–2016	Multivariate linear regression	Nitrate	Land cover, depth of groundwater, well depth	Agriculture (+/-), forests (+/-), urban areas (+), wastelands(-)
Lawniczak et al. (2016)	Poland (Wielkopolska Nationalpark)	2012	Multivariate analysis	Nitrate, phosphorus, ammonium	Land cover, season, fertilizer input	Agriculture, particularly arable land (+), forests (-), residential areas (-), spring (+), fertilizer (+)
Mair and El-Kadi (2013)	Hawaii, USA	2000–2012	Logistic regression	Nitrate, fumigants, chlorinated solvents	Land cover, depth of groundwater, soil media, aquifer media	Agriculture (+)
Wick et al. (2012)	Austria	1992–2008	Multivariate regression	Nitrate	Land cover, precipitation, soil porosity, air temperature	Agriculture (+), forests (-), urban areas (-), grassland (-), precipitation (-), temperature (-)

Source: own summary based on Ranjit Bawa and Puneet Dwivedi, "Impact of land cover on groundwater quality in the Upper Floridan Aquifer in Florida, United States," *Environmental Pollution* 252 (2019): 1828–1840 (available online); Ranhao Sun, Xian Cheng, and Liding Chen, "A precipitation-weighted landscape structure model to predict potential pollution contributions at watershed scales," *Landscape Ecology* 33, no. 9 (2018): 1603–1616 (available online); Tanya L. Gallagher and Sarah E. Gergel, "Landscape indicators of groundwater nitrate concentrations: an approach for trans-border aquifer monitoring," *Ecosphere* 8, no. 12 (2017): e02047 (available online); Agnieszka Ewa Lawniczak et al., "Impact of agriculture and land use on nitrate contamination in groundwater and running waters in central-west Poland," *Environmental Monitoring and Assessment* 188, no. 3 (2016): 172 (available online); Alan Mair and Aly I. El-Kadi, "Logistic regression modeling to assess groundwater vulnerability to contamination in Hawaii, USA," *Journal of Contaminant Hydrology* 153, (2013): 1–23 (available online); and Katharina Wick, Christine Heumesser, and Erwin Schmid, "Groundwater nitrate contamination: factors and indicators," *Journal of Environmental Management* 111 (2012): 178–186 (available online).

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The international empirical literature identifies the share of agricultural land in the catchment area of a groundwater monitoring station as a relevant factor for elevated nitrate levels.

limit the use of chemical fertilizers.²⁶ As a result, the nitrogen surplus from fertilization was reduced by an average of 37 percent between 1980 and 2007, which has led to a decline in nitrate pollution of groundwater since the mid-1980s.²⁷

Central to this process was the fertilizer accounting system.²⁸ Introduced in the 1990s and digitized in 2011, it records the annual nutrient surplus at farm level. Transparency on the amount of fertilizer applied makes it possible to regulate the nitrogen input, for example by introducing nitrogen quotas for each individual farm, taking into account the land area, the type of soil, livestock farming, and the crops grown. This reduces the risk of over-fertilization without reducing crop yields.²⁹

The Netherlands also struggled with high levels of nitrate contamination for a long time. However, in the past years, comprehensive measures and regulations enacted by the Dutch government drastically reduced the amount of nitrogen and phosphorus used in agriculture. For example,

²⁶ Cf. Ministry of Environment and Food of Denmark, *Overview of the Danish regulation of nutrients in agriculture and the Danish Nitrates Action Programme* (2017); cf. Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) (1991) (available online).

²⁷ Cf. Hansen et al., "Groundwater nitrate response," and Brigitte Hansen et al., "Regional analysis of groundwater nitrate concentrations and trends in Denmark in regard to agricultural influence," *Biogeosciences* 9 (2012): 3,277–3,286 (available online).

²⁸ Use of the fertilizer register is mandatory for all farms above a certain size, cf. Ministry of Environment and Food of Denmark, *Overview of the Danish regulation*.

²⁹ Cf. Ministry of Environment and Food of Denmark, *Overview of the Danish regulation*.

Table 2

Regression results: determinants of nitrate pollution

Dependent variable: annual mean nitrate concentration at the sampling site

Regressor	Coefficient	Standard error
Agriculture monitoring network	16.697***	2.388
Farmland	10.037*	5.303
Wine growing	63.152**	26.281
Fruit cultivation	2.751	13.433
Forest	-11.369***	3.540
Water	-9.473	49.201
Grasslands	-14.500***	5.214
Cattle density	-0.048	0.044
Pig density	0.023**	0.010
Sheep density	-0.251	0.192
Constant	24.915***	8.360
Number of observations	5 848	
Number of sampling sites	1 217	
R ²	0.193	

Notes: the results are based on a multivariate regression analysis using pooled OLS. The data refer to the years 2012 to 2016. In addition to the variables shown, the analysis includes fixed annual effects in the nitrate level of all sampling sites, indicators for the federal state of a sampling site and weather influences at the sampling site (temperature and precipitation) as regressors. Standard errors are clustered at the level of sampling sites to account for possible correlations between multiple measurements at the same site. Statistical significance levels: ***p<0.01; **p<0.05; *p<0.1.

Source: authors' own calculations based on data from the Federal Environment Agency, the CORINE Land Cover Database, the regional statistics of the Federal Statistical Office and the Statistical Offices of the Länder, and the German Weather Service.

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The average nitrate level is almost 17 milligrams per liter higher at sampling sites that are part of the specialized agriculture monitoring network.

Table 3

Regression results: nitrate pollution and water rates

Dependent variable: base fee for drinking water for each municipality with a nitrate sampling station

Regressor	Coefficient	Standard error
Medium nitrate pollution (25 to 40 mg/l)	4.918	3.107
High nitrate pollution (40 to 50 mg/l)	6.579	4.209
Very high nitrate pollution (above 50 mg/l)	5.591**	2.486
Constant	151.692***	4.336
Number of observations		4 302
Number of sampling sites		1108
R ²		0.300

Note: the results are based on a multivariate regression analysis using pooled OLS. The data cover the years 2012 to 2015. In addition to the variables shown, the analysis includes population size and population density at the municipality level as well as fixed annual effects as regressors. The base category is "low nitrate pollution" (0 to 25 mg/l). Standard errors are clustered at the level of sampling sites to account for possible correlations between multiple measurements at the same site. Statistical significance levels: ***p<0.01; **p<0.05; *p<0.1.

Source: authors' own calculations based on data from the German Federal Environment Agency and the regional statistics from the Federal Statistical Office and the Statistical Offices of the Länder.

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In municipalities with a nitrate concentration above the trigger value, households' annual base fee for drinking water is, on average, over five euros higher.

demand for nitrogen fertilizers fell by about half between 1990 and 2012.³⁰ This was achieved by setting upper limits for nitrogen and phosphate use, compliance with which is closely monitored. For example, slurry is spread under GPS monitoring and farmers face heavy fines for non-compliance.³¹ In addition, Dutch farms are required to process part of their surplus fertilizer into granulated fertilizer.³² This granulated fertilizer can be used in a similar way to mineral fertilizers, which in turn could reduce the use of mineral fertilizer.³³

Conclusion: New Fertilizer Ordinance must effectively reduce agricultural nitrogen surplus

Despite multiple lawsuits brought by the European Commission and threats of massive fines, Germany remains one of Europe's top nitrate offenders. Between 2012 and 2015, Germany's average nitrate concentration in the groundwater was second only to Malta's.³⁴ Since then, there has been

³⁰ Simultaneously, the average nitrogen surplus and nitrate concentration in the groundwater fell, cf. Hans J.M. van Grinsven, Aaldrik Tiktak, and Carin W. Rougoor, "Evaluation of the Dutch implementation of the nitrates directive, the water framework directive and the national emission ceilings directive," *NJAS-Wageningen Journal of Life Sciences* 78 (2016): 69–84 (available online).

³¹ Cf. BDEW, *Berechnung der Kosten der Nitratbelastung*.

³² Cf. van Grinsven, Tiktak, and Rougoor, "Evaluation of the Dutch implementation of the nitrates directive."

³³ Cf. Jean Gault et al., *Analysis of implementation of the Nitrates Directive by other Member States of the European Union* (2015) (available online).

³⁴ Cf. European Commission, *Report from the Commission to the Council and the European Parliament on the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2012–2015* (Brussels: 2018) (available online).

Box 3

Econometric estimation of the effects of nitrate pollution of groundwater on the base fee for water

The effect of nitrate pollution of groundwater on consumption-independent water rates within a municipality for the years 2012 to 2015 was investigated using a multivariate regression analysis. Every sampling site in the nitrate monitoring network is assigned to a municipality based on its location. Municipality characteristics, such as prices or population density, are mapped to the sampling sites.¹

The analysis considers four categories of nitrate pollution: low concentrations between zero and 25 mg/l (reference category), moderate concentrations between 25 and 40 mg/l, high concentrations between 40 and 50 mg/l, and trigger limit-exceeding concentrations above 50 mg/l.² At the district level, the analysis includes the population and population density as explanatory variables for the base fee.³ In addition, the analysis considers heterogeneous effects for each observation year as well as geographic location (east or west) using dummy variables. The latter should take into account existing differences in the water supply system between the new and old federal states, such as the age of the sewage system and equipment and facilities. These differences are mainly historical, but also result from the federal states' different infrastructure development strategies and financing policies.

¹ Considering information on water prices is not available for every municipality, the number of nitrate sampling sites has decreased by 109 compared to the first analysis in this report.

² These categories are also used in the Nitrate Report of the BMU and BMEL, cf. BMU and BMEL, *Nitratbericht 2016*.

³ Data on regional water rates and municipal characteristics are taken from the regional statistics of the Federal Statistical Office and the Statistical Offices of the Länder. In 2015, the base fee was 78.15 euros per year on a national average, while the consumption-based fee per cubic meter of water averaged 1.76 euros per cubic meter. There are major regional differences, especially in the base fee. The annual base fee ranges from between 17.58 euros in Berlin and 129.37 euros in Thuringia. Water rates dependent on usage tend to be highest in the eastern part of Germany in the federal states of Thuringia, Saxony, Saxony-Anhalt, Mecklenburg-Western Pomerania, and Brandenburg. However, the western federal states of North Rhine-Westphalia, Saarland, and Rhineland-Palatinate also have water rates higher than average.

no significant reduction in the average nitrate concentration and trigger values are regularly exceeded throughout Germany. In particular, areas with a high proportion of arable farming, wine growing, and intensive livestock farming are suffering from the effects of excessive nitrate pollution. This can lead to ecological, health, and economic consequences: loss of biodiversity, negative consequences for human health, and higher water rates.

In mid-February 2020, the EU Commission accepted the government's proposal to amend the Fertilizer Ordinance. If the Bundesrat approves the proposal, this will already be the second amendment of the fertilizer regulation within the last three years. Thus, in future, the focus should primarily

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be on reviewing the effectiveness of the tightened fertilizer regulations. If it is determined that the federal and state-level measures to curb contamination are insufficient, the existing regulations must be changed or additional measures enacted.

The requirement to pre-determine plant fertilizer needs for specific plots of agricultural land and the material flow balance, both introduced in 2017, are important steps towards accurate data and more transparency in Germany. Currently, only large farms are required to prepare a material flow balance; extending these reporting obligations to small and medium-sized farms would provide more accurate information on nitrogen surpluses at regional level. These farms

should be supported in adapting to the new fertilizer legislation and in converting to new environmentally friendly technologies for nutrient spreading. The experiences in Denmark and the Netherlands show that a systematic and centralized database increases transparency, improving the monitoring of and control of the use of farm fertilizers.

In any case, the environmental damage caused by excess nitrogen varies greatly from region to region and depends on a number of factors, such as soil properties or the depth of the groundwater table. These differences should be offset by spatially differentiated requirements for regulatory measures, for example at the federal state level.

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