WATER QUALITY AND AVAILABILITY

Outline

Water is our most precious resource, yet across the world, many regions are challenged with water scarcity and poor water quality.

To this end, the *2030 United Nation Agenda and Sustainable Development Goals* (SDGs) bring water quality issues to the forefront of international action by setting Goal 6 "Clean Water and Sanitation"[1] to respond to the pressing challenges posed by water quality issues.[2] Globally, one in nine people uses drinking water from unsafe sources: while lack of sanitation is one of the most significant forms of water pollution in developing countries, poor water quality and scarcity is present also in developed countries, due to non-point source pollution from agriculture and urban areas and industrial point source pollution, as showed in **Figure 1**.

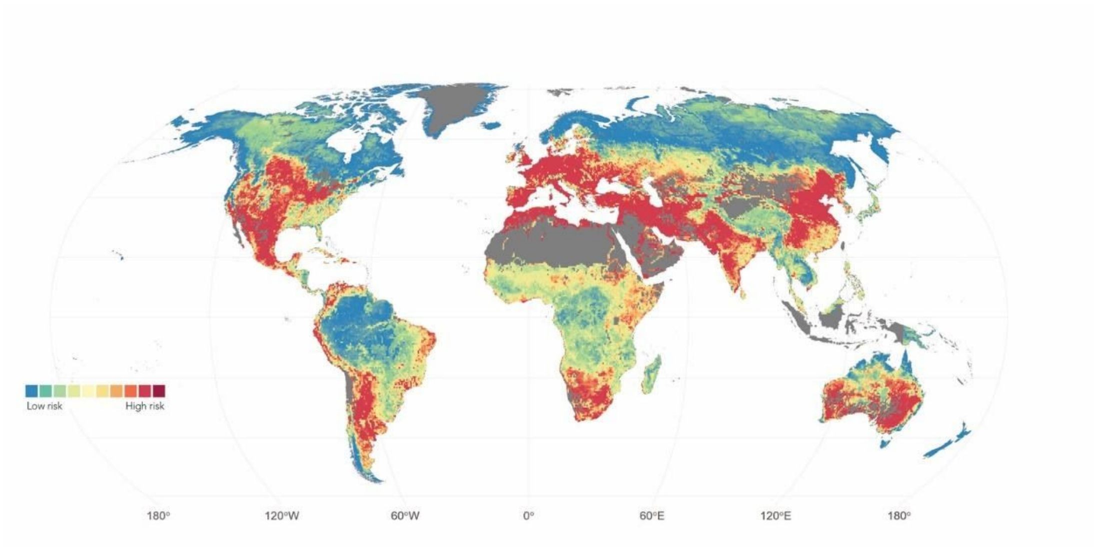

Figure 1 – Water Quality Risks. Global map of water quality risk based on 2000-2010 data for BOD, nitrogen and salinity. Source: World Bank.

Still, 90% of sewage in developing countries is discharged untreated directly into water bodies[3]: this means 2 million tons of sewage are poured into world's water every day.[4] Lack of wastewater treatment poses serious issues not only to human health, but also to aquatic ecosystems, where a reduction of about one-third of the global biodiversity is estimated to be due to pollution of water resources.

Water must be carefully managed during every part of the water cycle: from fresh water abstraction, pre-treatment, distribution, use, collection and post-treatment, to the use of treated wastewater and its ultimate return to the environment, ready to be abstracted to start the cycle again.[5]

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1 https://sdgs.un.org/goals/goal6

2 https://en.unesco.org/waterquality-iiwq/wq-challenge

3 http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2015-water-for-a-sustainable-world

4 https://www.ais.unwater.org/ais/pluginfile.php/225/mod_label/intro/sickwater_screen.pdf

5 https://www.unwater.org/water-facts/quality-and-wastewater-2/

Several free of charge resources are available for exploring water quality and availability in the US and in Europe, such as:

- USGS: https://www.usgs.gov/products/maps/map-topics/water
- European Environmental Agency – WaterBase: https://www.eea.europa.eu/data-and-maps/data/waterbase-water-quality-icm

De Nora is one of the leading companies offering solutions for ensuring high standards of water and wastewater treatment. Leveraging De Nora's know-how with digital innovations such as big data of open GIS databases, dashboards, digital tracking, simulations and IoT systems opens opportunities in addressing many of the following big challenges within the water sector.

Water quality monitoring

Water quality in distribution networks

Water Distribution Networks (WDNs) are complex systems made up of various interconnected nodes and pipes, which take water of suitable quality from sources to supply customers in the service area. While WDNs are commonly expected to guarantee effectiveness and acceptable standards of service, including water quality, forms of real time control have been found to achieve objective of enhanced quality of the supplied water.[6]

However, monitoring water quality across the network of buried pipes and tanks, in real-time with spatial resolution, is a major challenge. Alternatively, water quality can be also tested and monitored at the point of use[7], but equipment can be expensive, and crowdsourcing of such data to improve centralized water management, as well as proposing localized solutions, although possible, is far from being a reality.[8] In distributed systems, pH and chlorine levels are the most critical parameters to ensure high water quality levels.[9]

As a matter of fact, water quality can deteriorate dramatically within a distribution system. Drinking water samples may be affected by microbiological contamination, which is linked to a number of violations, such as coliform count, health threats, microbially originated tastes and odors, and higher pipes corrosion rates. Ensuring the right disinfectant residual, usually chlorine or chloramines, is the primary factor controlling the growth of bacteria within the distribution network.

Chloramination is usually considered better than chlorination, because, at a similar level of bacteria control, the chloramine compound's reaction with precursors to form trihalomethanes (THM's), a disinfection by-product which causes health risks, is extremely slow. This leaves little to no measurable THM's, even after extended contact times.[10]

De Nora's MicroChem® 3 residual analyzer and MicroChem® 450 controller are reliable instruments for chlorine and ammonia dosing and chloramination control.

[6] E. Creaco et al. / Water Research 161 (2019) 517-530

[7] https://sswm.info/sswm-solutions-bop-markets/affordable-wash-services-and-products/affordable-water-supply/water-quality-testing

[8] https://blogs.worldbank.org/water/can-you-crowdsource-water-quality-data

[9] https://blogs.worldbank.org/water/how-test-water-quality-chemical-tests-limited-budgets

[10] https://blog.denora.com/chloramination-control-in-drinking-water

Several other factors are very useful to monitor in WDNs, such as biodegradable organic matter (BOM), pH, temperature, storage reservoirs, corrosion control bacteria proliferation. Powerful multi-species decay models to predict water quality along the network have been developed, but their use for optimizing water treatment is still limited.[11] As an example, EPANET is an application for modeling drinking water distribution systems in the US and it is available for free.[12]

Taste, odor and color

The appearance, taste and odor of drinking-water should be acceptable to the consumer. Otherwise, the consumer may be led to use water from sources that are aesthetically more acceptable, but potentially less safe. Taste and odor can originate from natural inorganic and organic chemical contaminants and biological sources or processes (e.g. aquatic microorganisms), from contamination by synthetic chemicals, from corrosion or as a result of problems with water treatment (e.g. chlorination). Taste and odor may also develop during storage and distribution as a result of microbial activity.[13]

Point of use monitoring

Given the inhomogeneity of water quality along the distribution network, end users may be concerned about the quality of the water at their tap (or from individual wells). However, they may not have the ability or means to routinely pay for expensive testing, or the background needed to assess water quality information. While most utilities provide annual reports to their customers, these reports do not provide a high geographic resolution in the water quality data that can tell individual users about the quality of their water.

Citizen science and crowdsourcing may be an effective approach to monitor water quality issues, such as taste/odor/color or chlorine levels, as evidenced by several experiments run by the EPA in the US.[14]

Water pollution and emerging contaminants

Drinking water or wastewater may be contaminated due to geological reasons and/or due to human activities. Since the list of pollutants that represent a concern is long and constantly evolving, it is challenging to keep the pace with ever-changing regulations.

Across Europe, groundwaters generally have the best status (74% have good chemical status), whereas only 38% of surface waters are in good chemical status. Detailed data and graphs about the status of water sources in the European Union are available from the European Environmental Agency.[15]

Besides well-known pollutants, contaminants of emerging concern (CECs) present a new global water quality challenge with potentially serious threats to human health and ecosystems.[16] Some of them, although posing potential health risk, are still unregulated.[17]

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[11] Urban Water Journal, Vol. 2, No. 2, June 2005, 69 – 79

[12] https://www.epa.gov/water-research/epanet

[13] https://www.ncbi.nlm.nih.gov/books/NBK442378/

[14] https://www.epa.gov/sites/production/files/2015-09/documents/nacept_background_material_2.pdf

[15] https://www.eea.europa.eu/themes/water/european-waters/water-quality-and-water-assessment/water-assessments

[16] https://en.unesco.org/emergingpollutantsinwaterandwastewater

[17] https://tdb.epa.gov/tdb/home

CECs may occur in rivers, estuary areas, source water, drinking water, rainwater and groundwater.[18]

Digitally enabled identification, mapping and awareness campaigns about water sources polluted by these compounds is critical for the provision of proper water treatment.

> De Nora offers solutions based on Capital Controls® Ozone generators, which is available in various sizes, for advanced oxidation processes (AOPs), the most effective way to taste/odor/color issues as well as many issues related to disinfection by-products.[19]

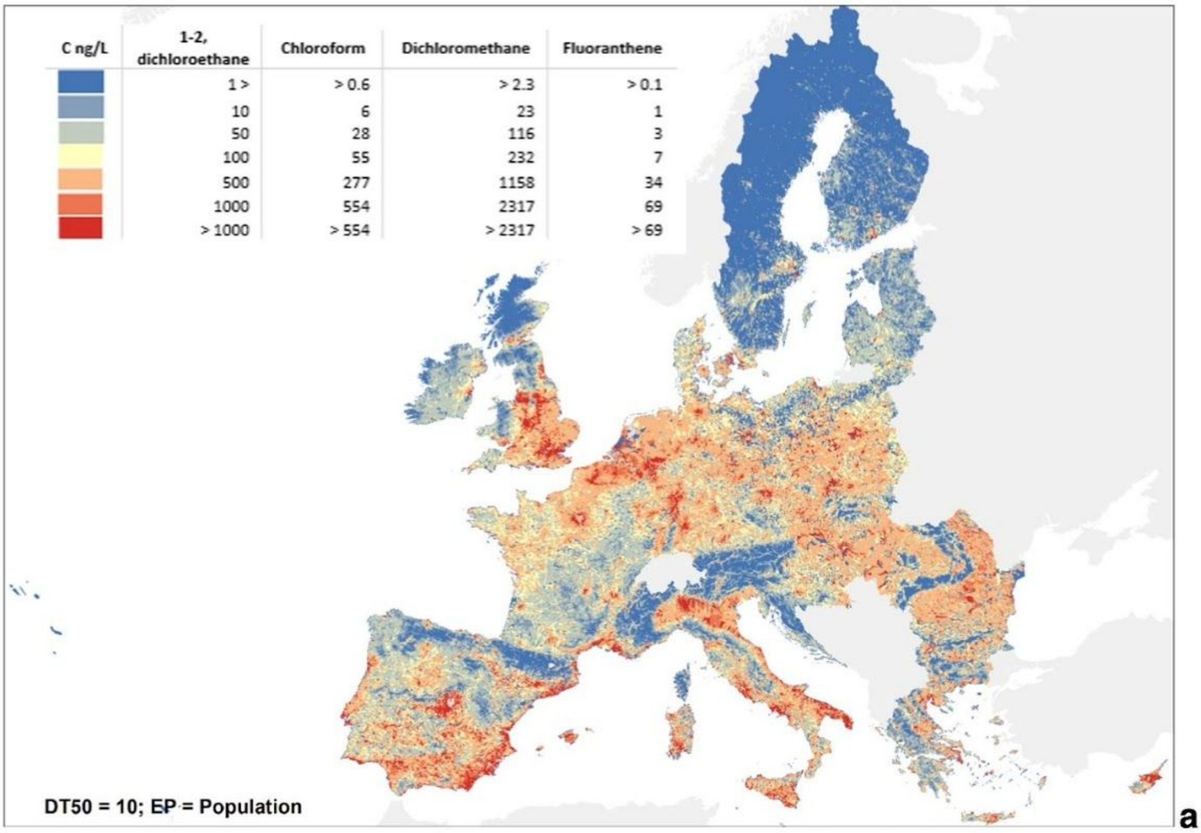

Figure 2 – Chemical Water Quality. Map of point and diffuse sources of pollution from population across Europe.[20]

Arsenic

Arsenic is among the most well-known, most feared drinking-water contaminants. If consumed, it can cause several severe symptoms and, in extreme cases, even death. For this reason, the World Health Organization recommended 10 parts per billion (ppb) maximum limit concentration in drinking water.

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[18] https://onlinelibrary.wiley.com/doi/abs/10.1002/wer.1163

[19] https://www.researchgate.net/publication/235347025_Removal_of_taste_and_odour_from_potable_water_by_ozone_and_Powdered_Activated_Carbon_PAC

[20] https://ec.europa.eu/jrc/en/science-update/measuring-pollutants-europes-water-resources

For instance, high levels of arsenic have been found in drinking water wells in more than 25 states in the USA, potentially exposing 2.1 million people to drinking water high in arsenic.[21] Possibly the worst case ever of arsenic poisoning occurred in Bangladesh, where over 100 million people were poisoned by arsenic in groundwater supplies.[22]

In Europe, almost 98% of the samples of drinking water collected by EFSA contained amounts of arsenic that were below the limit established at EU level for natural mineral water and water intended for human consumption.[23] An updated map of arsenic contamination in the US is available in the data.gov website.[24]

Machine learning approaches, combined with big data analysis, have been already explored to highlight possible hot spots on a global map where there are likely dangerous levels of arsenic in groundwater. In fact, it is likely that more hotspots than are currently known, exist.[25]

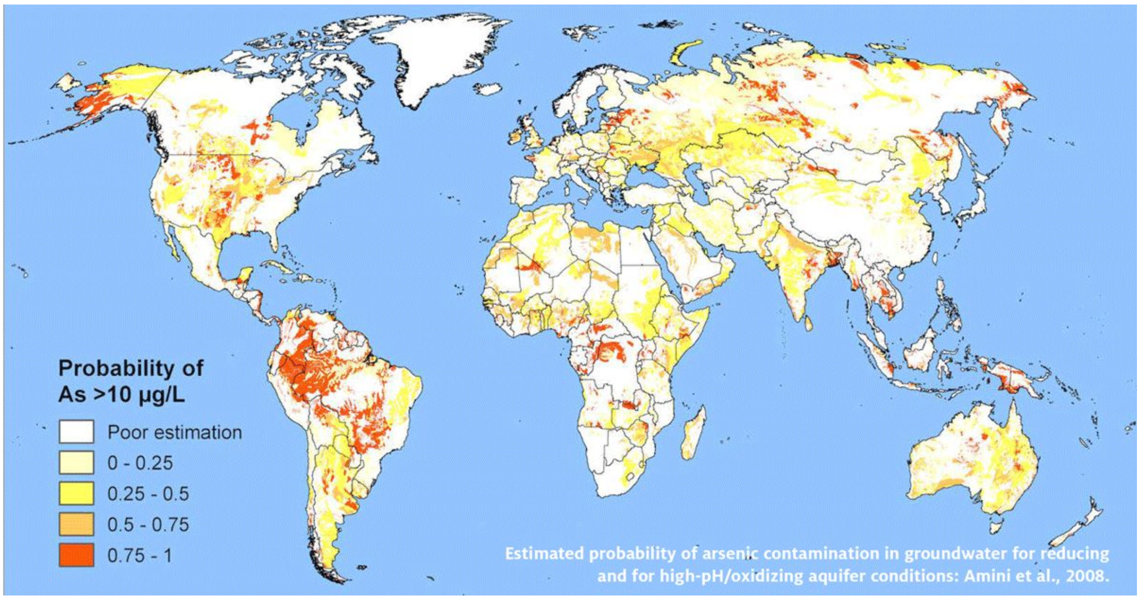

Figure 3 – Arsenic contamination in groundwater. Global estimation from Amini et al., 2008.

De Nora offers the SORB 33® arsenic removal system, a fixed-bed adsorption system that uses a granular ferric oxide media, for the adsorption of dissolved arsenic.[26] [Watch our webinar on Eliminating Arsenic in Water] to know more about the issue and the solutions offered by De Nora.

[21] https://www.usgs.gov/news/study-estimates-about-21-million-people-using-wells-high-arsenic
[22] https://pubs.er.usgs.gov/publication/70198882
[23] https://www.efsa.europa.eu/en/press/news/140306
[24] https://catalog.data.gov/dataset/map-of-arsenic-concentrations-in-groundwater-of-the-united-states
[25] https://science.sciencemag.org/content/368/6493/845
[26] https://blog.denora.com/the-health-risks-associated-with-arsenic-in-drinking-water

Fluoride

Most fluorine in earth's crust occurs as insoluble fluorides, but there is some ionized fluoride in soil and groundwater. There are large differences in the amount of fluoride found naturally in water supplies all over the world, depending on geological reasons. [27] Although beneficial for teeth, high consumption of fluoride can cause serious health issues: a maximum concentration limit in drinking water is then set to protect against increased risk of crippling skeletal fluorosis.

In the US, the current enforceable drinking water standard for fluoride is 4.0 mg/L.[28] In Europe, depending on the countries, this can be way lower, reaching 0.1 ppm.[29] This is the maximum amount that is allowed in water from public water systems.

SORB 09™ is the De Nora products offering a process using regenerable activated aluminat to treat naturally high levels of fluoride. The SORB 09 product by De Nora simplifies operation with automated operation and controls.[30]

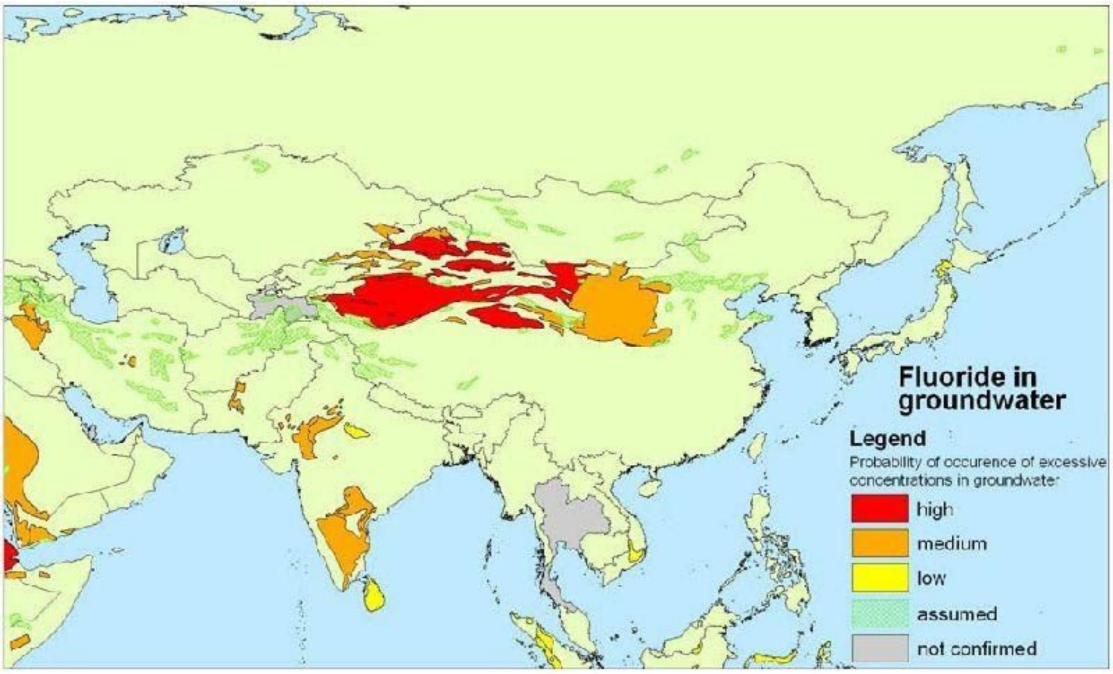

Figure 4 - Fluoride occurrence in groundwater in Asia.

Nitrate

Excess nitrogen from agricultural sources is one of the main causes of water pollution in Europe. In fact, nitrogen is a vital nutrient and is used as fertilizer: it helps plants and crops grow but high concentrations of nitrogen in any form - nitrates are the most common form in

27 https://www.intechopen.com/books/perspectives-in-water-pollution/ground-water-contamination-with-fluoride-and-potential-fluoride-removal-technologies-for-east-and-so

28 https://www.epa.gov/sites/production/files/2015-10/documents/2011_fluoride_questionsanswers.pdf

29 https://ec.europa.eu/health/scientific_committees/opinions_layman/fluoridation/en/l-2/1.htm

30 https://www.denora.com/products/brands/SORB.html

water bodies - are harmful to people and nature.[31] European Union's strategy to prevent nitrates considers the whole nitrogen cycle[32]: establishment of codes of good agricultural practices to prevent water pollution form nitrates; designation of nitrate vulnerable zones; monitoring of water bodies with regard to nitrate concentrations.

In the US, nitrate in groundwater drinking water systems is of concern because private self-supplied drinking water systems, which primarily draw from groundwater, are not federally regulated. It is the owner's responsibility to test and treat their own well for nitrate and other pollutants. While nitrates do occur naturally in groundwater, concentrations greater than 3 ppm generally indicate contamination. EPA's maximum contaminant level for nitrate set is 10 ppm.[33]

Consuming too much nitrate can affect how blood carries oxygen and cause methemoglobinemia in infants (also known as blue baby syndrome). However, there are health impacts of drinking water with high nitrate contents also for adults: there are potential associations with increased heart rate, nausea, headaches, abdominal cramps. Some studies also suggest an increased risk of cancer, especially gastric cancer.[34]

De Nora's SORB 07™ treats nitrate from surface or groundwater sources to meet the EPA maximum contaminant level of 10 mg/L nitrogen using a nitrate selective ion exchange resin process. The media is brine regenerable to ensure a long media life, and a variety of design considerations can be evaluated to minimize treatment costs and waste volumes

Perfluoroalkyl Substances (PFAS)

PFAS compounds are a class of non-stick, waterproof, stain-resistant compounds used in consumer products and industry. There are thousands of these per and poly fluorinated compounds, but the best known are PFOS and PFOA, which are no longer produced in Western countries. The PFAS issue isfar from being solved, since they are extremely bio-persistent and very chemically stable (I.e. difficult to destroy). Very low exposure to some PFAS has been linked to cancer, and many other health problems. Drinking water for up to 110 million Americans may be contaminated with PFAS. A non-exhaustive map of PFAS contamination across the US is freely available at EWG website.[35]

In 2019, the Environmental Protection Agency in the US released recommendation for safety limits to assess groundwater contamination by PFAS.[36] Risk exposure is particularly high for users of private groundwater wells - estimated to be more than 40 million in the US - who might be unaware of the potential issue.[37] In January 2021, EPA announced final

[31] https://ec.europa.eu/environment/water/water-nitrates/index_en.html

[32] https://ec.europa.eu/environment/water/water-nitrates/pdf/nitrates_directive_nitrogen_cycle_infographic.pdf

[33] https://www.epa.gov/nutrient-policy-data/estimated-nitrate-concentrations-groundwater-used-drinking

[34] https://www.health.state.mn.us/communities/environment/water/contaminants/nitrate.html

[35] https://www.ewg.org/interactive-maps/pfas_contamination/map/

[36] https://www.epa.gov/newsreleases/epa-releases-pfas-groundwater-guidance-federal-cleanup-programs-fulfilling-pfas-action

[37] https://www.ngwa.org/what-is-groundwater/groundwater-issues/Groundwater-and-PFAS

determinations to regulate PFOS and PFOA in drinking water and a proposal to require monitoring for 29 PFAS in drinking water under the fifth Unregulated Contaminant Monitoring Rule

Analogously, the European Union is setting the limit of 0.5 µg/L of total PFAS in drinking water, given the high concern of bioaccumulation in humans.[38]

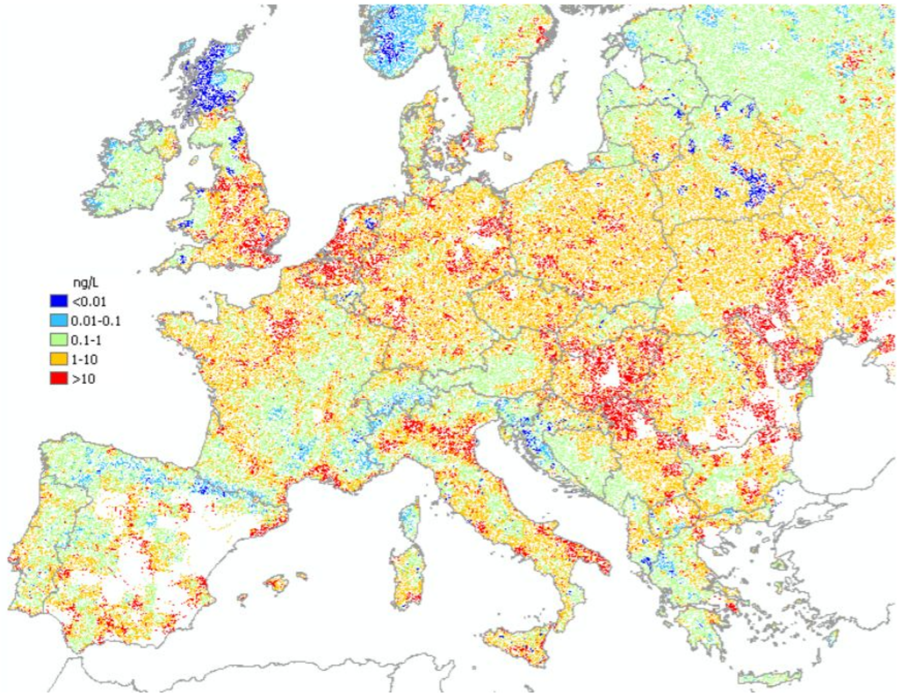

Figure 5 – PFOA concentration map in Europe.[39]

Blue-green algae in surface water intake

Another concern arises when surface water is used as source for drinking water, as typically happens for large metropolitan areas.[40] Cyanobacteria, also known as blue-green algae, can bloom in freshwaters, and some species can be toxic. Their toxins (cyanotoxins) can have diverse health effects on people and animals, ranging from mild to serious, and impacts on whole ecosystems.[41] Water intended for consumption generally needs to be treated to remove toxins before drinking, significantly adding to the cost of supply. In many countries, testing methods for cyanotoxins are not available and people may inadvertently be exposed to these health hazards.

Also, Harmful Algae Blooms (HABs) events may happen abruptly, causing sudden change in water safety. For instance, in 2014, a HAB event in Lake Erie left more than 400.000 people in the city of Toledo without safe water supply for two days. The toxic algae overburdened the local drink water supply utility and made their way into the water supply system. Similar issues occurred in other parts of the US, as well as in England and Wales.[42]

[38] https://www.eea.europa.eu/themes/human/chemicals/emerging-chemical-risks-in-europe
[39] https://pubs.acs.org/doi/10.1021/es901246d
[40] https://www.cdc.gov/healthywater/drinking/public/water_sources.html
[41] http://www.globalhab.info/files/Cyano_mitigation_GlobalHAB2019.pdf
[42] https://www.space-o.eu/the-algae-bloom-challenge-to-drinking-water/

In most cases, due to the nature of algae, problems with cyanotoxins generally occur during night, making immediate response often difficult and expensive.

As a possible solution collection and analysis of satellite images can measure magnitude of cyanobacteria blooms[43] to highlight areas threatened by major risks as well as designing and operating water treatment systems for the removal of cyanotoxins.

1,4 Dioxane and micropollutants

The likely human carcinogen 1,4-dioxane was first detected in drinking water more than 40 years ago, and a recent analysis suggests that almost 30 million people in the United States receive drinking water with 1,4-dioxane levels above the health-based reference[44] An interactive map showing identified water sources contaminated is available in the EWG website.[45] This contamination usually arose from past unregulated industrial practices, in which spent or unwanted solvents were legally dumped into unlined ponds or leaked from underground storage tanks, infiltrating aquifers. The manufacturing of polyesters, such as poly(ethylene terephthalate) (PET)—the clear plastic of beverage bottles,is one of the widespread chemical processes generating 1,4-dioxane as a by-product.[46]

There's no federal limit on 1,4-dioxane in tap water. The EPA set a nonbinding health advisory level for 1,4-dioxane in drinking water between 0.35 and 35 µg/L. The numbers correspond, respectively, to a lifetime cancer risk of 1 in a million and 1 in 10,000. The World Health Organization has a suggested a threshold of 50 µg/L.

Micropollutants — anthropogenic chemicals that occur in the aquatic environment well above a (potential) natural background level due to human activities but with concentrations remaining at trace levels (i.e. up to the microgram per litre range) - can have negative effects on plants, animals and humans. These compounds include pesticides, hydrocarbons, drug residues, and hormones It is a challenge for treatment plants to deal with these substances in wastewater due to their low concentration in water – micro or nano-grames per litere of water.[47]

Advanced Oxidation Processes (AOP) produce highly energetic free radicals that can destroy a wide variety of difficult to remove organic contaminants, such as 1,4-dioxane, persistent pharmaceutical, and cyanotoxins by converting them to carbon dioxide and water. De Nora offers Capital Controls® Ozone and Ultradynamics UV systems for AOP water treatment of such chemical substances. For more information, watch De Nora's webinar on [Micropollutants through AOP and Ozone].

[43] https://www.nature.com/articles/s41598-019-54453-y
[44] https://www.sciencedirect.com/science/article/abs/pii/S2468584418300485
[45] https://www.ewg.org/interactive-maps/2017_14D.php
[46] https://cen.acs.org/environment/pollution/14-Dioxane-Another-forever-chemical/98/i43
[47] https://www.euractiv.com/section/agriculture-food/news/study-micropollutants-have-significant-potential-impact-on-water-ecosystems-human-health/

Degradation over time and disinfection by-products

In the 20th century, chlorine revolutionized water purification, reduced the incidence of waterborne diseases across the western world, and remains the most widely used chemical for water disinfection.[48]

However, chlorine by-products are formed prior and during disinfection, causing risks to human health and the environment. In disinfection, gaseous chlorine (Cl_2) or liquid sodium hypochlorite (bleach, NaOCl) is added to the water stream to be treated.

Chlorates

The degradation over time of hypochlorite (ClO-) generates **chlorate** species (ClO_3^-), which are toxic through ingestion and typically lead to disruption to the production of thyroid hormones and goitrogens and methemoglobin. However, currently, chlorates are not currently regulated in the United States and there is no enforceable maximum contaminant limit, although this may come in future years. The World Health Organization (WHO) recommends a chlorate limit of 0.7 mg/L.[49]

Hypochlorite degradation depends on the freshness of the solution; concentration of delivered solution; storage temperature; solution pH (typically kept in the range of 12-13 to minimize chlorate production upon storage, making it a highly caustic chemical requiring safety oversight). The impact of these parameters on the stability of hypochlorite solutions can leadto a substantial increase in operational costs, due to cooling and required "born-on dating" labeling; limiting storage volumes, purchasing lower concentrations to slow hypochlorite degradation; dilution of the concentrated hypochlorite once it has been delivered to the treatment plant.[50]

On the one hand, digital tracking solutions may lighten the operational load of managing hypochlorite solutions. On the other hand, this is not solving the problem from its root, which can be instead solved by applying chlorine gas disinfection or on-site hypochlorite generation (OSHG): to this end, digital solutions may help highlighting the advantages of shifting from hypochlorite tanks to OSHG.

On-site generation is when basic, simple chemicals are used to generate a chemical at the point of use. With the De Nora ClorTec® on-site generator, the hypochlorite is generated using sodium chloride (common salt) and electricity. Hypochlorite generated on-site is always fresh, and <1% chlorine concentration has a very slow degradation rate, yielding to very low chlorate content. To know more, watch De Nora's webinar on Disinfection byproducts and Chlorates.

Disinfection Byproducts (DBP)

Either using hypochlorite or chlorine gas, water utilities must manage chlorinated disinfection by-products (DBPs) formation in the drinking water. Disinfection byproducts can be harmful to human health.[51]

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48 https://www.cdc.gov/safewater/chlorination-byproducts.html#three
49 https://blog.denora.com/status-of-chlorate-regulations-and-impact-clortec
50 https://blog.denora.com/future-proofing-water-disinfection-for-chlorate-regulation
51 https://blog.denora.com/efficacy-of-ozone-to-reduce-chlorinated-disinfection-by-products

To date, over 600 DBPs have been identified. Of these, trihalomethanes (THMs), such as chloroform or bromoform, and haloacetic acids (HAAs) have received the most attention and been subject to the most regulation. [52,53] The EU regulates total THMs and bromate in drinking water while the US regulates levels of THMs, HAAs and bromate.[54]

However, in recent years, there has been growing interest in the health risks posed by unregulated DBPs and emerging DBPs which, despite being found in lower concentrations, are often more toxic and so may represent a larger public health concern.[55]

De Nora has been developing and delivering ozone generation systems for municipal disinfection and advanced oxidation process (AOP) for industrial applications since the 1970s. Ozonation has been effectively shown to reduce significantly the amount of many DBPs in drinking water and has been increasingly adopted by water treatment plants all over the world.

Compliance to regulations

Governmental regulatory frameworks typically reflect how different water uses require different water qualities.[56] Water utilities, industries and private users shall comply to the most updated regulations for each use. However, violations are unfortunately still common, contributing to increase health and environmental hazards. Compliance to regulations is even more difficult in recent days, due to the destabilization of ecosystems for climate change, which magnify the risk of contamination of both surface and ground water.[57]

Drinking Water

Ensuring safe water supply for communities is a growing challenge in the face of aging infrastructure, impaired source water, and strained community finances. In the US, for instance, efforts to reduce violations are of national concern given that, in 2015, nearly 21 million people relied on community water systems that violated health-based quality standards.

Identifying hot spots and vulnerability factors associated with violations could better direct enforcement activity to struggling utilities and allow for increased compliance across the country. [58]

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[52] https://www.cdc.gov/safewater/chlorination-byproducts.html#three

[53] https://pubs.acs.org/doi/pdf/10.1021/acs.est.7b05440

[54] https://ec.europa.eu/environment/integration/research/newsalert/pdf/disinfection_by_products_drinking_water_new_detector_for_monitoring_detection_broader_range_dbps_sweden_514na1_en.pdf

[55] https://pubs.acs.org/doi/abs/10.1021/bk-2015-1190.ch011

[56] https://iwa-network.org/wp-content/uploads/2015/12/Compendium-of-Water-Quality-Main-Report_4.pdf

[57] https://www.sciencedirect.com/science/article/pii/S2214241X15002904

[58] https://www.pnas.org/content/pnas/115/9/2078.full.pdf

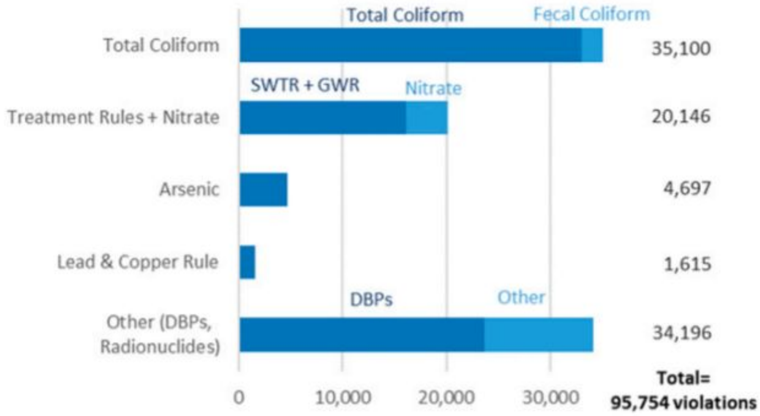

Figure 6 - Number of health-based violations, 1982–2015, by contaminant type.

The list of regulations applicable to drinking water are included in the Safe Drinking Water Act for the US,[59] the Drinking Water Directive in the European Union.[60]

Wastewater Discharge

Regulatory standards for wastewater discharged to surface waters and municipal sewage treatment plants wastewater treatment are issued by government to allow discharging while preserving the environment. These are divided by industrial categories, based on the performance of treatment and control technologies.

In general, the main issue of wastewater discharge concerns nutrient release to the water bodies. In fact, excessive nitrogen and phosphorus loadings to watersheds impact water quality by stimulating the growth of algae which may result in depletion of dissolved oxygen, shifts in pH, degradation of habitat, impairment of drinking water sources, and in some cases harmful algal blooms. According to the EPA, nearly every state has nutrient related pollution with impacts in over 80 estuaries/bays, and thousands of rivers, streams, and lakes.[61] The amount of nitrogen that can be released into freshwaters is regulated in most countries.[62]

Recent literature showed that it is possible to apply advanced decision control systems, based on artificial intelligence, for effluent violations removal in wastewater treatment plants. This allows for better complying to effluent limits violations removal as well as achieving a simultaneous improvement of effluent quality and reduction of operational costs.[63, 64]

[59] https://www.epa.gov/laws-regulations/summary-safe-drinking-water-act
[60] https://ec.europa.eu/environment/water/water-drink/legislation_en.html
[61] https://www.waterworld.com/home/article/16192413/wastewater-discharge-rules-evolving-to-protect-watersheds
[62] https://www.epa.gov/wqc/aquatic-life-criteria-ammonia
[63] https://www.sciencedirect.com/science/article/pii/S0967066116300053
[64] https://www.mdpi.com/1424-8220/19/6/1280

De Nora's TETRA® filters creates an ideal environment for simultaneous biological and physical/chemical treatment. This technology is very efficient in removing nutrients, such as phosphorus and nitrogen, organic compounds, and solids in tertiary fixed-film biological filters. Common applications include polishing municipal wastewater effluent to reuse standards and/or regulatory discharge limits.