# Clean Drinking Water Global Scarcity: A Review

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Review Article


# Clean Drinking Water Global Scarcity: A Review


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## 1. Abstract

Clean drinking water is essential. Although 71% of the global population are considered to have access to safe drinking water, non-contaminated drinking water cannot be taken for granted; also bottled water and tap water in industrialized countries can be severely contaminated. This review paper summarizes the findings from the recent literature on drinking water contamination by anthropogenic sources, viz. chemicals (emerging pollutants) and their degradation products, which can also have disadvantageous effects even at very dilute concentrations. Approx. 1000 compounds are known to be present in drinking waters, at concentrations starting at the ng/L range. Advances on analytics have allowed us to witness now an alarming trend of contamination in drinking water. Not all contaminants are regulated, and more research is needed. Protection of water resources and a careful selection of drinking water sources has become more critical in recent years and will continue to be of utmost importance in future.


## 3. Background

Planet Blue is covered to more than 70% by oceans. Freshwater makes up no more than 2.5% of Earth's total water, and fresh and unpolluted water accounts for less than 0.003% of the total globally available water [1].

Human activities have threatened the groundwater quality because of inadequate collection, treatment, and disposal of solid and liquid wastes [2] and various activities such as fertilizer (over) use.

Drinking water is our most important comestible. We cannot live without it. Each human needs on the order of 2-5L/day and 1-2 orders of magnitude more are typically consumed. Since only a fraction of potable water is used for drinking and cooking, huge amounts of valuable pure water are wasted in some parts of the world, e.g. for irrigation, where also less qualitative water (grey water) could be used. Not everybody has access to fresh and unpolluted water, which is a huge - and often deadly - concern. According to the WHO, health risks may arise from consumption of water contaminated with infectious agents, toxic chemicals, and radiological hazards. Improving access to safe drinking-water can result in tangible improvements to health [3].

Protecting the integrity and quality of our water resources has become one of the most essential environmental tasks [4].

The EU Directive 98/83/EC defines '*water intended for human consumption*' as '*all water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers*', and '*all water used in any food-production undertaking for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form*' [5].

On the one hand, huge efforts have been taken in the last decades to provide access to clean drinking water for all people in the world, and the fraction of uncatered-for humans could be pushed back successfully. On the other hand, a novel water crisis has started to emerge. Climate change [6] is considered to have an impact on drinking water availability and security [7]. In the news, one can witness countless reports on water shortage [8] also in well-developed economies, for instance the 2018 Cape Town water crisis [9], which could be averted 90 days before water shutdown "Day Zero", or the 2014/2015 Flint water crisis in the US [10], where cost cutting measures had caused drinking water to be contaminated by bacteria and dangerous levels of lead. Other water-stressed cities are Sao Paulo/Brazil (settlements close to reservoirs), Beijing/


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China (huge population), Cairo/Egypt (infrastructure), Bangalore/India (low water conservation), Jakarta/Indonesia (lack of infrastructure upgrades), and Moscow/Russia (Soviet-era pollution and unmonitored dumping) [11]. Some countries are more at risk than others to suffer from water crises, see (Figure 1) below.

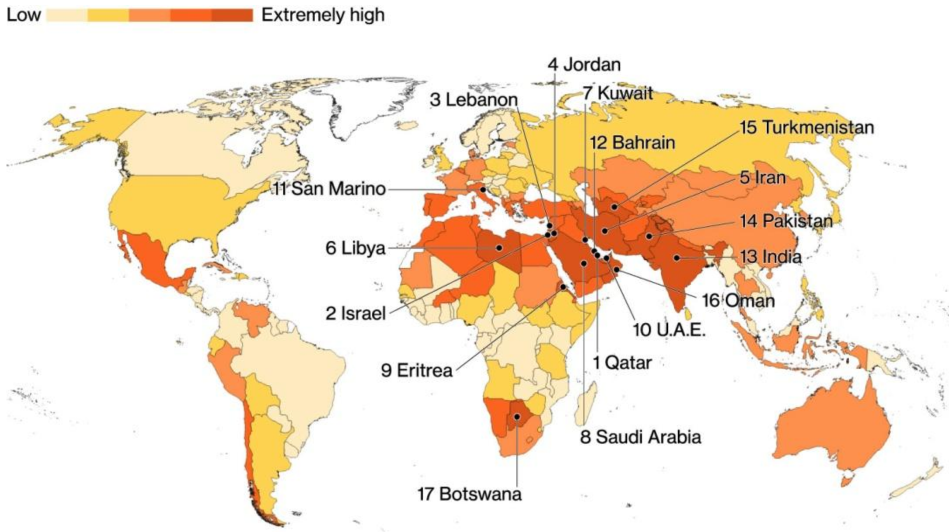



**Figure 1:** Countries at high risk for a water crisis. Source: [12]. Compare also the "Water Scarcity Clock" [13].

Water scarcity can be either physical (absolute) water scarcity or economic water scarcity. It arises from the fact that freshwater resources are limited, and that the human population is a) exploding and b) using water very inefficiently. For instance, the production of one hamburger uses up 2400 liters of water [14].

Symptoms of physical water scarcity include environmental degradation and declining groundwater levels. It is more difficult to solve, if at all possible, than economic scarcity. Water use has grown at more than twice the rate of population increase in the last century [14], and valuable water resources are being exploited and depleted. This fact has not gone unnoticed, and already in 1993**,** the U.N. General Assembly has designated March 22 as World Water Day [15]. Today, 29% of the world does not have access to safe drinking water [16]. Unsafe water sources are known to be responsible for 1.2 million premature deaths per year (which corresponds to 2.2-6% of all deaths), and it has been a huge concern that unsafe water is one of the world's largest health and environmental problems, especially for the poorest countries in the world [16].

Key facts put together by the WHO are [17]:

*"In 2017, 71% of the global population (5.3 billion people) used a safely managed drinking-water service – that is, one located on premises, available when needed, and free from contamination.*

*90% of the global population (6.8 billion people) used at least a basic service. A basic service is an improved drinking-water source within a round trip of 30 minutes to collect water.*

*785 million people lack even a basic drinking-water service, including 144 million people who are dependent on surface water.*

*Globally, at least 2 billion people use a drinking water source contaminated with faeces.*

*Contaminated water can transmit diseases such diarrhoea, cholera, dysentery, typhoid, and polio. Contaminated drinking water is estimated to cause 485 000 diarrhoeal deaths each year.*

*By 2025, half of the world's population will be living in water-stressed areas.*

*In least developed countries, 22% of health care facilities have no wa- ter service, 21% no sanitation service, and 22% no waste manage- ment service."*

Clean water is an explicit and pivotal part of the UN sustainable development goals (SDG) [18], as Goal 6: *"Ensure access to water and sanitation for all*". Subgoal 6.1 reads "*By 2030, achieve universal and equitable access to safe and affordable drinking water for all"* [18]. Without water, education and other highly relevant aspects vanish in importance, as water is so crucial for our lives.

Water as such is available abundantly on earth, for drinking, sanitation, crop irrigation, etc. It is through manmade pollution that vast amounts have been rendered unusable.

China, now the world's most populous country, once emerged as one of the world's first civilizations, in the fertile basin of the Yellow River. Today, the important water resources are in bad shape. Almost 90% of underground water in cities is reported to be inflicted by pollution, as are 70% of China's rivers and lakes [19]. In 2007, the head of China's national development agency said that one quarter the length of China's seven main rivers were so poisoned the water harmed the skin [20]. This is just one example.

*"There is a water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people - and the environment - suffer badly."* (Table 1) World Water Vision Report [21].

Nitrate [23, 24] concentration of more than 45 mg/L in drinking water can lead to human and animal health issues [2].

For bacteria in bottled water, see [25, 26], and for mould growth [27]. Water dispensers can exhibit growth of bacteria when not being well-maintained [28].

According to a report by the World Economic Forum, the water crisis is the number four global risk with regard to impact to society [29].

By 2025, two-thirds of the world's population may face water shortages. And ecosystems around the world will suffer even more [30]. Water shortage is and will be no local phenomenon, but a global challenge in the very near future.

## 4. Drinking Water Supply

Drinking water can be obtained from municipal supply, small-scale supplies or from domestic drinking water wells. Private Wells supply 44million people in the US and are also quite common on a global level [31]. In the EU, the largest population depending on their own wells is in Finland [32]. Small-scale water supplies are the backbone of water supply in rural areas in the entire pan-European region [33].

While public drinking water supply is managed and subjected to strict controls, small-scale water supplies are often not regulated or regulated differently compared to larger supplies [33]. Private wells need no monitoring at all, and so domestic drinking water wells can become contaminated in an unnoticed way, for instance from septic tanks close by [31]. A main reason for the risk of private wells is that they tend to be shallow. Often, their contamination exceeds drinking water standards [31].

(Figure 2) shows the results of a study on 20 domestic drinking water wells in a sand and gravel aquifer on Cape Cod, Massachusetts, USA, for organic wastewater compounds (OWCs) and for inorganic markers of septic system impact. 27 OWCs, including 12 pharmaceuticals, five per- and polyfluoroalkyl substances (PFASs), four organophosphate flame retardants [34], and an artificial sweetener (acesulfame) were detected. The maximum concentrations of several PFASs and pharmaceuticals were found to be relatively high compared to public drinking water supplies in the US.

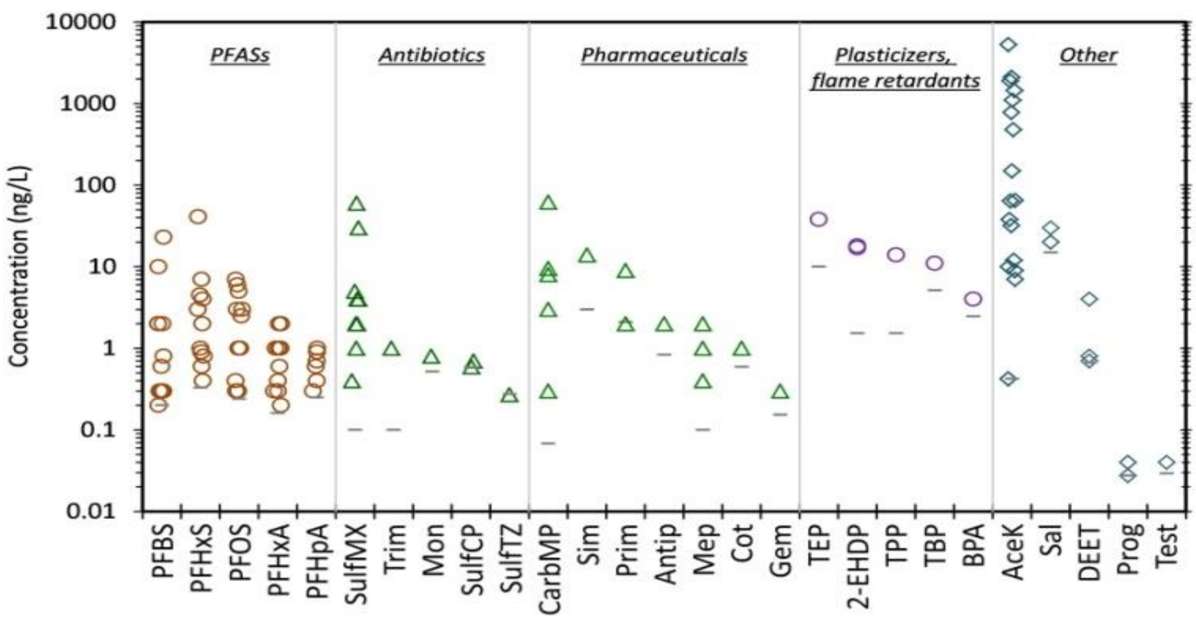



**Figure 2:** OWC (organic wastewater compounds) concentrations in 20 domestic wells on Cape Cod/US (PFASs = per- and polyfluoroalkyl substances). Horizontal gray lines indicate method detection limits. Source: [31]

An examination over the entire USA in 2006 found exceedances of drinking water standards in 8.4% of wells for nitrate and 11% of wells for arsenic [35].

For private wells in Canada, it was recommended to routinely test these wells for contamination, and to use treatments to eliminate bacteria [36].

Perfluorinated compounds in private wells in Germany were reported in [37, 38], copper and lead in Australia [39], and manganese in Costa Rica [40], or PAHs (polycyclic aromatic hydrocarbons) and BTEX (benzene, toluene, ethylbenzene, xylenes) in Ecuador [41], all in vicinity of respective contaminating activities such as banana plantations or oil activities, to cite but a few examples.

## 5. Labelling of Drinking Water

EU Directive 2009/54/EC has established rules on the exploitation and marketing of natural mineral waters, which are defined as *'microbiologically wholesome water […] originating in an underground water table or deposit and emerging from a spring tapped at one or more natural or bore exits'*. The Directive also includes certain labelling requirements in addition to the general labelling rules for foodstuffs of Regulation (EU) 1169/2011, such as the analytical composition, the name and place of the spring of origin, and information on any of the permitted treatments.

The term *spring water* should be used for water that *'is intended for human consumption in its natural state and bottled at source'* and which fulfils the various criteria and conditions described in Dir. 2009/54/EC. Effervescent mineral waters instead can be divided in naturally carbonated mineral water, natural mineral water fortified from gas from the spring, or carbonated mineral water in which the added carbon dioxide is of a different origin from the water source [5].

The European Commission has also authorized health claims in relation to water intake (EU Register on nutrition and health claims), referring to maintenance of normal physical and cognitive functions as well as body temperature. In order to bear the claims, information shall also be given to the consumer that at least 2 litres of water, from all sources, should be consumed per day [5].

## 6. Drinking Water Consumption

In general, it is recommended to drink 1.5 to 2 l of water per day [5]. The demand varies depending on outside temperatures, activity level, etc. (Table 2) below shows actual drinking water consumption values by the example of Austria.

**Table 1:** Most common contaminants in water. Source: [22]

| Parameter | Occurrence | Health Significance | Limit Value |
|---|---|---|---|
| Non-biological | | | |
| Ammonia | Results in microbiological activity | Irritations to eyes, nose and throats, non-deadly threats to human | 0.5mg/L |
| Arsenic | Dissolution of minerals from industrial | Very toxic to humans, high risk of skin cancers | 10µg/L |
| Barium | Natural occurring chemicals | Painful swallowing, ulcer | 5µg/L |
| Boron | Natural occurring chemicals, leach of rocks and soil | Kidney failure, depression | 0.5mg/L |
| Chlorine | Industrial effluents | Toxicity to humans, hazardous | 5mg/L |
| Chromium | Industrial Processes | Skin irritation, damage kidney, liver | 10µg/L |
| Cadmium | Sediments of rock and soil | Hazardous to human, effect respiratory system and bone disease | 3µg/L |
| Lead | Leaching from ores, attack on water pipes | Toxic cumulative poison | 10mg/L |
| Mercury | Normally from industrial waste | very toxic, human fatal | 1µg/L |
| Nickel | Chemical used in water treatments | Cancer of lungs and nose | 20µg/L |
| Nitrate | Presence from agricultural activities | Risk of lifetime cancer | 3mg/L |
| Sodium | Natural waters, abundant of rocks and soil | High-blood pressure, heart diseases | 200mg/L |
| | | | |
| Biological | | | |
| Cryptosporidium | Present in human and animal waste | Infections, fever, stomachache, diarrhoea | 630mg/L |
| Escherichia coli | Sewages and similar waste | Pathogenic Properties, effect human health | 10CFU/ml |
| Giardia | Present in human and animal waste | Effect human health, rarely fatal | 10cysts/L |
| Legionella | Sediments of water | Risk of Legionnaire's disease and Pontiac fever | 100CFU/mL |
| Pesticide | Agricultural discharges, spillages | Eyes and ears infection | 0.1g/L |
| Pseudomonas | Abundant in sewage | Hypertension if taken excess | 500CFU/mL |

**Table 2:** Austrian study on nutritional status (ASNS 2008), sub study on water consumption in a 1-day-drinking protocol. Source: [5].

| Age group | Drinking water intake (mean unless otherwise indicated)ml/d | | Total non-alcoholic beverage intake (mean unless otherwise indicated)ml/d | |
|---|---|---|---|---|
| | Males | Females | Males | Females |
| 17-30 | 1573 | 1335 | 2543 | 2395 |
| 31-45 | 1476 | 1497 | 2383 | 2558 |
| 46-64 | 1281 | 1297 | 2120 | 2262 |
| 65-81 | 1610 | 1762 | 2236 | |

## 7. Bottled Water: Natural Mineral Water and Spring Water

Bottled water is available in different types, carbonated and non-carbonated (still).

The global bottled water consumption is on the order of 300 billion liters per year [42].

Medicinal water and flavored water, just as (carbonated) soft drinks, are excluded from the considerations made here. One can distinguish between mineral waters as: waters with a very low mineral content, waters low in mineral content, waters with a medium mineral content, and strongly mineralized waters. Another classification based on ion composition is: bicarbonate waters, sulfate waters, sodium chloride or saltwater, sulfurous waters. Based on their biological activity mineral waters can be grouped as: diuretic waters, cathartic waters, waters with antiphlogistic properties [43].

The use of spring water for nutrition and bathing and drinking can be traced back to Roman times, and several springs that were exploited in ancient times are still in use in our times [44].

Packaged Spring Waters (SPW) and Natural Mineral Waters (NMW) can be clearly distinguished from ordinary drinking water by their protected groundwater origin and by the fact they are not subjected to any treatment to remove contaminants of human origin nor to any disinfection (Directive 2009/54/EC) [42].

The demand for bottled water has increased steadily over the last decades in virtually all areas of the globe. A trend fostering increased bottled water consumption is urbanization [45]. “City people” tend to prefer bottled water because it is associated with being natural [46], and because they often object to unpleasant tastes and odors from municipal water supplies in many areas of the world [47]. Also, bottled water is commonly seen as being safer and healthier than tap water [48]. There is also a common belief that natural (spring) waters have beneficial health effects [49].

Each country has dozens or hundreds of different bottled (mineral) water brands, with different market approaches. Also, their composition varies, often significantly.

Study [50] has compared 189 Turkish bottled water brands by their chemical composition. The differences were attributed to the waters’ natural environment (geologic formations, climate, topography, etc.) and their varying is further modified by the treatment technologies (disinfection and purification) carried out by bottled water manufacturers during the production. Bottled water is produced for domestic consumption or for export.

Mineral waters containing sulphur compounds can have beneficial health effects [51] and [52].

## 8. Bottled Water and Quality

*“Many consumers buy bottled water on the assumption that it’s safer than what flows out of their tap. That has helped fuel the growth of the bottled water industry, which reached $31 billion in sales in 2018. Forty percent of Americans believe bottled water is safer than tap”* [53].

In a scientific study [54], that assumption could be confirmed for microbial contamination. Packaged water was less likely to contain fecal indicator bacteria compared to other water sources used for consumption. However, also bottled water can be contaminated [53], as well as tap water intended for human consumption.

Quality monitoring is typically performed on samples in the laboratory. Some parameters can be measured instantly, such as pH, while microbiological results can take up to a day or more. (Table 3) lists parameters that can be measured online.

For online and near-real-time methods in microbiology, see [55].

**Table 3:** Parameters for online water quality monitoring. Source [22].

| Category | Water Quality Parameter |
|---|---|
| Physical | Turbidity, color, conductivity, hardness, temperature |
| Inorganic | pH, disinfactants, metals, fluoride, nutrients |
| Organic | TOC, hydrocarbons, VOCs, pesticides, DBP |
| Biological | Algae, protozoa, pathogens, BOD |
| Hydraulics | Flow, pressure |

## 9. Analytical Chemistry

Analytical techniques have become more and more sensitive over the years, and today minute amounts of contaminants can be detected, up to single molecule detection [56], [22].

Detection limits are commonly at sub ng/l levels, e.g. at 0.02 ng/L for PFHxS (perfluorohexane sulfonate) and 0.85 ng/L for PFOA (perfluorooctanoic acid) [57, 58], two emerging pollutants [59] (see below).

## 10. Drinking Water Contamination

Drinking water can become contaminated chemically and/or biologically through different routes, see (Figure 3) and compare [60].

While (ground) water can contain various substances such as heavy metals naturally, anthropogenic influences are common to cause pollution. There is "typical" pollution such as lead (e.g. from old plumbing installations), but drinking water may also contain (low levels of) Micro Pollutants (MP) and disinfection by products (DBP) [62]. The latter can form from organic and inorganic matter contained in the raw water (e.g. humic acids) [63] and transformed by treatment processes such as UV irradiation or chlorination. Chlorine, chloramine and ozone were reported to form DBP. There are hundreds of known DBP, and they are ubiquitous [62].

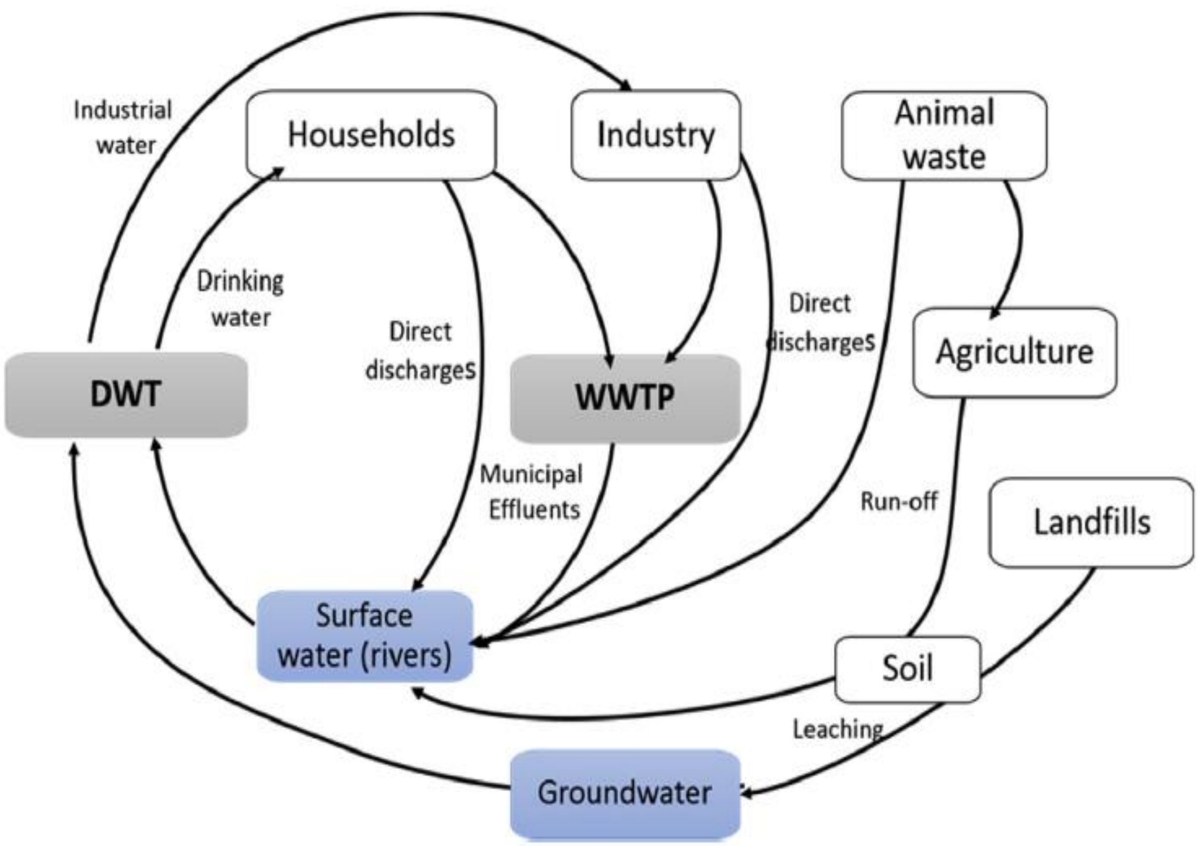



**Figure 3:** Pathways for emerging pollutants (EP) and impacts; DWT = drinking water treatment; WWTP = waste water treatment plant. Source: [61]

In 1974, chloroform was detected and identified as the first disinfection byproduct (DBP) in chlorinated drinking water [62].

Also, so-called micro pollutant transformation products (TP) can form during water treatment with disinfectants and during other advanced oxidation processes [64].

Pharmaceuticals, together with their metabolites/transformation products, mainly enteraquatic environments via the effluents of municipal waste water treatment plants, discharges of sewage sludge, livestock waste, and aqua culture activities [65].

Also, cytostatic drugs from cancer treatments have emerged as novel water contaminants [66].

The literature has suggested to use in vitro bioassays [67-71] or a cell-based metabolomics approach [72] for analysis due to the complex mixture of trace chemicals in drinking water where a targeted chemical analysis alone is not considered sufficient for monitoring [73].

(Figure 5) gives an insight into typical contamination.

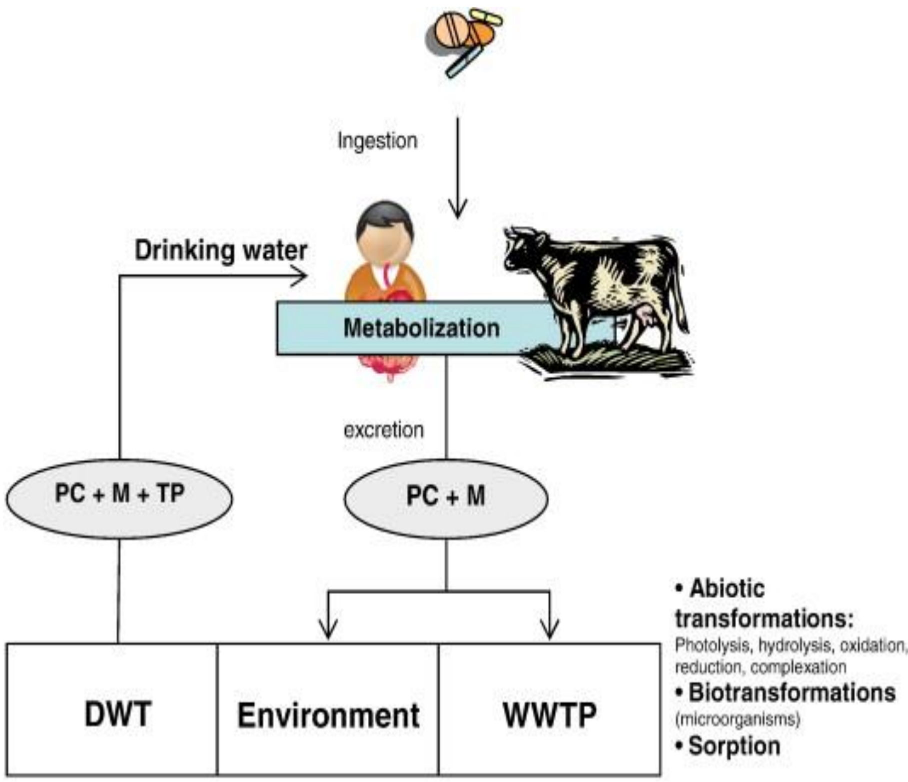



**Figure 4:** Transformation pathways of pharmaceutical products (PPs; PC: parent compound, M: Metabolite(s), TP: Transformation Product(s), WWTP: Waste Water Treatment Plant; DWT: Drinking Water Treatments). Source: [60].

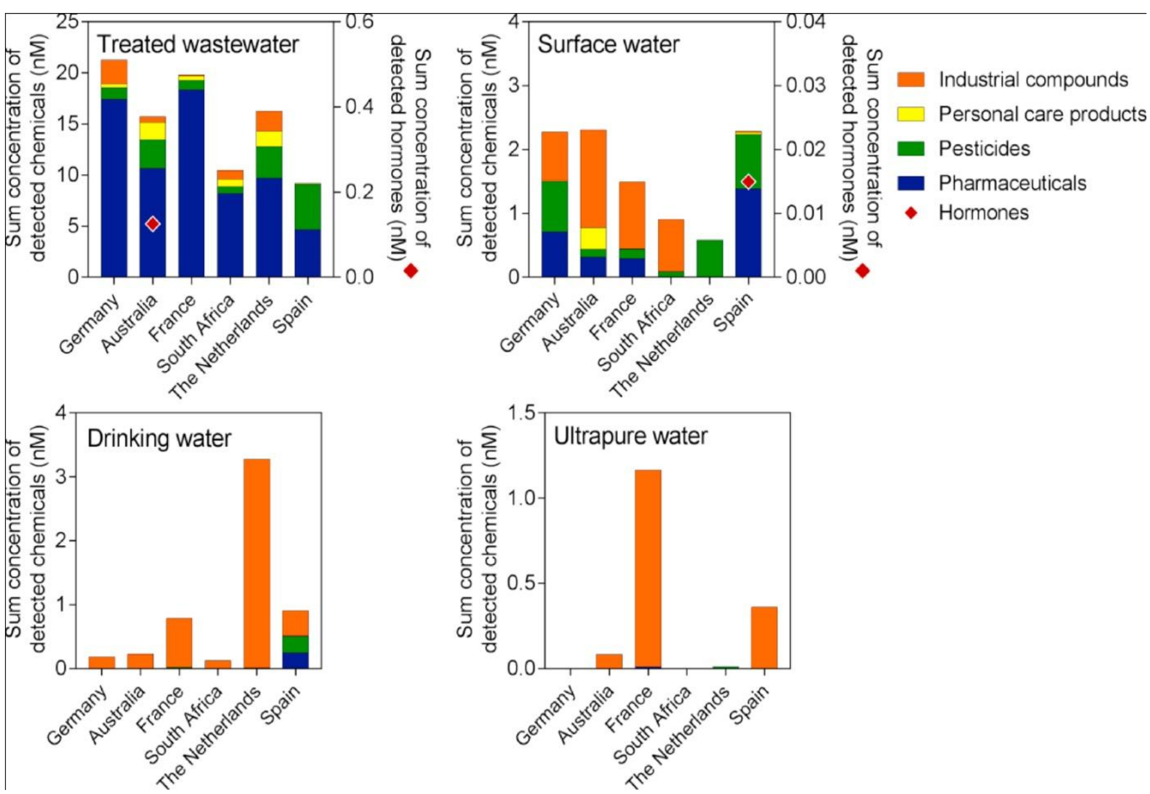



**Figure 5**: Sum chemical concentration detected in each country (nM) by chemical class excluding hormones (left axis) for treated wastewater, surface water, drinking water and ultrapure water, with sum hormone concentration (right axis) for treated wastewater and surface water. Note different y-axis scales in each figure. Source: [68].

As for the Micro Pollutants (MPs), one also speaks about Emerging Pollutants (EPs) [59], Contaminants of Emerging Concern (CECs), Priority Pollutants (PPs), Persistent Toxic Substances (PTS) or Substances of Very High Concern (SVHC) [61]. These substances have deleterious health effects on humans, and they are persistent in the environment. Pesticides, pharmaceuticals, personal care products, detergents, disinfection by-products, drugs, flame-retardants are a few examples of EPs [61].

Pharmaceuticals are so-called "pseudo-persistent" contaminants in aquatic environments [65]. Pharmacologically active substances in the water environment are mostly derived from pharmaceuticals for human use, including prescription drugs, over-the-counter drugs, as well as veterinary drugs [74].

In 1995, the United Nations Environment Programme had an initial focus on what became known as the "Dirty Dozen", a group of 12 highly persistent and toxic chemicals: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and toxaphen. By now, additional substances such as carcinogenic polycyclic aromatic hydrocarbons (PAHs) and brominated flame-retardants, as well as organometallic compounds such as tributyltin (TBT) have been added to the list of EPs [75].

Sources of EP include the improper use and/or disposal of agrochemicals and industrial chemicals and unwanted by-products of industrial processes or combustion. EPs areeco-toxicological and bio-accumulative, and due to their lipophilic nature, the concentrations in fatty tissue can become magnified by up to 70 000 times higher than the background levels [75].

The Norman Network, a network of reference laboratories, research centres and related organizations for monitoring of emerging environmental substances [76] defined EPs as substances detected in the environment but currently not included in routine environmental monitoring programmes but with adverse effects and/or persistency. More than1000 substances, gathered in 16 classes (algal toxins, antifoaming and complexing agents, antioxidants, detergents, disinfection byproducts, plasticizers, flame retardants, fragrances, gasoline additives,

nanoparticles, perfluoroalkylated substances, personal care products, pharmaceuticals, pesticides, anticorrosives), are classified as EPs [61]. The European Environmental Agency considers that EPs should be closely monitored as concentrations and effects, since they are increasingly being found in water bodies across the EU [61]. Common plasticizers are phthalates. In an Iranian study, it was found that the phthalate levels of drinking water significantly increased by contact of hot water with disposable plastic and paper cups and by sunlight exposure of bottled water [77].

Standard water purification technologies are not suitable to remove EPs. There are, however, advanced drinking water treatment (ADWT) techniques, see (Table 4):

Since most POPs are non-polar, the application of filters, such as activated carbon filters, has resulted in a significant decrease in their presence [78]. Today, it is the polar pollutants which are more problematic. Pharmaceuticals, Personal Care Products (PPCPs) and Endocrine Disrupting Chemicals (EDCs) are polar, and their removal is insufficient both in waste water treatment and drinking water production plants [78].

The formation of MP, TP and DPB in drinking water is depicted schematically in (Figure 6) below.

In (Figure 6), BEQ stands for the bio analytical equivalent concentration, which relates the effect of a sample to the concentration of a reference compound that would elicit the same responseas the mixture of chemicals in the tested water sample [64], [67].

In a study on the transformation of Endocrine Disrupting Chemicals (EDC), Pharmaceutical and Personal Care Products (PPCPs) during drinking water disinfection [63], it was found that EDCs and PPCPs do produce a large number of TPs, but these are unlikely to increase specific toxicity (e.g., endocrine activity), but may result in increased reactive and non-specific toxicity.

For perchlorate, as an example of a substance of concern where no limits have been set yet, see [79] and [80].

Some EP in drinking water are known or suspected Endocrine Disrupting Compounds (EDCs), but EDCs are not routinely measured [81]. Pesticides, for instance, are suspected to be such EDCs, and they were found in US (Iowa) drinking water samples [81]. EDCs [82], [71] encompass Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), Polybrominated Biphenyls (PBBs), dioxins, furans, alkylphenols(APs), Pharmaceuticals And Personal Care Products (PPCPs), and pesticides [83].

Endocrine disruptors [84] are chemicals that may interfere with the production or activity of human hormones. Exposure to endocrine disruptors can cause cancer or an increased risk of cancer, changes in the development and behavior of infants and children, changes in reproductive organs and function, infertility, endometriosis, disturbances in the immune and nervous system functions, heart disease/stroke and asthma [85]. (Table 5) gives an overview of EDCs.

**Table 4:** Overview of EP removal possibilities by ADWT at pilot and full scale. Source: [61].

| Treatment processes | Eps class target | Removal efficiencies |
|---|---|---|
| **Single processes Ozonisation** | Pharmaceuticals | >98% |
| **UV-photolysis** | Pharmaceuticals | 30-70% |
| Nanofiltration | Pharmaceuticals | 15-100% |
| GAC adsorption | Mix of 30 Pharmaceuticals, pesticides | 20-50% as DOC |
| **Combined processes** Dioxychlorination, coagulation/flocculation, sand filtration, ozonation, carbon filtration, and final disinfection with chlorine | Pharmaceuticals and drugs of abuse | >98% |
| coagulation, ultrafiltration, and GAC filtration | Pharmaceuticals, hormones, antibiotics and flame retardants | 99% |
| UV-pre-disinfection, filtration, nanofiltration, reverse, osmosis, reminerelization and chlorine disinfection | Pharmaceuticals | >85% |
| Chlorine, coagulation/flocculation, sedimentation, filtration, chloramine, ozonation, GAC filtration, chlorine disinfection | Drugs of abuse | 89-100% |
| Chlorine, coagilation/flocculation, filtration, ozonation, granular activated carbon, final chlorination | Drugs of abuse | 88-100% |
| Coagilation/flocculation, filtration and final chlorination | Drugs of abuse | 0-18% |
| Filtration, coagilation/flocculation and final chlorination | Pharmaceuticals, flame retardants, plasticizers, biocides, pesticides, herbicides, UV filters | >60% |
| Coagilation, flocculation, sedimentation, rapid sand filtration, ozonisation, two-step GAC filtration and Ultraviolet disinfection | Pharmaceuticals | 51-95% |
| Advanced oxidation | Pharmaceuticals | >99% |
| Ultrafiltration and nanofiltration | Estrogens | >90% |
| Photocatalysis and solar photolysis | Pharmaceuticals | 66-82% |
| UV/H2O2 integrated into an existing full scale plant | 10 pesticides, Pharmaceuticals, Microorganisms | 60-98%<br>67-98%<br>100% |
| Ultraviolet -photolysis | Pharmaceuticals | 80% |
| Dioxychlorination, coagulation/flocculation, setting, sand filtration, ultrafitration, ultraviolet disinfection, reverse osmosis and remineralization | perfluorooctane sulfonate (PFOS)/perfluorooctanoate | ≥99% |

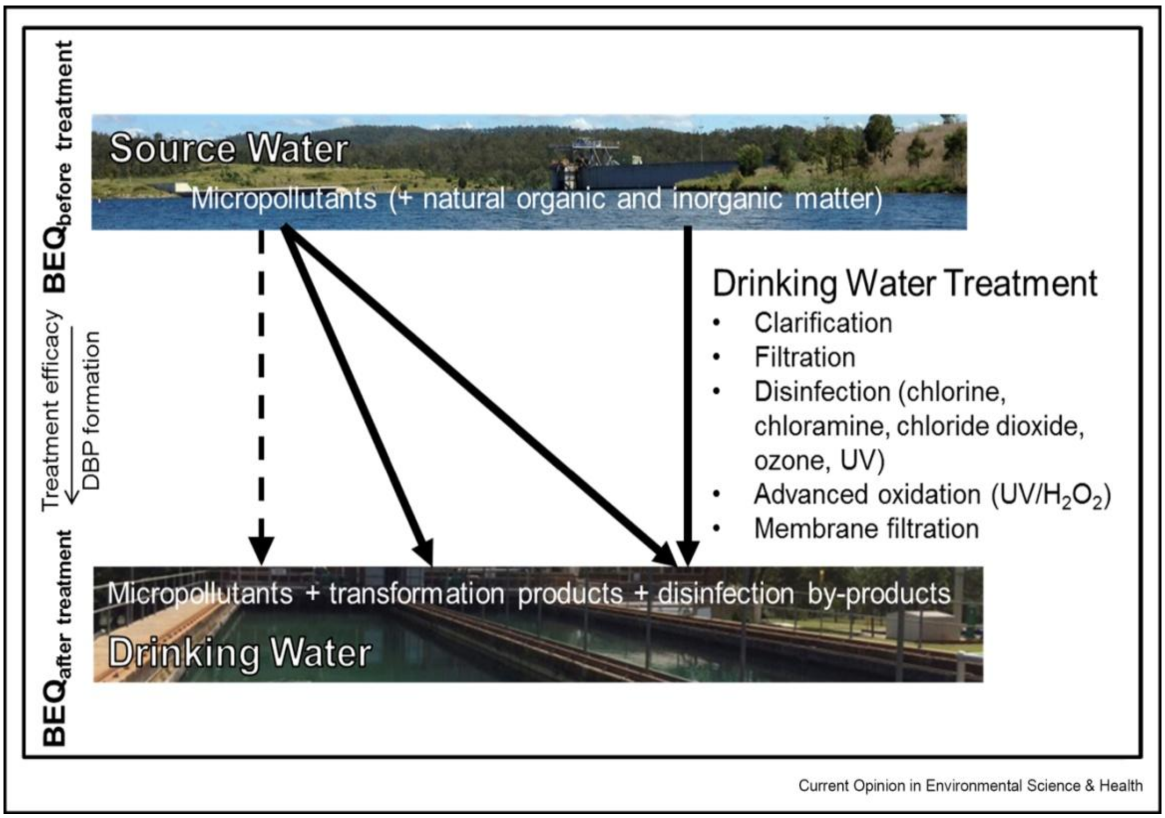
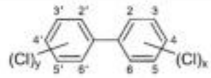
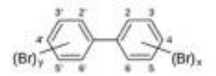
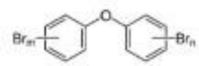
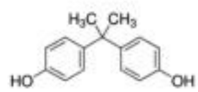
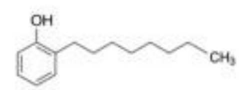
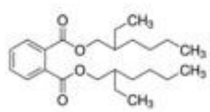
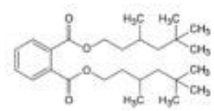
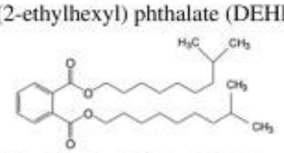
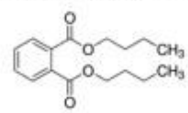
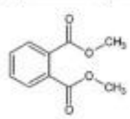
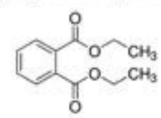
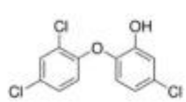
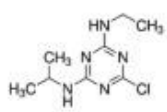
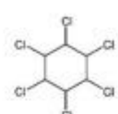
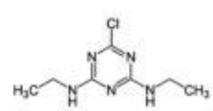



**Figure 6:** Overview of chemicals potentially present in source water and treated drinking water with the solid arrows indicating the formation of new chemicals after treatment. Comparison of bioanalytical equivalent concentrations before treatment (BEQbeforetreatment) and after treatment (BEQafter treatment) can shed light on treatment efficiency and disinfection by-product (DBP) formation. Source: [64].

**Table 5**: Respective usage of different groups of EDCs. Source: [83].

| EDC class | Example and structure | Usage |
|---|---|---|
| Polyhalogenated compounds |  Polychlorinated biphenyls (PCBs)  Polybrominated biphenyls (PBBs)  Polybrominated diphenyl ethers (PBDEs)  Perfluorooctanesulfonic acid (PFOS)  Perfluorooctanoic acid (PFOA) | - Flame retardants<br>- Surfactants |
| Phenolic compounds |  BisphenolA (BPA)  Nonylphenol (NP)  Octylphenol (OP) | - Plasticizers<br>- Surfactants<br>- Lubricants<br>- Fragrances<br>- Antioxidants<br>- Additives |
| Phthalates |  Di-(2-ethylhexyl) phthalate (DEHP)  Di-isononyl phthalate (DINP)  Di-isodecyl phthalate (DIDP)  Dibutyl phthalate (DBP)  Dimethyl phthalate (DMP)  Diethyl phthalate (DEP) | - Plasticizers<br>- Lubricants<br>- Fragrances<br>- Additives |
| Pesticides |  Triclosan  Atrazine  Lindane  Simazine | - Pest controls<br>- Antimicrobial or antifungal agents |

In [86] pharmaceutical residues in drinking water from Putrajaya (Malaysia) were studied. Previous comparable studies had focused on developed/industrialized countries. Amoxicillin, caffeine, chloramphenicol, ciprofloxacin, dexamethasone, diclofenac, nitrofurazone, sulfamethoxazole, and triclosan were investigated in drinking water. On the highest level, up to 0.38 ng/L of caffeine were detected, and atthe lowest concentration, that of diclofenac, still 0.14 ng/L were found.

The authors of [87] determined pesticide occurrence in Dutch groundwater and surface water sources used for drinking water. As a result, in the majority of drinking water sources, pesticides and/or metabolites were detected, also in concentrations above the water quality standard from the Water Framework Directive. Two neonicotinoids were detected in highest concentrations: acetamiprid (1.1 mg/L) and thiamethoxam (0.4 mg/L)[87].

Another study was done in Sweden, were in 2013 very high levels of PFOS and PFHxS were found in the drinking water from one of the two waterworks supplying the municipality of Ronne by [88]. Per- and polyfluoroalkyl substances (PFAS) are extremely persistent manmade substances.

A study in Brazil has looked at the presence of pharmaceuticals from different therapeutic classes in six Drinking Water Treatment Plants (DWTPs) in Minas Gerais state [89]. From the 28 pharmaceuticals analyzed, 18 were detected in the surface water source at concentrations between Method Quantification Limit (MQL) and 11,960 ng/L, and still at up to 6,323 ng/L in drinking water.

Betamethasone, Fluconazole, Atorvastatin and Prednisone were the most detected pharmaceuticals. Conventional DWTPs were not able to remove the pharmaceuticals completely [89].

What is special about Brazil in this case is that many cities do not have Wastewater Treatment Plants (WWTPs), and domestic sewage hence directly enters water bodies.

Bisphenol A, a well-known EDC, in drinking water from PET and glass bottled water samples of diverse trademarks and origin purchased in Riyadh/Saudi Arabia, was measured by [90].

It was found that PET bottled samples contained lower amounts of BPA ranging from 0.29 μg/L to 24.88μg/L, whereas glass bottled samples contained higher amounts of BPA that ranged from 4.34 μg/L to41.19 μg/L.

In Hong Kong, benzophenones (BPs) and other Ultra Violet (UV) filters used in sun block and other personal care products were detected in tap water and distilled bottle water, with detection rates of 100% and geometric means of 9.64 and 14.5 ng/L, respectively [91]. A toxicological risk assessment of EP in drinking water was done for 163 substances, out of 686 chemicals present in surface water, groundwater and/or drinking water, and for 39 of which only (statutory) drinking water guideline values had been reported. Based on measured concentrations it was concluded that the majority of substances do not occur in concentrations which individually pose an appreciable human health risk. A health concern could however not be excluded for vinylchloride, trichloroethene, bromodichloromethane, aniline, phenol, 2-chlorobenzenamine, mevinphos, 1,4-dioxane, and nitrolotriacetic acid [92].

In a French study [42], 40 bottled waters were tested. No phthalate, hormone or pharmaceutical substances were quantified; however, 11 samples showed contamination at the low-ng/L level of herbicides or their metabolites, 6 samples contained PFAS (perfluoroalkyl substances) and 2 of them APs (alkylphenols).

In another study [121], drinking water in Eastern China was assessed for toxicological and chemical status. Particularly for Huaihe River water, an urgent need for advanced drinking water treatments was established.

In [93], researchers looked for EP in 21 wells from the drinking water network of Milan/Italy. Thirteen EP were detected in the low ng/L range in approx ½ of the wells. Pharmaceuticals, perfluorinated substances, personal care products, and anthropogenic markers were most frequently detected [93].

In the Netherlands, an industrialized country, it was found that 15 industrial waste water treatment plants had a high impact on drinking water production [94].

In a Spanish study [95], nicotine was detected in concentrations between 7 ng/Land 15 ng/L in 5 of 10 bottled mineral waters. Although the concentration is low, the mere presence raises concerns, and the authors concluded that more research is needed particularly with regard to vulnerable people such as newborns or pregnant women.

For migration of contaminants from the packing into bottled water, see [96-98].

For an approach of prioritizing anthropogenic chemicals in drinking water, see [99].

## 11. Significance of EP Contamination

EP in drinking water, from tap or bottle, will give a feeling of unease to consumers, but there is even more to it.

Contaminants of Emerging Concern (CECs) in the environment can lead to undesired ecological and human health effects such as endocrine disruption, behavioral alteration, and antibiotic resistance [100].

In [101], the effect of contamination by manure on the drinking behavior of cows was studied. In that work, clean (tap water) and water contaminated with either 0.05 mg (low) or 1 mg (high) fresh manure/g water were administered to cows [101], and a clear preference to drink clean water was found. That study highlighted the importance of providing cattle with clean drinking water. Another study on the consumption of drinking water contaminated by N-nitrosamines was found to alter the gut micro biome and to increase the obesity risk in young male rats [102].

Trace contaminants are not always harmless. In a recent study [103] of atrazine, the most commonly used herbicide in the U.S. and a wide-spread groundwater contaminant; it was found that exposure, at levels below the US EPA MCL (Maximum Contaminant Levels), was associated with increased menstrual cycle irregularity. Also, the long-term consumption of drinking water containing low or trace levels (ng/L or mg/L) of DBPs is suspected to have chronic adverse effects on human health, potentially leading to bladder cancer, colorectal cancer, birth defects, amongst other effects [62].

Typical EP concentrations in drinking water can be at the ng/L level and do not pose a direct risk for consumers [78]. *"Nevertheless, the influence of pharmaceutical mixtures is still unknown and there are gaps in risk assessments of long-term and low-level exposure to pharmaceutical residues"*[78].

## 12. Treatment of Water to make it Potable

On the one hand, we see a growing presence of emerging pollutants in the aquatic environment, and it is known that they cannot be removed by conventional water and/or wastewater treatment processes. New solutions are needed.

In [104], the removal of pharmaceuticals and personal care products by two-stage biofiltration for drinking water treatment was discussed.

The most effective treatment steps were peroxidation and chloramination, and up to 99.8% for all target compounds could be eliminated [105].

In a Spanish study [106], the presence of fifty-five pharmaceuticals, hormones and metabolites in raw waters used for drinking water production and their removal through different drinking water treatment processes (prechlorination, coagulation, sand filtration, ozonation, granular activated carbon filtration and post-chlorination) were studied. Thirty-five out of fifty-five drugs were detected in the raw water at the facility in take with concentrations up to 1200 ng/L. The most difficult-to-remove compounds were the pharmaceuticals phenytoin, atenolol and hydrochlorothiazide, which could be detected in finished waters at concentrations of approx. 10 ng/L. Sotalol and carbamazepine epoxide were found still at concentrations of 2 ng/L in the final water for consumption. Removal rates of these 5 chemicals were approx. 95% [106]. The key finding from that study is that we see an incomplete degradation or incomplete removal of EP in the potabilization process [106].

[122] suggests that a combination of biological, chemical and physical treatment be applied to effectively reduce the concentration of EDCs, PhACs (pharmaceutically active compounds), and artificial sweeteners.

Ozonation was found to exhibit the highest removal efficiency for PPCPs and EDCs [107], compare (Figure 7).

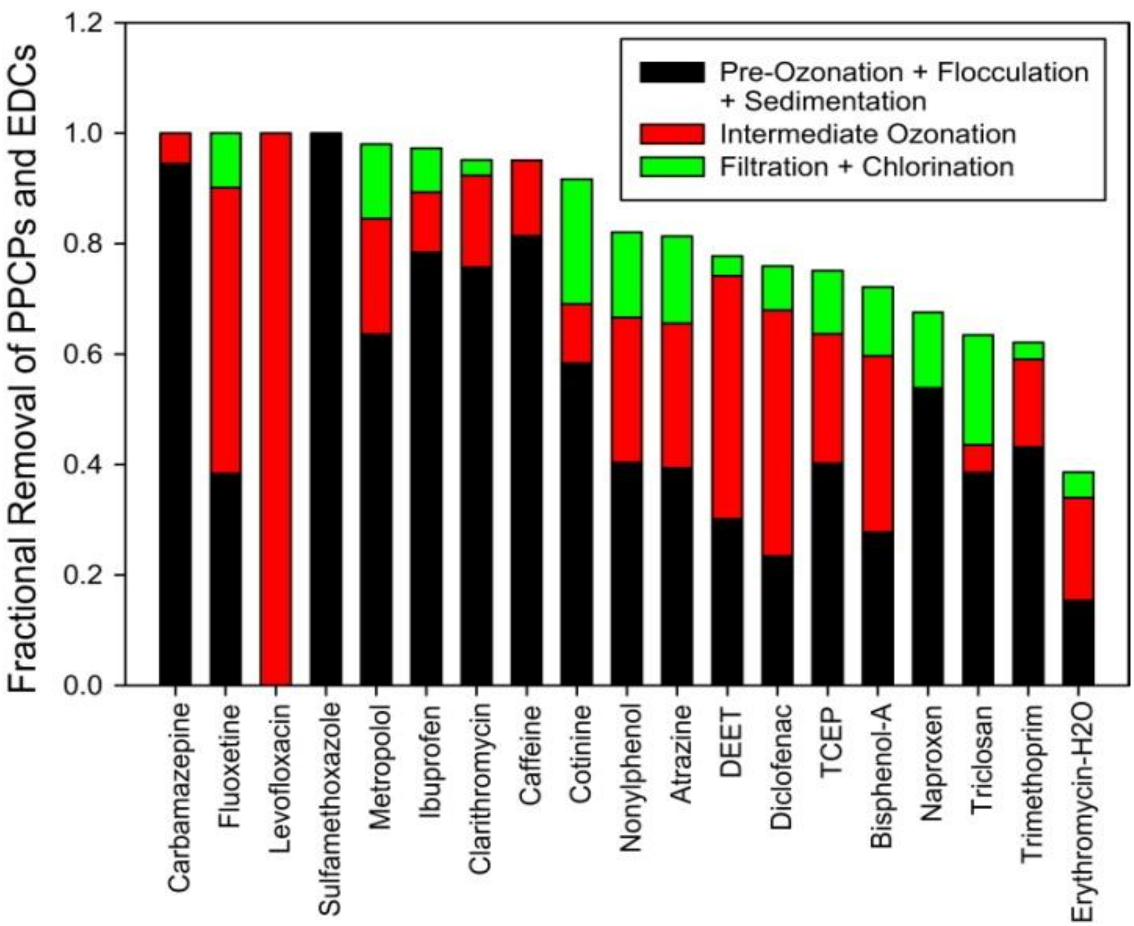



**Figure 7:** Fractional removal of individual PPCPs and EDCs by (i) pre-ozonation + flocculation + sedimentation, (ii) intermediate ozonation, and (iii) filtration + chlorination at the DWTP (Drinking water treatment plant). Source: [107].

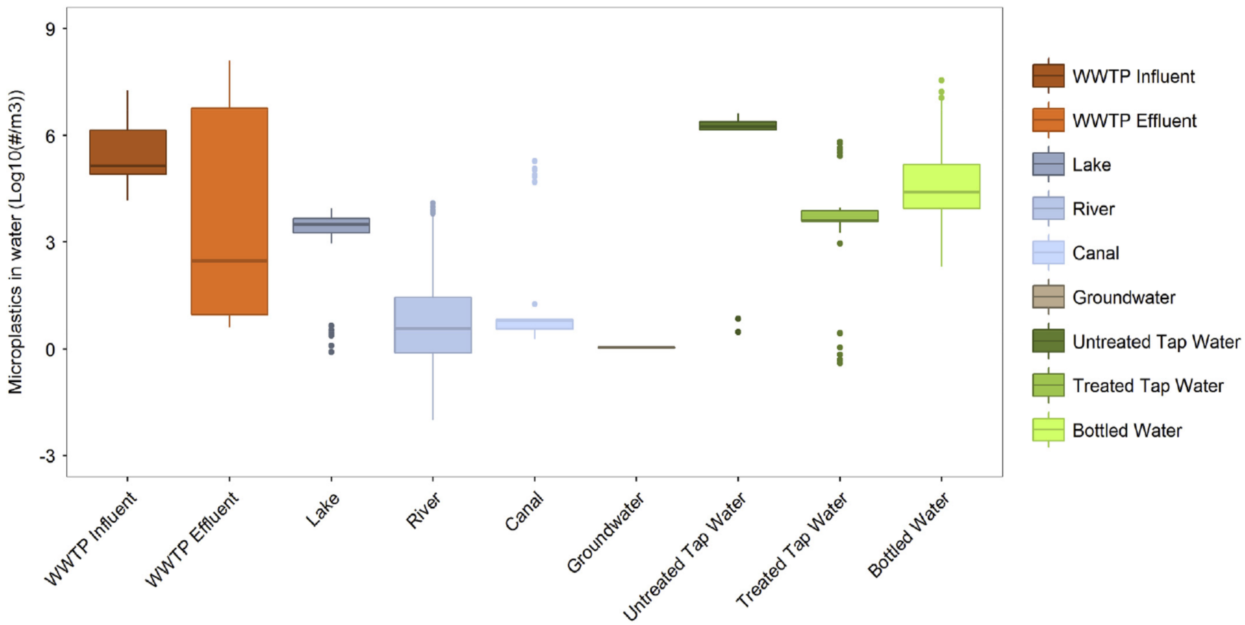



**Figure 8:** Box and whisker plot showing median and variation in micro plastic number concentrations in individual samples taken from different water types. Data relate to individual samples unless only means were reported, in which case the mean value was taken into account n times, with n being the number of samples which the mean was based on. Source: [109].

## 13. Micro Plastics

Micro plastics are small pieces of plastics which pollute the environment. The US National Oceanic and Atmospheric Administration (NOAA) define micro plastics as fragments below 5mm in length. One can distinguish between primary micro plastics particles, e.g. microfibers from clothing or micro beads from tooth pastes, and secondary micro plastics particles, which are formed e.g. in the sea by attrition of larger plastics objects. Micro plastics particles can be virtually any type of polymer [108]. To date, more than 50 studies providing concentration data for micro plastics in drinking water or its freshwater sources have been published [109]. Also, bottled water can be concerned [110, 111].

While polymers themselves are inert and, when ingested, travel through the human body without causing harm, micro plastics particles from the environment can be a serious health problem, because the micro plastics particles can carry large amounts of toxins into the body [112, 113]. Micro plastics particles produced from plastics water bottles e.g. through attrition will hence be of negligible influence to consumers.

## 14. Mineral Content

The human body needs minerals. Water from reverse-osmosis not enriched in minerals is considered disadvantageous for health. A study that investigated the effect of demineralized Direct Drinking Water (DDW) in schoolchildren found that low-mineral DDW may retard height growth and promote the incidence of dental caries in these pupils [114]. On the other hand, not all minerals in “natural spring water” are healthy. Natural concentrations of potentially harmful elements can be surprisingly high [115], and for many of them, maximum allowable concentration levels for drinking water have not been set [115]. One example of an often-unexpected element in natural water is uranium [116-119].

## 15. Conclusion

The power of analytical techniques has become astonishing, and minute quantities of virtually any compound can be detected - and often are detected as reviewed here in the case of emerging pollutants in mineral waters. Substances of concern, such as those with endocrine disruptive properties [84], [120], are not desired even in lowest quantities, and despite the absence of acute disadvantageous health effects from the single compound at ng/litre concentrations, consumers do not approve their drinking water to be laden with pesticides, hormones, etc., and their degradation products. Clean drinking water, on a global level, is a very limited, scarce resource which must be managed well, particularly in light of observations and predictions that such clean and potable water will continue to become less in future. Drinking water crises are pending in many areas of the world, and predictions that future wars might be about water rather than oil are becoming more likely.

One can witness considerable variation in the quality of source water for tap and bottled water production within geographical areas [115]. Therefore, one should carefully select water for drinking purposes vs. water for other purposes, and could consider a cascaded approach, using only the highest quality for drinking and cooking, medium quality water for e.g. crop irrigation and lower quality, such as grey water, for other purposes such as cooling water, toilet flushing or washing in diverse industrial and private settings. Rain water could also be utilized to a larger extent than today. In any case, the scarce high quality drinking water resources are too valuable to be wasted for other purposes, since the pressure is still increasing due to increasing population and environmental pollution. Pure drinking water is one of our most valuable resources and needs to be protected and used wisely.

Natural mineral waters benefit from their natural geological protection; the water bodies are not in contact with (polluted) surface waters, and transit times from infiltration to abstraction are very long, on the order of decades and beyond. They are the best choice for sensitive and health-conscious people.

## References


1. Nitti, Gianfranco. "Water is not an infinite resource and the world is thirsty". The Italian Insider. Rome. 2011; 8.
2. Prakasa Rao EVS, Puttanna K, Sooryanarayana KR, Biswas AK, Arunkumar JS, Assessment of Nitrate Threat to Water Quality in India.
3. https://www.who.int/topics/drinking_water/en/
4. Zorica D. Jaukovi C, Svetlana D. Grujic, Ivana V. Matic Bujagic et al. Determination of sterols and steroid hormones in surface water and wastewater using liquid chromatography-atmospheric pressure chemical ionization-mass spectrometry, Microchemical Journal. 2017; 135: 39-47.
5. https://ec.europa.eu/jrc/en/health-knowledge-gateway/promotion-prevention/nutrition/water
6. Chen WY, Suzuki TT, Lackner M (Editors). Handbook of Climate Change Mitigation and Adaptation, Springer, 2nd edition. 2017; 978: 14408-5.
7. Boholm A, Prutzer M. Experts understandings of drinking water risk management in a climate change scenario, Climate Risk Management. 2017; 16: 133-44.
8. https://www.unicef.org/topics/water-shortage
9. https://www.weforum.org/agenda/2019/08/cape-town-was-90-days-away-from-running-out-of-water-heres-how-it-averted-the-crisis/
10. https://edition.cnn.com/2016/03/04/us/flint-water-crisis-fast-facts/index.html
11. https://www.arcgis.com/apps/MapTour/index.html?appid=8f1a14dc053945edb9463b2facf9920f
12. https://www.bloomberg.com/graphics/2019-countries-facing-water-crisis/
13. https://worldwater.io/?utm_source=google&utm_medium=search&utm_campaign=Waterscarcity
14. https://www.nationalgeographic.com/environment/freshwater/freshwater-crisis/
15. https://www.worldwaterday.org/
16. Ritchie H, Roser M. 2019 - "Clean Water". Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/water-access.
17. https://www.who.int/news-room/fact-sheets/detail/drinking-water
18. https://www.un.org/sustainabledevelopment/water-and-sanitation/
19. Miao Hong. "China battles pollution amid full-speed economic growth." Chinese Embassy (UK).

    2006.
20. Wachman, Richard (December 9, 2007). "Water becomes the new oil as world runs dry". The Guardian. London. Retrieved September 23, 2015.
21. https://www.worldwatercouncil.org/en/water-crisis
22. Zulkifli SN, Rahim HA, Lau WJ, Detection of contaminants in water supply: A review on state-of-the-art monitoring technologies and their applications, Sensors and Actuators B: Chemical. 2018; 255: 2657-89.
23. Anna M. Fan, Health, Exposure and Regulatory Implications of Nitrate and Nitrite in Drinking Water, Reference Module in Earth Systems and Environmental Sciences, Encyclopedia of Environmental Health (Second Edition) 2019; 417-35.
24. Fan AM. Nitrate and Nitrite in Drinking Water: A Toxicological Review, Encyclopedia of Environmental Health. 2011; 137-45.
25. Silva MEZD, Santana RG, Guilhermetti M, Filho IC, Filho BPD. Comparison of the bacteriological quality of tap water and bottled

mineral water, International Journal of Hygiene and Environmental Health. 2008; 211: 504-9.

26. Bischofberger T, Cha SK, Schmitt R, Konig B, Schmift-Lorenz W. The bacterial flora of non-carbonated, natural mineral water from the springs to reservoir and glass and plastic bottles, International Journal of Food Microbiology. 1990; 11: 51-71.

27. Criado MV, Virginia E, Pinto F, Badessari A, Cabral D. Conditions that regulate the growth of moulds inoculated into bottled mineral water, International Journal of Food Microbiology. 2005; 99: 343-9.

28. Park JW, Park KY, Na Y, Park S, Maeng SK. Evaluation of organic migration and biomass formation on polymeric components in a point-of-use water dispenser, Water Research. 2019; 165: Article 115025.

29. https://water.org/our-impact/water-crisis/global-water-crisis/

30. https://www.worldwildlife.org/threats/water-scarcity

31. Schaider LA, Janet M. Ackerman, Ruthann A. Rudel. Septic systems as sources of organic wastewater compounds in domestic drinking water wells in a shallow sand and gravel aquifer, Science of The Total Environment. 2016; 547: 470-81.

32. Samira El Fellah, Geoffroy Duporté, Heli Sirén, Steroid hormones, inorganic ions and botrydial in drinking water. Determination with capillary electrophoresis and liquid chromatography-orbitrap high resolution mass spectrometry, Microchemical Journal. 2017; 133: 126-136.

33. http://www.euro.who.int/__data/assets/pdf_file/0018/140355/e94968.pdf

34. Ding J, Shen X, Liu W, Covaci A, Yang F. Occurrence and risk assessment of organophosphate esters in drinking water from Eastern China, Science of The Total Environment. 2015; 538: 959-65.

35. Focazio MJ, Tipton D, Shapiro SD et al. The chemical quality of self-supplied domestic well water in the United States. Ground Water Monitoring and Remediation. 2006; 26: 92-104.

36. Brenda L. Coleman, Marie Louie, Marina I. Salvadori, Scott A. McEwen, Allison J. McGeer, Contamination of Canadian private drinking water sources with antimicrobial resistant Escherichia apcoli, Water Research. 2013; 47: 3026-36.

37. Wilhelm M, Bergmann S, Dieter HH, Occurrence of perfluorinated compounds (PFCs) in drinking water of North Rhine-Westphalia, Germany and new approach to assess drinking water contamination by shorter-chained C4–C7 PFCs, International Journal of Hygiene and Environmental Health. 2010; 213: 224-32.

38. Weiß O, Gerhard A. Wiesmuller, Anne Bunte, Thomas Goen, Jurgen Holzer et al. Perfluorinated compounds in the vicinity of a fire training area – Human bio monitoring among 10 persons drinking water from contaminated private wells in Cologne, Germany, International Journal of Hygiene and Environmental Health. 2012; 215: 212-5.

39. Harvey PJ, Handley HK, Taylor MP. Widespread copper and lead contamination of household drinking water, New South Wales, Australia, Environmental Research. 2016; 151: 275-85.

40. Berna van Wendel de Joode, Benoit Barbeau, Maryse F. Bouchard, Ana María Mora, Donna Mergler. Manganese concentrations in drinking water from villages near banana plantations with aerial mancozeb spraying in Costa Rica: Results from the Infants' Environmental Health Study (ISA), Environmental Pollution. 2016; 215: 247-57.

41. Maurice L, Lopez F, Becerra S, Jamhoury H, Schreck E, Drinking water quality in areas impacted by oil activities in Ecuador: Associated health risks and social perception of human exposure, Science of The Total Environment. 2019; 690: 1203-17.

42. Coadou LL, Menach KL, Labadie P, Dévier MH, Pardon P. Quality survey of natural mineral water and spring water sold in France: Monitoring of hormones, pharmaceuticals, pesticides, perfluoroalkyl substances, phthalates, and alkylphenols at the ultra-trace level, Science of The Total Environment, 2017; 15: 651-62.

43. Petraccia L, Liberati G, Masciullo SG, Grassi M, Fraioli A. Water, mineral waters and health, Clinical Nutrition. 2006; 25: 377-85.

44. George LD. 2001. Uses of spring water. In: La Moreaux, P.E., Tanner, J.T. (Eds.), Springs and Bottled waters of the world. Springer-Verlag, Berlin. 106-19.

45. Williams SP. Put the lid on bottled water,News week 2001; 137: 61.

46. Saad B, Pok FW, Sujari ANA, Saleh MI. Analysis of anions and cations in drinking water samples by capillary ion analysis, Food Chemistry. 1998; 61: 249-54.

47. LM Tamagnini, González RD. Bacteriological stability and growth kinetics of Pseudomonas aeruginosa in bottled water, Journal of Applied Microbiology. 1997; 83: 91-4.

48. Armas AB, Sutherland JP. A survey of the microbiological quality of bottled water sold in the UK and changes occurring during storage, International Journal of Food Microbiology 1999; 59-65.

49. Warburton DW, Dodds KI, Burke R, Johnston MA, Laffey PJ. A review of the microbiological quality of bottled water sold in Canada between 1981 and 1989, Canadian Journal of Microbiology. 1992; 38: 12-9.

50. Guler C. Characterization of Turkish bottled waters using pattern recognition methods, Chemometrics and Intelligent Laboratory Systems. 2007; 86: 86-94.

51. Stefanovski G, Popović T, Stefanovski M. Effects of PEMF and sulfurous mineral water on bone in experimental osteoporosis, Bone, 2012; 50: s126-s7.

52. Altaany Z, Almuthanna Alkaraki, Abu-siniyeh A, Momani WA, Taani O. Evaluation of antioxidant status and oxidative stress markers in thermal sulfurous springs residents, Heliyon. 2019; 5: Article e02885.

53. https://www.consumerreports.org/bottled-water/the-fda-knew-the-bottled-water-was-contaminated-the-public-didnt/

54. Ashley Williams, Robert Bain, Michael B. Fisher, Jamie Bartram, A Systematic Review and Meta-Analysis of Fecal Contamination and Inadequate Treatment of Packaged Water, PLoS ONE. 2015.

55. Lackner M , Grabow W, Stadler P. Handbook of Online and Near-real-time Methods in Microbiology, CRC Press, ISBN: 9781498764025, 2017.

56. Akkilic N, Geschwindner S, Hook F. Single-molecule biosensors: Recent advances and applications, Biosensors and Bioelectronics. 2020; 151: Article 111944.

57. Domingo JL, Nadal M. Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: A review of the recent scientific literature, Environmental Research. 2019; 177: Article 108648.

58. Post GB, Cohn PD, Keith R. Cooper, Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: A critical review of recent literature, Environmental Research. 2012; 116: 93-117.

59. Schriks M, Minne B. Heringa, Margaretha ME. van der Kooi, Pim de Voogt, Annemarie P. van Wezel, Toxicological relevance of emerging contaminants for drinking water quality, Water Research. 2010; 44: 461-76.

60. Mompelat S, Le Bot B, Thomas O. Occurrence and fate of pharmaceutical products and by-products, from resource to drinking water, Environment International. 2009; 35: 803-14.

61. Teodosiu C, Andreea-Florina Gilca, George Barjoveanu, Silvia Fiore. Emerging pollutants removal through advanced drinking water treatment: A review on processes and environmental performances assessment, Journal of Cleaner Production. 2018; 197: 1210-21.

62. Yang M, Hannah K. Liberatore, Zhang X. Current methods for analyzing drinking water disinfection byproducts, Current Opinion in Environmental Science & Health. 2019; 7: 98-107.

63. Frederic DL, Leusch, Peta A. Neale, Francesco Busetti, Marcella Card, Beate I. Escher, Transformation of endocrine disrupting chemicals, pharmaceutical and personal care products during drinking water disinfection, Science of The Total Environment, 2019; 657: 1480-90.

64. Peta A. Neale, Beate I. Escher. In vitro bioassays to assess drinking water quality, Current Opinion in Environmental Science & Health. 2019; 7: 1-7.

65. Sun J, Luo Q, Wang D, Wang Z. Occurrences of pharmaceuticals in drinking water sources of major river watersheds, China, Ecotoxicology and Environmental Safety. 2015; 117: 132-40.

66. Franquet-Griell H, Ventura F, Boleda MR, Lacorte S. Do cytostatic drugs reach drinking water? The case of mycophenolic acid, Environmental Pollution. 2016; 208: 532-6.

67. Rosenmai AK, Lundqvist J, Godec TL, Ohlsson A, Oskarsson A. In vitro bio analysis of drinking water from source to tap, Water Research. 2018; 139: 272-80.

68. Leusch FDL, Neale PA, Arnal C, Aneck-Hahn NH, Balaguer P, Bruchet A et al. Analysis of endocrine activity in drinking water, surface water and treated wastewater from six countries, Water Research. 2018; 139: 10-8.

69. Justin M. Conley, Nicola Evans, Heath Mash, Laura Rosenblum, Vickie S. Wilson, Comparison of in vitro estrogenic activity and estrogen concentrations in source and treated waters from 25 U.S. drinking water treatment plants, Science of The Total Environment. 2017; 579: 1610-7.

70. Brand W, de Jongh CM, van der Linden SC, Mennes W, Puijker LM, van Leeuwen CJ et al. Trigger values for investigation of hormonal activity in drinking water and its sources using CALUX bioassays, Environment International. 2013; 55: 109-18.

71. Na Li, Weiwei Jiang, Kaifeng Rao, Mei Ma, Satyanarayanan Senthik Kumaran, Estrogen-related receptor γ disruption of source water

and drinking water treatment processes extracts, Journal of Environmental Sciences. 2011; 23: 301-6.

72. Huajun Zhen, Drew R. Ekman, Timothy W. Collette, Susan T. Glassmeyer et al. Assessing the impact of wastewater treatment plant effluent on downstream drinking water-source quality using a zebrafish (Danio Rerio) liver cell-based metabolomics approach, Water Research. 2018; 145: 198-209.

73. Hebert A, Feliers C, Lecarpentier C, Peta A. Neale, Beate I. Escher. Bioanalytical assessment of adaptive stress responses in drinking water: A predictive tool to differentiate between micropollutants and disinfection by-products, Water Research. 2018; 132: 340-9.

74. Simazaki D, Kubota R, Suzuki T, Akiba M, Kunikane S. Occurrence of selected pharmaceuticals at drinking water purification plants in Japan and implications for human health, Water Research. 2015; 76: 187-200.

75. https://www.unenvironment.org/cep/persistent-organic-pollutants-pops-and-pesticides

76. https://www.norman-network.net/

77. Abtahi M, Dobaradaran S, Torabbeigi M, Jorfi S, Saeedi R. Health risk of phthalates in water environment: Occurrence in water resources, bottled water, and tap water, and burden of disease from exposure through drinking water in tehran, Iran, Environmental Research. 2019; 173: 469-79.

78. Caban M, Lis E, Kumirska J, Stepnowski P. Determination of pharmaceutical residues in drinking water in Poland using a new SPE-GC-MS(SIM) method based on Speedisk extraction disks and DIMETRIS derivatization, Science of The Total Environment. 2015; 538: 402-11.

79. Harvey J. Clewell, Gentry PR, Hack CE, Greene T, Rebecca A. Clewell. An evaluation of the USEPA Proposed Approaches for applying a biologically based dose-response model in a risk assessment for perchlorate in drinking water, Regulatory Toxicology and Pharmacology. 2019; 103: 237-52.

80. Maria W. Tikkanen. Development of a drinking water regulation for perchlorate in California, Analytica Chimica Acta, 2006; 567: 20-5.

81. Jones RR, Diana A. Stavreva, Peter J. Weyer, Lyuba Varticovski, Mary H. Ward. Pilot study of global endocrine disrupting activity in Iowa public drinking water utilities using cell-based assays, Science of The Total Environment, In press, journal pre-proof, Available online. 2019; 29: Article 136317.

82. Valcárcel Y, Valdehíta A, Becerra E, López de Alda M, Navas JM. Determining the presence of chemicals with suspected endocrine activity in drinking water from the Madrid region (Spain) and assessment of their estrogenic, androgenic and thyroidal activities, Chemosphere. 2018; 201: 388-98.

83. Wee SY, Aris AZ. Endocrine disrupting compounds in drinking water supply system and human health risk implication, Environment International. 2017; 106: 207-33.

84. Chevolleau S, Debrauwer L, Stroheker T, Viglino L, Gioia LD. A consolidated method for screening the endocrine activity of drinking water, Food Chemistry. 2016; 213: 274-83.

85. https://toxtown.nlm.nih.gov/chemicals-and-contaminants/endocrine-disruptors

86. Praveena SM, Rashid MZM, Nasir FDM, Yee WS, Aris AZ. Occurrence and potential human health risk of pharmaceutical residues in drinking water from Putrajaya (Malaysia), Ecotoxicology and Environmental Safety. 2019; 180: 549-56.

87. Rosa MA, Sjerps, Pascal JF, Kooij, Arnaut van Loon, Annemarie P. Van Wezel, Occurrence of pesticides in Dutch drinking water sources, Chemosphere. 2019; 235: 510-8.

88. Eva M. Andersson, Kristin Scott, YiYi Xu, Ying Li, Kristina Jakobsson, High exposure to perfluorinated compounds in drinking water and thyroid disease. A cohort study from Ronneby, Sweden, Environmental Research. 2019; 176: Article 108540.

89. Eduarda O. Reis, Ana Flávia S. Foureaux, Júlia S. Rodrigues, Victor R. Moreira, Liséte C. Lange, Occurrence, removal and seasonal variation of pharmaceuticals in Brasilian drinking water treatment plants, Environmental Pollution. 2019; 250: 773-81.

90. AlAmmari AM, Khan MR, Aqel A. Trace identification of endocrine-disrupting bisphenol A in drinking water by solid-phase extraction and ultra-performance liquid chromatography-tandem mass spectrometry, Journal of King Saud University - Science, In press, journal pre-proof. Available online 2019.

91. Na Li, Wingkei Ho, Rudolf Shiu Sun Wu, Eric P. K. Tsang, Wen-Jing Deng, Ultra violet filters in the urine of preschool children and drinking water, Environment International, 2019; 133: Article 105246.

92. Kirsten A. Baken, Rosa M. A. Sjerps, Merijn Schriks, Annemarie P. van Wezel, Toxicological risk assessment and prioritization of drinking water relevant contaminants of emerging concern, Environment

International. 2018; 118: 293-303.

93. Riva F, Castiglioni S, Fattore E, Manenti A, Zuccato E. Monitoring emerging contaminants in the drinking water of Milan and assessment of the human risk, International Journal of Hygiene and Environmental Health. 2018; 221: 451-7.

94. Annemarie P. van Wezel, Floris van den Hurk, Rosa M. A. Sjerps, Erwin M. Meijers, Thomas L. ter Laak et al. Impact of industrial waste water treatment plants on Dutch surface waters and drinking water sources, Science of The Total Environment. 2018; 640: 1489-99.

95. Gonzalez Alonso S, Valcárcel Y, Montero JC, Catalá M. Nicotine occurrence in bottled mineral water: Analysis of 10 brands of water in Spain, Science of The Total Environment. 2012; 416: 527-31.

96. Carneado S, Hernández-Nataren E, López-Sánchez JF, Sahuquillo A. Migration of antimony from polyethylene terephthalate used in mineral water bottles, Food Chemistry. 2015; 166: 544-50.

97. Welle F. Migration of Acetaldehyde From PET Bottles Into Natural Mineral Water, Reference Module in Food Science. 2018.

98. Keresztes S, Tatár E, Czégény Z, Záray G, Mihucz VG. Study on the leaching of phthalates from polyethylene terephthalate bottles into mineral water, Science of The Total Environment. 2013; 458: 451-8.

99. Andrea M. Brunner, Milou ML. Dingemans, Kirsten A. Baken, Annemarie P. van Wezel, Prioritizing anthropogenic chemicals in drinking water and sources through combined use of mass spectrometry and ToxCast toxicity data, Journal of Hazardous Materials. 2019; 364: 332-8.

100. Batt AL, Edward T. Furlong, Heath E. Mash, Susan T. Glassmeyer, Dana W. Kolpin, The importance of quality control in validating concentrations of contaminants of emerging concern in source and treated drinking water samples, Science of The Total Environment. 2017; 579: 1618-28.

101. Karin E. Schutz, Frances J. Huddart, Neil R. Cox, Manure contamination of drinking water influences dairy cattle water intake and preference, Applied Animal Behaviour Science. 2019; 217: 16-20.

102. Zhu J, Yuan Kong, Jie Yu, Shuai Shao, Siqing Yue. Consumption of drinking water N-Nitrosamines mixture alters gut microbiome and increases the obesity risk in young male rats, Environmental Pollution,. 2019; 248: 388-96.

103. Cragin LA, Kesner JS, Annette M. Bachand, Barr DB, John S. Reif. Menstrual cycle characteristics and reproductive hormone levels in women exposed to atrazine in drinking water, Environmental Research. 2011; 111: 1293-1301.

104. Jie Fu, Wan-Ning Lee, Clark Coleman, Kirk Nowack, Ching-Hua Huang. Removal of pharmaceuticals and personal care products by two-stage bio filtration for drinking water treatment, Science of The Total Environment. 2019; 664: 240-8.

105. Azzouz A, Ballesteros E. Influence of seasonal climate differences on the pharmaceutical, hormone and personal care product removal efficiency of a drinking water treatment plant, Chemosphere. 2013; 93: 2046-54.

106. Huerta-Fontela M, Galceran MT, Ventura F. Occurrence and removal of pharmaceuticals and hormones through drinking water treatment, Water Research. 2011; 45: 1432-42.

107. Lokesh P. Padhye, Yao H, Francis T. Kung'u, Ching-Hua Huang. Year-long evaluation on the occurrence and fate of pharmaceuticals, personal care products, and endocrine disrupting chemicals in an urban drinking water treatment plant, Water Research. 2014; 51: 266-76.

108. M. Lackner, Bioplastics – in: Kirk Othmer's Encyclopaedia of Industrial Chemistry. 2015.

109. Albert A. Koelmans, Nur Hazimah Mohamed Nor, Enya Hermsen, Merel Kooi, Jennifer De France, Microplastics in freshwaters and drinking water: Critical review and assessment of data quality, Water Research. 2019; 155: 410-22.

110. Barbara E. Oßmann, George Sarau, Heinrich Holtmannspötter, Monika Pischetsrieder, Wilhelm Dicke, Small-sized microplastics and pigmented particles in bottled mineral water, Water Research. 2018; 141: 307-16.

111. Zuccarello P, Ferrante M, Cristaldi A, Copat C, Oliveri G. Conti Exposure to microplastics (<10 μm) associated to plastic bottles mineral water consumption: The first quantitative study, Water Research. 2019; 157: 365-71.

112. Barboza LGA, Dick Vethaak A, Beatriz RB, Lavorante O, Lundebye AK, Guilhermino L et al. Marine microplastic debris: An emerging issue for food security, food safety and human health, Marine Pollution Bulletin. 2018; 133: 336-48.

113. Mato Y, Isobe T, Takada H, Kanehiro H, Ohtake C, Kaminuma T et al. Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment, Environ. Sci. Technol. 2001; 35: 318-24.

114. Huang Y, Wang J, Tan Y, Wang L, Shu W. Low-mineral direct drinking water in school may retard height growth and increase dental caries in schoolchildren in China, Environment International. 2018; 115: 104-9.

115. Cicchella D, Albanese S, Vivo BD, Dinelli E, Giaccio L, Lima A et al. Trace elements and ions in Italian bottled mineral waters: Identification of anomalous values and human health related effects, Journal of Geochemical Exploration. 2010; 107: 336-49.

116. Shin W, Choung S, Han JH, Han WS, Chang BU. Accumulation of naturally occurring radioactive materials on the filters utilized in bottled mineral-water facilities, Applied Geochemistry. 2017; 85: 154-16.

117. Botezatu E, Iacob O, Elisei G, Capitanu O. Exposure of the population through mineral water consumption, Radioactivity in the Environment. 2005; 7: 1099-107.

118. Wallner G, Wagner R, Katzlberger C. Natural radio nuclides in Austrian mineral water and their sequential measurement by fast methods, Journal of Environmental Radioactivity. 2008; 99: 1090-4.

119. Nuccetelli C, Rusconi R, Forte M. Radioactivity in drinking water: regulations, monitoring results and radiation protection issues, Ann Ist Super Sanità. 2012; 48: 362-73.

120. Hu X, Shi W, Zhang F, Cao F, Yu H. In vitro assessment of thyroid hormone disrupting activities in drinking water sources along the Yangtze River, Environmental Pollution. 2013; 173: 210-5.

121. Shi P, Zhou S, Xiao H, Qiu J, Hollert H. Toxicological and chemical insights into representative source and drinking water in eastern China, Environmental Pollution. 2018; 233: 35-44.

122. Michael J. McKie, Susan A. Andrews, Robert C. Andrews. Conventional drinking water treatment and direct biofiltration for the removal of pharmaceuticals and artificial sweeteners: A pilot-scale approach, Science of The Total Environment. 2016; 544: 10-7.