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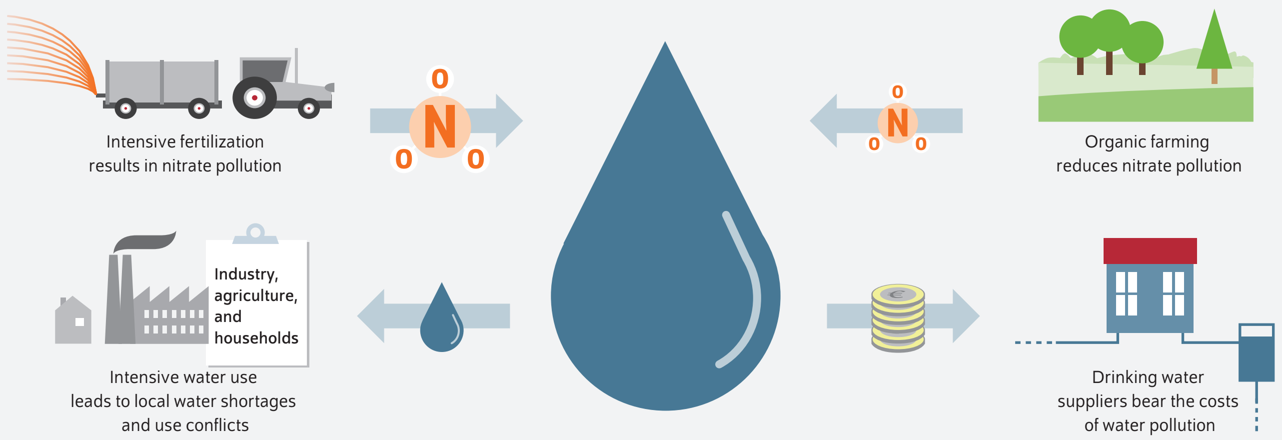
AT A GLANCE

Water resources in Germany: Increasingly polluted and regionally overused

By Astrid Cullmann, Greta Sundermann, Nicole Wägner, Christian von Hirschhausen, and Claudia Kemfert

- Global challenges like water scarcity and water pollution are also becoming increasingly prevalent in Germany
- One major problem is nutrient pollution from agriculture, which increases the drinking water supply cost
- Expanding organic farming can contribute to reducing nitrate pollution
- Sanitary innovations can help improve water quality
- More transparency in the distribution and pricing of water abstraction is also important

Water treatment costs rise due to nitrate pollution: Organic farming can reduce nitrate pollution—intensive fertilization leads to nitrate pollution



Source: Authors' depiction.

FROM THE AUTHORS

"Even here in Germany, water resources are coming under increasing pressure. In particular, groundwater nitrate pollution due to intensive agricultural fertilization results in high ecological and social costs and drives up drinking water treatment costs."

— Astrid Cullmann —

MEDIA

Audio Interview with Astrid Cullmann (in German)
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Water resources in Germany: Increasingly polluted and regionally overused

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ABSTRACT

The effects of the climate crisis are worsening water shortages, not only in the Global South but also in Europe, for example in the Berlin-Brandenburg region. Due to inadequate pricing of surface and groundwater abstraction and a lack of regulatory instruments, water overuse is occurring in some regions of Germany. Overuse is especially an issue for industry, which has contractually secured high volumes of water withdrawals at very low cost. In addition, there is extensive water pollution as a result of contaminants released into water bodies by households, industry, sewage treatment plants, and agriculture, which further reduces the clean water supply. In particular, nitrate pollution due to intensive fertilization in agriculture is an increasing problem. As a consequence, households and businesses must bear the additional costs, for example due to increasing costs for drinking water treatment. Organic farming can improve water quality; sanitary innovations such as urine-diverting dry toilets (UDDTs) can also contribute. This Weekly Report summarizes current research results and contributes to the German National Water Strategy, a series of measures to be taken by 2030 to address the inter-generational challenges of water management.

Water is vital to human existence, an integral part of the ecosystem and cultural landscapes, and serves as a habitat for a variety of plants and animals. Access to clean water was recognized as a human right by the United Nations in 2010.[1] Water is also indispensable to industry, agriculture, and the energy sector. Careful management, effective conservation, and sustainable use of water are key prerequisites for preserving biodiversity and protecting ecosystems.[2] Clean water and sanitation are integral parts of sustainable development and universal access to both is one of the 17 UN Sustainable Development Goals (SDGs) to be achieved by 2030. This SDG is closely connected with other sustainability goals, especially those relating to health, education, the economy, and the environment.[3]

The climate crisis will further deplete global water resources.[4] The issue of water scarcity is reinforced by water pollution stemming from increasing urbanization, industrialization, and intensive agriculture—globally and also in Germany. Given these challenges, the subject of water, and water pollution in particular, receives surprisingly little attention in economic research, especially when compared to air pollution.[5] Opinion polls confirm that the general population is concerned about water shortages: A survey from the Center for Responsible Research and Innovation at Fraunhofer IAO reveals a pronounced awareness of the problem among

1 United Nations, *Resolution adopted by the General Assembly on 28 July 2010* (available online; accessed on November 20, 2022. This applies to all other online sources in this report unless stated otherwise).

2 Markus Siehlow, Georg Meran, and Christian von Hirschhausen, *Water: Economics and Management of a Key Resource* (Berlin: German Institute for Economic Research, 2012).

3 United Nations, *The 17 Sustainable Development Goals* (United Nations Department of Economics and Social Affairs, 2015) (available online).

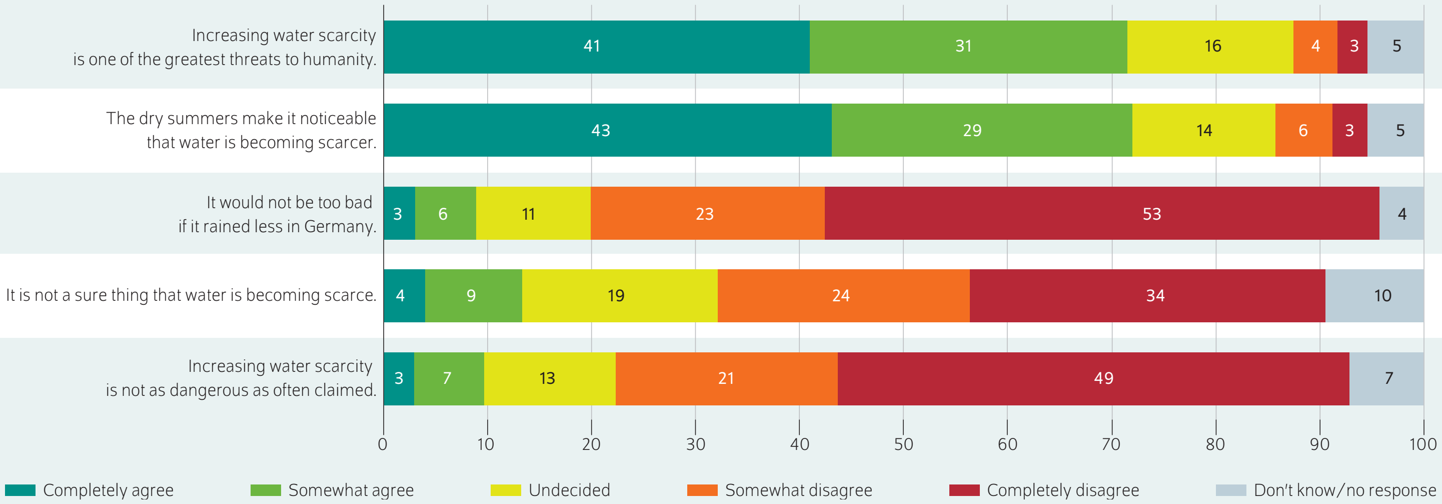
4 Water scarcity and water pollution are worsened by climate change. This is due, for example, to higher water temperatures, melting glaciers, the intensification of the hydrological cycle, and an increase in floods and droughts. Water scarcity and water pollution, conversely, affect climate change: For example, human nutrient accumulation in lakes leads to methane emissions, cf. John A. Downing et al., "Protecting local water quality has global benefits," *Nature Communications* 1, no. 12 (2021): 2709 (available online).

5 Cf. David A. Keiser and Joseph S. Shapiro, "US Water Pollution Regulation over the Past Half Century: Burning Waters to Crystal Springs?" *Journal of Economic Perspectives* 33, no. 4 (2019): 51–75.

DOI: https://doi.org/10.18723/diw_dwr:2022-49-1

Figure 1

Awareness of the water scarcity issue in Germany
Agreement in percent



Note: The figure depicts to what extent the respondents agree with statements about water scarcity in Germany. The evaluation scale has six categories ranging from "completely agree" to "completely disagree" and also has a "no response" option. From August 4 to 9, 2022, 2,046 respondents were surveyed via the YouGov platform.

Source: Representative survey from the Center for Responsible Research and Innovation at Fraunhofer IAO.

The majority of the respondents view water scarcity and droughts in Germany to be a problem.

German residents (Figure 1).[6] Surveys conducted in other countries, such as the USA, also show that water pollution is one of the top environmental concerns.[7]

Germany has extensive water resources. However, due to a lack of incentives for efficient use of water, there have been local shortages in recent years. In addition, there is nationwide pollution of surface and groundwater bodies by nutrients such as nitrate and phosphorus as well as various other substances, which endangers the ecological status of the water bodies. Moreover, it makes the treatment of drinking water complex and expensive.

Moreover, nutrients in wastewater remain largely unused. Through effective nutrient recovery using productive sanitation systems, human excreta can be processed into fertilizer, closing material cycles in a regional, climate-friendly, and safe way.

Within the context of political efforts in Germany—such as the 2050 National Water Strategy, which envisions fundamental changes in how water is handled to achieve sustainable water management—current research findings on the causes and effects of water pollution are discussed below and proposed solutions are outlined (Box 1).

Water shortages in Brandenburg

Water use conflicts—between households' drinking water supply, industrial and commercial use, and agricultural irrigation —have so far been limited to water-scarce regions of the world. However, with climate change and increasing average temperatures and heatwave frequency, these conflicts become more relevant in Germany.[8] Questions of water distribution are predominantly dealt with administratively: For example, the amount of water new customers may obtain is capped and watering open spaces during the summer months is prohibited.[9] In contrast, industrial users mostly secure their water via long-term contracts covering high withdrawal volumes at low prices.[10] For example, the chemical company BASF in Schwarzheide, Brandenburg, extracts 3.3 million cubic meters of water per year.[11] In Grünheide,

6 Cf. Hannah Bergmann, *Akzeptanzbefragung zu Trockentoiletten in Deutschland im Rahmen des BMBF-geförderten Projects zirkulierBAR* (2022) (in German).

7 Cf. Keiser and Shapiro, "US Water Pollution Regulation over the Past Half Century."

8 Government agencies, agriculture, and industry are fighting more and more often over water in court. One sample shows that the number of legal conflicts has drastically risen in 11 of 16 federal states over the past ten years. For example, the number of lawsuits in Bavaria increased by nearly 50 percent, cf. Correctiv, *Ausgetrocknet – Deutschland kämpft um Wasser. Correctiv Recherchen für die Gesellschaft* (2022) (in German; available online).

9 Cf. Wasserverband Strausberg-Erkner, *Amtsblatt* no. 3, vol. 4 (2021) (in German; available online).

10 According to the Federal Water Act, industrial abstraction requires a permit or authorization, with more extensive regulations set forth in state water laws and state ordinances. Permission is granted by the relevant local authorities, usually on a first come, first served basis, cf. Alexandra Lux, "Handelbare Wasserentnahmerechte als Ergänzung der ordnungsrechtlichen Vergabepolitik?" *netWORKS – Papers* (Deutsches Institut für Urbanistik: 2005) (in German; available online).

11 BASF Schwarzheide GmbH, *Umwelterklärung – Daten und Fakten 2021* (2022) (in German; available online).

Box 1

National Water Strategy

The Federal Ministry for Environment, Nature Conservation, and Nuclear Safety (*Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz*, BMUV) presented a draft of its National Water Strategy in June 2021.[1] This draft discusses water management challenges and creates an action program for a joint transition to sustainable water management by 2050. The National Water Strategy aims to ensure that sufficient high-quality and affordable drinking water will continue to be available at all times everywhere in Germany in 30 years, that bodies of water (groundwater, lakes, streams, rivers, and seas) become cleaner, that further overexploitation and overloading of water resources will be avoided, that wastewater disposal will continue to function excellently, that the costs will be causally and equitably distributed, and that water management and users will adapt to the consequences of the climate crisis and the changes in demographics.

The National Water Strategy sets targets and measures to be gradually taken by 2030. It focuses on ten strategic points: 1) Raising awareness of water as a resource; 2) Working together to conserve global water resources in a sustainable manner; 3) Conserving, restoring, and permanently safeguarding the near-natural water supply, preventing conflicting objectives; 4) Implementing water agreements and land use in rural and urban areas adapted to climate change; 5) Further developing sustainable water management; 6) Limiting risks from substance inputs; 7) Further developing water infrastructure; 8) Linking water, energy, and substance cycles; 9) Strengthening efficient administration, improving data flows, optimizing regulatory frameworks, and securing funding; 10) Protecting marine areas [North Sea and Baltic Sea] more intensively against substance inputs from land.

This Weekly Report mainly focuses on points 1, 3, 6, 8, and 9.

1 Cf. BMUV, *Nationale Wasserstrategie* (Bonn: 2021) (in German; available online).

Brandenburg, Tesla applied for extraction of nearly 3.8 million cubic meters per year.[12] The LEAG open-cast lignite mine in Jänschwalde, Brandenburg, required over 100 million cubic meters of groundwater per year, of which only 42 million were officially approved.[13] This high water consumption places an additional burden on the hydrological system: Intensive use of groundwater resources coupled with low groundwater recharge leads to falling groundwater levels. For example, the average groundwater level in the state of Brandenburg has decreased by a half meter since the 1970s (Figure 2). This will further intensify local water shortages of some regions in Brandenburg, and thereby endanger the regional drinking water supply.[14]

It is already apparent today that the needs of industry are being met preferentially and at the expense of citizens. This is facilitated not only by a lack of transparency and oversight in water extraction but also arbitrary pricing. As of 2022, water abstraction fees are only levied in 13 of 16 federal states. In the states that do levy fees, there are many exceptions. Mining and agriculture are frequently exempted, for example. In Berlin, Hamburg, and the Saarland, fees are only levied on groundwater extraction, not surface water extraction. Some federal states earmark the collected funds for water conservation measures, while others do not. Overall, prices for extraction vary widely between the federal states. For example, prices for agricultural water extraction range between 0.5 and 31 cents per cubic meter and between 6 and 31 cents per cubic meter for mining.[15]

Water pollution amplifies the problems

Water pollution is a serious, multi-faceted problem that leads to a scarcity of available clean water. It originates from a wide variety of substances (nutrients such as nitrate and phosphorus, trace substances like pesticides and pharmaceutical residues, and pathogens or heavy metals) from different sources such as agriculture, industry, or urban settlements. This results in surface and groundwater pollution, with groundwater pollution usually being irreversible and endangering drinking water supplies. In high-income industrialized economies, water pollution from trace substances and nutrients from fertilizers and wastewater treatment plant discharges poses the biggest problem.[16]

Agriculture is the main driver of nitrogen emissions

Intensive agriculture is usually the main source of these nutrient inputs, which enter the environment via the use of nitrogen fertilizers on agricultural land. Due to overfertilization, i.e., supplying plants with more nutrients than they need, nitrogen accumulates in the soil. There it undergoes biochemical processes that transform it into nitrate, which

12 Following a lawsuit filed by environmental associations, the permit to increase extraction volumes from 1.3 to 3.8 million cubic meters, which had been approved by the *Landesamt für Umwelt Brandenburg* in 2020, was rejected by the Frankfurt/Oder Administrative Court in 2022, cf. Verwaltungsgericht Frankfurt/Oder, *Urteil vom 04.03.2022 – VG 5 K 469/21* (2022) (in German; available online).

13 Since 2017, LEAG has extracted around 240 million cubic meters more groundwater than legally permitted. As a result of an urgent application by Deutsche Umwelthilfe and the Grüne Liga, the open-cast mine was shut down in May 2022, cf. Verwaltungsgericht Cottbus, *Entscheidung 3 L 381/21* (2022) (in German; available online).

14 In Germany, over 70 percent of drinking water comes from groundwater, cf. UBA, *Grundwasser: Nutzung und Belastung* (2022) (in German; available online).

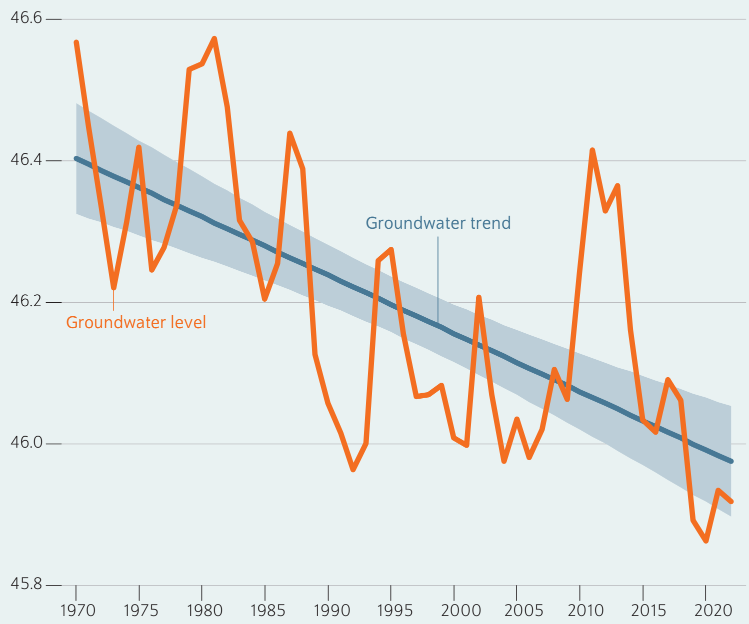
15 Cf. BUND, *Die Wasserentnahme der Länder. Kurzgutachten* (Bund für Umwelt und Naturschutz Deutschland e.V.: 2019) (in German; available online).

16 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 2016–2019* (2021) (available online); cf. Bijay-Singh and Eric Craswell, "Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem," *SN Applied Sciences* 3, no. 518 (2021).

is then washed out by rain or seeps into the ground, thereby polluting ground- and surface waters. The process is additionally amplified by a years-long practice of using purely synthetic mineral fertilizer and poor humus management that results in agricultural soils being less able to retain water and nutrients. In Germany, nitrate pollution in many groundwater bodies exceeds the EU limit value of 50 milligrams per liter, in some cases even by over 700 percent.[17] In the past, these limit exceedances, in combination with insufficient countermeasures, led to an infringement proceeding against Germany by the European Commission.[18] In the short term, the EU threatened fines in the millions of euros, which were ultimately avoided by repeatedly revising the fertilizer ordinance and designating nitrate-vulnerable and eutrophic areas.[19] However, the most recent figures from the 2021 nitrate report show that the groundwater quality has not improved.[20] Nitrate pollution has a far-reaching impact on biodiversity (through water eutrophication, for example), the climate (due to increasing greenhouse gas emissions via eutrophication, for example), and human health (such as diseases caused by methemoglobinemia).[21] Thus, nitrate pollution is associated with significant ecological and social costs, which have either not or only partially been empirically quantified.[22]

Figure 2

Annual groundwater levels of selected groundwater monitoring wells in Brandenburg from 1970 to 2022
In meters above standard elevation zero



Note: The figure represents the average annual groundwater levels in Brandenburg. The annual averages are based on individual measurements at 244 groundwater monitoring wells that have had at least one reading per year since 1970, i.e., have been observed continuously over the years. To calculate the linear trend (blue), the annual groundwater levels were regressed on time in years. The shaded area shows the 95 percent confidence interval of the linear regression.

Source: Authors' calculations based on data from the Landesamt für Umwelt Brandenburg.

Groundwater levels in Brandenburg have been decreasing since 1970.

High nitrate levels increase drinking water costs

The high nitrate levels in groundwater do not only have negative environmental effects, but also impact the cost of drinking water treatment. Drinking water companies must take measures to maintain the nitrate concentration in drinking water[23] in accordance with legal requirements to avoid damaging consumer health. For this purpose, they blend polluted and unpolluted raw water, relocate wells to deeper or less polluted groundwater bodies, and carry out technical separation processes or biological denitrification.[24] These measures lead to cost increases, for example due to higher energy or procurement costs for operating supplies. Using new data on drinking water companies and nitrate pollution, empirical analyses at DIW Berlin demonstrate the cost-driving effect of nitrate pollution in the drinking water sector (Box 2). According to estimates, a 10 milligram per liter increase in nitrate pollution increases overall costs by nearly 110,000 euros per year for the average drinking water company with around 50,000 customers.[25] These additional costs are potentially passed on to consumers in the form of higher water prices, such that consumers carry the cost of agricultural overfertilization.

Organic farming could reduce the nitrate problem

To reduce nitrate pollution in ground and surface waters, the nitrogen surpluses from agricultural fertilization must be reduced in the long term. Organic farming, which uses

17 Cf. Greta Sundermann et al., "Nitrate Pollution of Groundwater Long Exceeding Trigger Value: Fertilization Practices Require More Transparency and Oversight," *DIW Weekly Report*, no. 8/9 (2020): 61-72 (available online).

18 Cf. Ruling of the European Court of Justice (Ninth Chamber) of June 21, 2018 (available online).

19 Eutrophic areas are surface waters with high nutrient levels that excessively stimulate the growth of algae and other aquatic plants. Cf. Bundesrat, *Verordnung zur Änderung der Düngeverordnung und anderer Vorschriften, Drucksache 98/20* (2020) (in German; available online) and Bundesrat, *Allgemeine Verwaltungsvorschrift zur Ausweisung von mit Nitrat belasteten und eutrophierten Gebieten, Drucksache 275/22* (2022) (in German; available online).

20 Cf. Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit and the Bundesministerium für Ernährung und Landwirtschaft, *Nitratbericht 2020* (Berlin: 2020) (in German; available online).

21 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, cf. Sundermann et al., "Nitrate pollution of groundwater long exceeding trigger value."

22 Alexandra Evans, "Agricultural water pollution: Key knowledge gaps and research needs," *Current Opinion in Environmental Sustainability* 36 (2018): 20–27.

23 The nitrate trigger value for drinking water was set 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 the Quality of Water Intended for Human Consumption (*Trinkwasserverordnung*) (in German; available online).

24 Separation processes make it possible to separate nitrate and water. German drinking water suppliers use the CARIX process or reverse osmosis for this purpose. Denitrification is a microbiological process that separates nitrate from water and decomposes it to gaseous nitrogen.

25 Cf. Greta Sundermann, Nicole Wägner, and Astrid Cullmann , "Organic farming, water quality, and drinking water supply cost – an empirical analysis for Germany," (lecture, International Interdisciplinary Conference on Land Use and Water Quality, Maastricht, 2022).

Box 2

Econometric estimation of the influence of groundwater nitrate concentrations on the costs of drinking water supply

The relationship between groundwater nitrate contamination and total costs of drinking water companies was examined using multivariate regressions. The analysis uses company data from the Federal and State Statistical Offices of Germany as well as data from the German Environment Agency's nitrate monitoring network covering 2008 to 2016. In addition, control variables were derived from the regional statistics of the Federal Statistical Office. Descriptive statistics on the variables used are presented in Table 1.

The effect of average nitrate levels at the locations of companies' water abstraction sites was estimated using a total cost model based on microeconometric theory. The company's total costs were the dependent variable (Table 2), while input prices (labor and capital), output quantities (total volume of drinking water supplied, number of residents served), nitrate concentration, and other control variables (share of groundwater abstraction, share of water supplied to private households, population density of the water company's supply area) were considered explanatory variables. All variables have been logarithmized, such that the point estimates represent percentage changes. In addition, company-specific dummy variables controlled for unobserved, time-invariant effects.

Table 1

Descritpive statistics on drinking water companies and groundwater nitrate concentrations

Annual average per drinking water company analyzed

	Average
Total costs [1,000 euros]	16,794.28
Total water abstraction [1,000 m³]	3,052.09
Water purchases [1,000 m³]	567.16
Volume of drinking water delivered [1,000 m³]	3,619.25
Number of residents supplied	53,415.56
Share of groundwater of water abstracted in percent	73.25
Population density [inhabitants/km²]	352.16
Nitrate concentration in raw water [mg/l]	29.48

Note: The observation units are 342 drinking water companies that abstract and treat groundwater. The data cover the years 2008 to 2016.

Source: Authors' calculations using data from the German Environment Agency, regional statistics from the Federal and State Statistical Offices, and the Research Data Center of the Federal and State Statistical Offices.

Table 2

Effects of various influencing factors on total cost of drinking water supply

Percentage change in total costs of drinking water companies given a one-percent change of variables

Independent variables	Change in percent
Nitrate concentration in raw water	0.018*
Contract price per hour	0.733***
Quantity of drinking water delivered	0.840***
Number of residents supplied	0.236
Share of groundwater of water abstracted	0.040
Share of household customers of total customers	−0.024
Population density of the municipalities supplied	−0.058
Number of observations	1,846
Number of companies	342

Note: Results are based on a multivariate regression accounting for company and year fixed effects and estimated by the ordinary least squares (OLS) method. The observation units are drinking water companies that extract and treat groundwater. Data cover the years 2008 to 2016. Standard errors are clustered at the company level. Asterisks denote the significance level, which indicates the statistical precision of the estimate. The more asterisks, the lower the probability of error: ***, **, and * indicate significance at the one-, five-, and ten-percent levels, respectively.

Legend: A one-percent increase in nitrate pollution results in a 0.02-percent increase in the total costs.

Source: Authors' calculations using data from the German Environment Agency, regional statistics from the Federal and State Statistical Offices, and the research data center at the Federal and State Statistical Offices.

a sustainable farming system, can contribute to this reduction.[26] Unlike other methods of farming, especially conventional ones, organic farms must achieve as closed an operational nutrient cycle as possible, increase or maintain soil fertility, and adhere to proper welfare conditions for farm animals.[27] Thus, organic farming must fulfill higher standards for environmental protection and animal welfare. They are not allowed to use synthetic pesticides or mineral fertilizers, for example, and livestock farming is restricted and space dependent. Several field studies indicate that organic farming systems could reduce nitrogen leaching by up to 64 percent.[28] Less nitrogen leaching could reduce the nitrate

26 According to the European Green Deal, organic farming systems in particular are of crucial importance for the transition to sustainable agriculture, cf. European Parliament, "European Parliament resolution of 15 January 2020 on the European Green Deal," *Official Journal of the European Union* C270/2 (2020): 2–20 (available online). As part of its Farm to Fork Strategy, the EU aims to expand organic farming land to 25 percent by 2030, cf. European Commission, *Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system* (2020) (available online); European Parliament and the Council of the European Union, Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007 (2018) (available online).

27 Cf. Bundesministerium für Ernährung und Landwirtschaft (BMEL), *Ökologischer Landbau in Deutschland* (Bonn: 2022) (in German; available online).

28 Christian Schader, Matthias Stolze, and Andreas Gattinger, "Environmental performance of organic farming," in *Green Technologies in Food Production and Processing*, eds. Joyce I. Boye and Yves Arcand (Springer: 2012): 183-210. Various studies show that both nitrogen input intensities and nitrate leaching per unit area are generally lower in organic farming than in conventional farming, but this effect does not necessarily apply to nitrogen leaching per unit product, cf.

Box 3

Econometric estimation of the impact of organic farming on groundwater nitrate concentrations

The impact of organic farming on groundwater nitrate concentrations was estimated using regional data and location-specific nitrate measurements for 2008 to 2018 (Table). Annual averages of nitrate concentrations at groundwater monitoring sites, provided by the German Environment Agency, were used as the dependent variable. The explanatory variable is the share of organically farmed agricultural land (relative to total utilized agricultural area) in the county where the monitoring site is located; the data on organic farming were taken from the regional statistics of the Federal and State Statistical Offices. The relationship was estimated using an autoregressive regression model. It was assumed that the nitrate concentration of the observation year depends not only on the share of organically farmed land, but also on the nitrate concentration of the previous year, as the process of nitrate formation is relatively persistent over time. In addition, a number of other influencing factors were controlled for, such as high mineral fertilizer use (> 100 kilograms per hectare), land use in the vicinity of the monitoring site (shares of agricultural, viticultural, orchard, grassland, and forest land within a 500-meter radius of the monitoring site), and weather influences, which were pooled from various sources (regional statistics from the Federal and State Statistical Offices, CORINE Land Cover Database, German Weather Service).[1] In addition, fixed effects were used to control for hydrogeologic features at the monitoring site that were invariant over time and for year-specific influences. The generalized method of moments according to Blundell and Bond[2] was used for the estimation, which instrumented the previous year's nitrate values with nitrate values from the past.

Table

Effects of agricultural land use and weather on nitrate concentrations in groundwaters
In milligrams per liter for a one-unit increase in the variable

Variables	In milligrams per liter
Share of organic farming	−0.298***
Mineral fertilizer	1.598*
Share of agricultural land	0.134***
Share of viticultural land	0.411**
Share of orchard land	0.049
Share of grasslands	−0.041*
Share of forest land	−0.058***
Average temperature	1.086*
Total precipitation	0.001
Average precipitation	0.563
Nitrate concentration of the previous year	0.550***
Number of observations	7,311
Number of monitoring wells	1,323

Note: Results are based on a multivariate regression accounting for company and year fixed effects and estimated using the generalized method of moments. The observation units are groundwater monitoring wells. Data are for 2008 through 2018, and standard errors were clustered at the monitoring well level. Asterisks denote the significance level, which indicates the statistical precision of the estimate. The more asterisks, the lower the probability of error: ***, **, and * indicate significance at the one-, five-, and ten-percent levels, respectively.

Legend: A one-percentage point increase in the share of organically farmed agricultural land is associated with a nitrate concentration reduction of about 0.3 milligrams per liter.

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

1 Cf. Uwe Häußermann et al., *Stickstoff-Flächenbilanzen für Deutschland mit Regionalgliederung Bundesländer und Kreise – Jahre 1995 bis 2017. Methodik, Ergebnisse und Minderungsmaßnahmen* (Dessau-Roßlau: German Environment Agency, 2019).

2 Cf. Richard Blundell and Stephen Bond, "Initial conditions and moment restrictions in dynamic panel data models," *Journal of Econometrics* 87 (1998): 115–143.

inputs in groundwater, but there is not yet any empirical evidence of this.

Results from an econometric analysis at DIW Berlin show that an increasing share of organic farming relative to total utilized agricultural area is accompanied by decreasing nitrate concentrations in the surrounding groundwater bodies. The regression results show that a one-percent increase in organic farming area is associated with a 0.3-milligram reduction in the nitrate concentration. The results represent an approximation of the actual effect, as the data on organically farmed land are only available at the county level and thus are not small-scale enough to model hydrogeologic conditions (Box 3).

Sanitary innovations can contribute to improving water quality

In regard to water pollution, wastewater-based sanitation is also a challenge for sustainable water supply.[29] For example, large amounts of fresh water are used to transport human excreta and are subsequently contaminated with nutrients

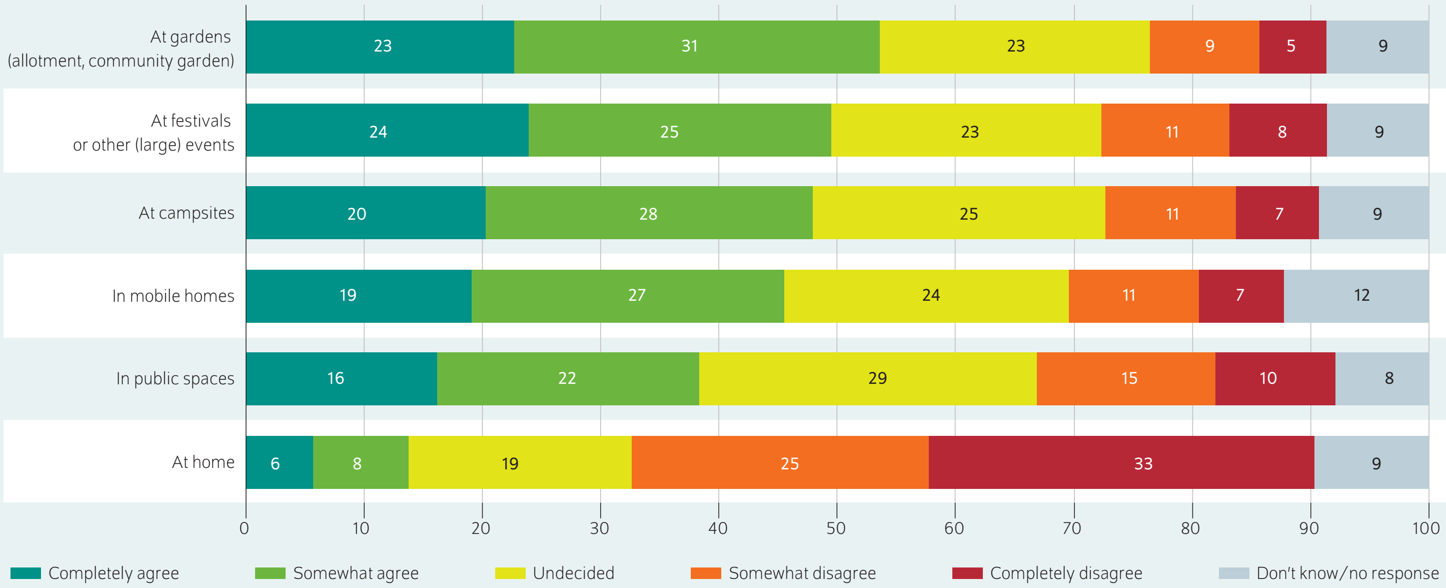
Hanna Tuomisto et al., "Does organic farming reduce environmental impacts? A meta-analysis of European research," *Journal of Environmental Management* 112 (2012): 309-320.

29 Our current sanitation system promotes a linear, non-sustainable, and inefficient use of resources and is associated with process-related environmental emissions that are damaging to the environment and human health, cf. Ariane Krause et al., *Ressourcen aus der Schüssel sind der Schlüssel. Diskussionspapier zur Sanitär- und Nährstoffwende. Wertstoffe zirkulieren, Wasser sparen und Schadstoffe eliminieren* (2021) (in German; available online).

Figure 3

Evaluation of the use of dry toilets

Agreement in percent



Note: The figure depicts to what extent the respondents agree with statements about the use of dry toilets. The evaluation scale has six categories ranging from "completely agree" to "completely disagree" and includes a "no response" option.

Source: Representative survey of the population from the Center for Responsible Research and Innovation at Fraunhofer IAO.

The majority of respondents positively evaluate the use of urine-diverting dry toilets at garden plots and community gardens. In contrast, the willingness to use them at home is low.

and trace substances such as pharmaceutical residues and hormones. In addition, wastewater can be contaminated with other pollutants, such as heavy metals like cadmium or quicksilver from road drains, when it mixes with rainwater. While the energy-intensive treatment processes remove much of these residues, the wastewater treatment plant discharges to surface waters are far from harmless. For example, despite state-of-the-art technology, wastewater treatment plants are considered one of the main sources of nutrient emissions[30] and potentially pathogenic germs in surface waters.[31]

Resource-oriented and circular sanitation management is one possible solution. This type of management is based on the technical approach of wastewater separation at the source. Separate collection (such as via UDDTs) and treatment of different wastewater streams, such as urine, feces and rainwater, keeps the water and nutrient cycles technically separate. In this way, individual groups of substances are neither diluted nor mixed or cross-contaminated with each other, enabling more targeted and efficient treatment. Pathogens are killed and remaining nutrients are safety and sustainably returned to the cycle. In addition, the water and energy saved by using this process reduces the pressure on natural resources.[32]

In this way, recycling the contents (urine and feces) of UDDTs into hygienically safe, nutrient-rich, and low-pollutant recycled fertilizer for agriculture can also contribute to sustainable water management and the strategic goals of the National Water Strategy.[33] Results of a representative survey from the Center for Responsible Research and Innovation at Fraunhofer IAO indicate that the societal acceptance barriers

30 Nearly 22 percent and 33 percent of the overall nitrogen and phosphorus inputs in surface waters are from communal wastewater treatment plants and urban sewer systems, cf. German Environment Agency, *Stickstoff- und Phosphoreinträge aus Punktquellen und diffusen Quellen in die Oberflächengewässer in Deutschland* (2020) (in German; available online).

31 Cf. German Environment Agency, *Antibiotika und Antibiotikaresistenzen in der Umwelt – Hintergrund, Herausforderungen und Handlungsoptionen* (Dessau-Roßlau: Umweltbundesamt, 2018) (in German); German Environment Agency, "Erarbeitung anspruchsvoller Standards für die mittelfristige Fortführung der bodenbezogenen Verwertung von Klärschlämmen aus Abwasserbehandlungsanlagen mit kleiner Ausbaugröße Bakterielle Resistenzen in Klärschlamm," *Umwelt & Gesundheit* 3 (2022) (in German).

32 By using water-saving and UDDTs, an average of nearly 15 to 30 cubic meters of drinking water could be saved annually per person, cf. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V., *Neuartige Sanitärsysteme. Begriffe, Stoffströme, Behandlung von Schwarz-, Braun-, Gelb-, Grau- und Regenwasser, Stoffliche Nutzung* (Bauhaus-Universitätsverlag Weimar: 2015) (in German). More information on the effects of wastewater-based sanitation systems and the benefits of nutrient separation can be found here (in German).

33 Results are from the research project *zirkulierBAR: Interkommunale Akzeptanz für nachhaltige Wertschöpfung aus sanitären Nebenstoffströmen*, funded by the BMBF as a part of the REGION.innovative funding measure. Together with municipalities, future-oriented companies, universities, and research institutes, the project creates a laboratory for a sustainable and regional circular economy.

for UDDTs and fertilizer made from human excreta are lower than expected, especially for use at gardens or festivals (Figure 3). In addition, over half of the respondents positively evaluate the use of UDDTs to collect human waste to be further processed into fertilizer. While most people generally are unaware of what the food they purchase was fertilized with, 44 percent of respondents are willing to eat vegetables grown with fertilizer made from human excreta.[34] In contrast, there is a lack of political acceptance for a broad implementation of this innovative technology: Unlike sewage sludge, manure, or organic waste, the current regulatory framework does not provide for the use of fertilizer from human excreta collected separately from wastewater. This represents a diffusion barrier for sanitary innovations. In order to enable the establishment of alternative sanitation systems, laws on waste and fertilizer regulation need to be revised.[35]

Conclusion: Improve water quality, solve use conflicts

Water resources are coming under increasing pressure in Germany. In addition to the challenges caused by climate change, water pollution from nitrates, phosphorous, and other nutrients endangers the ecological status of water bodies and increases the costs of extracting and treating drinking water. Moreover, water use conflicts between industry, households, and agriculture are becoming more and more frequent in Germany.

To avoid future conflicts of water use, targeted measures for sustainable water abstraction for industry should be implemented, such as efficient water use as a prerequisite for abstraction permissions. In particular, industry's preferential treatment, a sector that currently consumes large quantities at very low prices, should be ended to create incentives for efficient use.

To reduce nitrate inputs, the implemented regulations for agricultural fertilization must be enforced consistently, especially in nitrate-vulnerable zones. Organic farming can also contribute to reducing overfertilization and its expansion should continue, as is planned in the EU Farm to Fork Strategy.[36]

Implementing resource-based and circular sanitation using wastewater separation at the source and UDDTs saves water and reduces pressure on natural resources. Energy, water, and nutrient cycles should be linked in terms of content, but technically separated. Sanitary innovations offer the possibility of effectively recovering nutrients from human excreta and closing material cycles in a regional, climate-friendly, and safe way. However, the current legal framework does not provide for producing fertilizer from human excreta that is collected separately from wastewater. The relevant laws should be revised and expanded on to effectively disassemble diffusion barriers.

A prerequisite for dealing with water use conflicts in a forward-looking manner is a comprehensive database on water supply and water demands. Currently, data collection is mostly the responsibility of regional authorities; for example, no nationwide data are available on groundwater levels. Such a high-quality, public database could contribute to intensifying environmental economic research in this area and is called for in the National Water Strategy.

34 Cf. Bergmann, *Akzeptanzbefragung zu Trockentoiletten in Deutschland.*

35 Cf. Krause et al., *Ressourcen aus der Schüssel sind der Schlüssel.*

36 Cf. European Commission, *Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system*

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LEGAL AND EDITORIAL DETAILS

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