Scientific Papers. Series D. Animal Science. Vol. LXVIII, No. 1, 2025
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

THE BOTTLED WATER QUALITY INFLUENCED BY PACKAGING MATERIALS AND STORAGE CONDITIONS - A MINI REVIEW

Daniela Valentina VATAMANU, Nela DRAGOMIR, Maria Luiza MIRCEA, Minodora TUDORACHE, Ioan CUSTURĂ, Gratziela Victoria BAHACIU

University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: nela.dragomir@usamv.ro

Abstract

The quality of bottled water is significantly influenced by packaging materials and storage conditions, both of which have direct implications for human health. This mini-review explores how common packaging materials - such as polyethylene terephthalate (PET), polycarbonate (PC), glass, and aluminium affect water safety through chemical migration and leaching. Hazardous compounds like antimony, bisphenol A (BPA), phthalates, and microplastics can migrate from the container into the water, posing potential risks to endocrine, neurological, and reproductive health. Storage conditions further exacerbate contamination risks. High temperatures, prolonged storage periods, and exposure to light accelerate chemical leaching and microbial growth, increasing the likelihood of waterborne illnesses. This review highlights the critical need for regulatory frameworks that address both material selection and proper storage guidelines. Public education on optimal storage practices and further research into alternative packaging materials with minimal environmental and health impacts are essential to ensuring bottled water safety.

Key words: *chemical migration, contaminant exposure, environmental impact, food contact materials, water safety.*

INTRODUCTION

Water is vital for life since it aids in bodily metabolism and cell function. Potable water should have no taste, color, or odor and be free of any organisms or chemicals that could be harmful to human health. Drinking high-quality water is essential for human health and development. A consistent supply of safe drinking water is required to ensure healthy living among the residents of any geological location (Akharame et al., 2018). Human and animal activities have a significant impact on the availability and accessibility of fresh, clean water for human consumption.

Water is the only known liquid that efficiently hydrates the body and physically relieves thirst while simultaneously supplying a large amount of minerals (Sievers, 2005).

Water is the basic ingredient of living beings, and as the world's population grows by 1.1% every year, the need for water, including mineral water, is predicted to rise (Lee, 2011).

Drinking water is any type of water, in its natural state or after treatment, intended for drinking, food preparation, or other household purposes, regardless of its origin and whether it is supplied through a distribution network, from tanks, or distributed in bottles or other containers.

Bottled water has become a ubiquitous commodity worldwide, with its consumption steadily increasing due to urbanization, convenience, and perceived safety advantages over tap water (Zhang et al., 2021). Thus, in 2013, 52.8 billion liters of bottled water were consumed in the EU, which increased to approximately 63.2 billion liters in 2023 (Statista, 2024).

Numerous individuals prefer bottled water for several reasons, including convenience, aversion to the taste of tap water (attributable to chlorine and other impurities), apprehensions regarding tap water quality, its health benefits compared to carbonated soft drinks and other previously consumed beverages, and the diverse array of flavors and types of flavored water available. Growth in the culinary service sector, in conjunction with the expansion of the travel industry, has stimulated market growth. In addition, population growth, increasing disposable income, urbanization, and premiumization are additional factors (Zvěřinová et al., 2024).

The global bottled water market, valued at over $300 billion in 2023, reflects this trend, driven by consumer demand for portable and reliable hydration (Statista, 2024).
However, the quality of bottled water is not solely determined at the source; it is profoundly influenced by packaging materials and storage conditions, which can introduce chemical and microbial contaminants (Xu et al., 2021).
Plastic packaging, particularly polyethylene terephthalate (PET) and polycarbonate (PC), dominates the industry due to its lightweight and cost-effective properties. Yet, these materials are associated with the migration of hazardous compounds such as antimony, bisphenol A (BPA), and phthalates into water, especially under suboptimal storage conditions (Franz & Welle, 2021). For instance, antimony, a catalyst used in PET production, can leach into water at levels exceeding safety thresholds when bottles are exposed to high temperatures (Reimann et al., 2012). Similarly, BPA, an endocrine disruptor found in PC containers, has raised health concerns despite regulatory limits (Chen et al., 2023).
Beyond chemical risks, microbial contamination poses another challenge. Improper handling, prolonged storage, or compromised seals can determine bacterial growth, like *Pseudomonas* spp. and *E. coli*, which thrive in nutrient-poor environments (Diduch et al., 2016). Studies have shown that even "minimally processed" bottled water can harbour microbial communities after extended shelf life (Dhaka et al., 2022).
This mini-review critically evaluates recent research (2020-2024) on how packaging materials (PET, PC, glass, and alternatives) and storage factors (temperature, light, duration) impact bottled water quality.

MATERIALS AND METHODS

A targeted literature study was performed on PubMed, Scopus, and Google Scholar to locate original peer-reviewed articles regarding the purity of bottled water, food contact materials, and water safety. The searched key words included "bottled water", "drinking water", "tap water", "food packaging", "storage conditions", "safety", and "quality" in various permutations. Furthermore, the reference lists of the discovered papers were scrutinized to uncover any further publications. Moreover, procedural blank samples were necessary. Furthermore, we sought statistical data regarding bottled water use on Eurostat, Statista, and other available platforms. Experimental research and non-English publications were omitted.

RESULTS AND DISCUSSIONS

Bottled water consumption and consumer preferences

Accordingly, to Order 7/2023, drinking water must be healthy and clean, with no microorganisms, substances or parasites that, by their number or concentration, may be hazardous to human health.
A fundamental component of food safety and security is the access to safe and healthy drinking water which also enhances social and economic development of the societies (WHO, 2021).
The criteria for selecting a water source for potable use are: quantitative (the source must provide the required amount of water throughout the year); qualitative (the source must be in line with the specific regulatory standards for water intended for drinking), technical (referring to the method of source extraction, treatment recommendations, and the equipment used) and economic (includes the costs of design, construction, and operation (Bodor et al., 2021).
Ensuring high-quality drinking water involves management strategies that guarantee the control of hazardous components in the water.
The consumption of water from the distribution network is limited or very limited, being replaced by bottled water consumption as a general trend. The main reason for rejecting tap water is the significantly altered organoleptic properties due to excessive iron and manganese content. People choose tap water because of its low cost, but at the same time, they fear its quality. Even if it is microbiologically clean and meets physicochemical standards, the main issue in certain areas is the piping system. The old and potentially contaminated pipes through which drinking water reaches consumers are a concern, leading many people to opt for bottled water instead (Zvěřinová, 2024).

Romania has over 2,000 mineral springs, whose chemical diversity reflects the highly complex geological conditions that have influenced their formation. Most springs contain carbonated mineral waters, originating from post-volcanic phenomena associated with Neogene magmatism.

The most significant mineral water deposits in Romania, which are used for bottling, are located in mountainous areas and intramountain depressions, far from pollution sources typically found in industrial zones or regions with intensive agriculture (Feru, 2012).

According to the National Society of Mineral Waters study, Romania possesses 60 percent of Europe's mineral water deposits, although barely one-fifth of these resources are utilized (FRD Center Market, 2016). According to Directive 2009/54/EC, Romania recognizes 71 varieties of natural mineral waters (European Commission, 2020). The origin and location of the analyzed mineral waters indicate that the majority of brands are located in Harghita, Suceava, and Covasna counties (Figure 1) (Bodor et al., 2021).

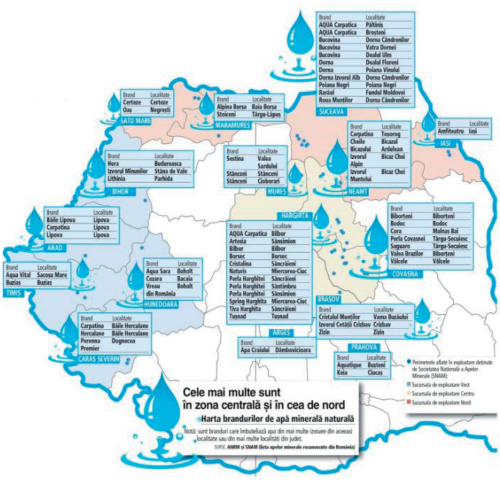

Figure 1. Geographical representation of mineral water sources in Romania (https://bihornews.ro/wp-content/uploads/2022/08/y-15-768x730.jpg)

Natural mineral water is microbiologically pure water that originates from a groundwater table or an underground aquifer and is sourced through one or more natural springs or boreholes (HG 1020/2005).

The attributes that could provide advantageous health benefits of natural mineral water require assessment: (a) from the geological, hydrological, physicochemical, microbiological characteristics; clinical and physiological perspectives; (b) according to criteria related to research methodology; (c) in accordance with scientifically validated techniques sanctioned by the appropriate government.

According to the definition, natural mineral water should be of subterranean origin. Due to its natural protection, reinforced by human intervention through the establishment of strictly regulated activity zones around the springs, natural mineral water has to be microbiologically pure, with no content of contaminants, and maintain a stable physicochemical composition over time. Unlike regular drinking water, natural mineral water has no set limits for its major chemical constituents (Feru, 2012).

The primary criteria for the predominant categorization include *geological origin* (the source of water), *chemical composition* (the presence and stability of minerals), and *carbonation* (the inclusion of carbon dioxide), determining whether the water is sparkling or still. Moreover, all bottled waters can be classified into two primary categories: natural and treated, although this simplistic classification may not adequately represent the diverse array of bottled water varieties. This analysis focused mostly on bottled water varieties that exhibit minimal or no flavor differentiation from municipal tap water. These varieties are classified into the following categories.

Natural mineral water (Figure 2), derived from subsurface sources that are naturally protected from contamination, is characterized by the presence of minerals and trace elements. The elemental composition differs by geographical region, lending a unique flavor and commercial label to the water (e.g., Evian, Fiji Natural Artesian).

No definitive statement or definition exists for the classification of water as a "mineral." Despite the fact that the European Bottled Water Standard is 50 ppm, the International Bottled Water Association (IBWA) standard is 250 ppm. Bottled water's mineral content must

stay unchanged from source to consumer, without any treatment.
The mineral amount and content, provenance and source must be explicitly specified.
Treated water. Purified, processed, prepared, or table water are all terms that are occasionally used to describe treated water. The information as to its origin is irrelevant to its branding, and there are no legal obligations to disclose it. An unconfined aquifer, a surface water source, or a municipal or community water system could be the source. To ensure its safety for consumption, this water undergoes necessary remedies, including disinfection. The treatment may involve the use of deionization, distillation, reverse osmosis, or other methods.
Regarding the bottled (packaged) water consumption in European Union, in 2022, it can be observed (Figure 4) that Italy has the highest amount (249L/capita/year), doubled compared to the EU average consumption, followed by Germany, Hungary, Greece, France, Portugal and Spain. In Romania, the annual consumption was 123L/capita).
Still bottled water is preferred by 64% of consumers, with thirty eight percent of consumers indicating their preference for sparkling waters (Figure 2).

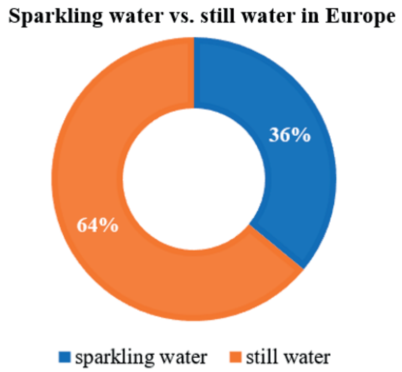

Figure 2. Sparkling water versus still water consumption in the EU in 2022 (https://naturalmineralwaterseurope.org/statistics/)

48% of EU consumers, consider bottled water as their most liked and appropriate way of healthily hydrating. In the meantime, 39% of European consumer choose to consume soft drinks. Bottled water maintains a consistent market share in comparison to other packaged non-alcoholic beverages, according to the most recent statistics (Figure 3).

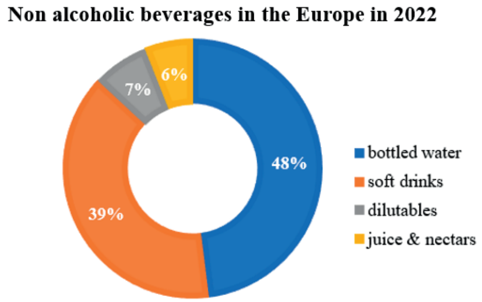

Figure 3. Non-alcoholic beverages in the EU, 2022 (https://naturalmineralwaterseurope.org/statistics/)

In a ten-year EU water consumption analysis (Figure 5), it can be seen an increasing of the water quantity per capita, with almost same amount in 2022 and 2023 (Statista, 2024).
Consumers also appear to clearly prefer natural mineral water in their choice of drinking water, with spring waters coming in second place.
The main reasons for people choosing bottled water are: preference for bottled water taste, convenience, dislike the quality and sensorial perceiving of tap water (due to chlorine and other content), concerns about the quality of tap water, consideration that is healthier than carbonated soft drinks and other beverages that consumers were drinking before, the availability of different kinds of flavoured water. Growth in the travel industry, together with the rising food service sector, has also had an impact on market growth. Other causes include population growth, rising disposable income, rapid urbanization, and premiumization.

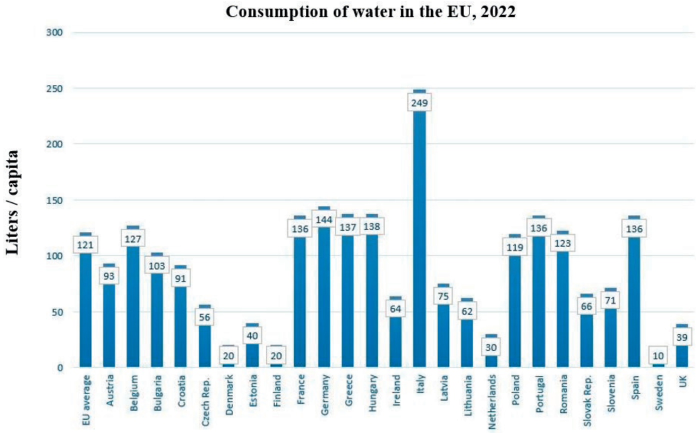

Figure 4. Water consumption in the EU in 2022, Liters per capita / year (https://naturalmineralwaterseurope.org/statistics/)

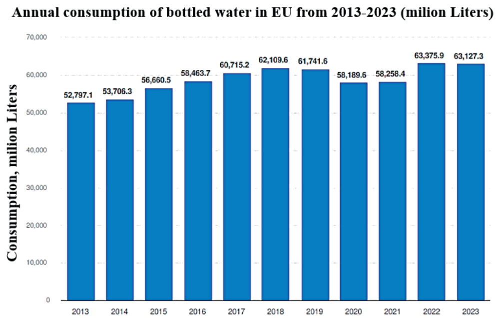

Figure 5. Annual consumption of bottled water in EU from 2013-2023 (Statista, 2024)

Bottled water quality

The description of natural mineral waters is "natural mineral water" or, in the case of an effervescent natural mineral water as defined in "naturally carbonated natural mineral water", "natural mineral water fortified with gas from the spring" or "carbonated natural mineral water" as of the EU Directive 2009/54.

The labels must include the analytical composition, the spring's place of extraction (including its name), and the treatments applied.

There are no upper or lower limits for minerals contents in natural mineral water; instead of the tap drinking water, that are strictly regulated as regards the fixed residue at 180°C. Mineral waters are also classified by other physical parameters, like pH, temperature at source and hardness. In terms of pH, mineral waters are classified as acid water (pH = 7). Waters can be classified as frigid (<20°C), hypothermal (20-30°C), mesothermal (30-40°C), or hyperthermal (>40°C) based on the water temperature at the source. According to Directive 2009/54/EC, mineral waters may be classified as very soft (0-100 mg/L of $CaCO_3$), soft (100-200 mg/L of $CaCO_3$), hard (200-300 mg/L of $CaCO_3$), or very hard (> 300 mg/L of $CaCO_3$), which is indicative of the presence of alkaline earth metals.

As stated in the abovementioned Directive, mineral waters can be labelled with different claims (criteria) shown in Table 1.

The transportation of mineral water has evolved significantly over time, from oak barrels carried by carts and bottling in clay vessels to a large-scale industry today. In the past, daily production was limited to around 2,000 liters per day, whereas now, the industry operates on a much larger scale.

Table 1. Indications and criteria for mineral water (EU Directive 2009/54/ Annex III)

Indications	Criteria
“Low mineral content”	Mineral salt content, expressed as a fixed residue, < 500 mg/L
“Very low mineral content”	Mineral salt content, expressed as a fixed residue, < 50 mg/L
“Rich in mineral salts”	Mineral salt, expressed as a fixed residue, >1500 mg/L
“Contains bicarbonate”	Bicarbonate > 600 mg/L
“Contains sulphate”	Sulphate > 200 mg/L
“Contains chloride”	Chloride > 200 mg/L
“Contains calcium”	Calcium > 150 mg/L
“Contains magnesium”	Magnesium > 50 mg/L
‘Contains fluoride”	Fluoride > 1 mg/L
“Contains iron”	Bivalent iron >1 mg/L
“Acidic”	Free carbon dioxide > 250 mg/L
“Contains sodium”	Sodium > 200 mg/L
“Suitable for a low-sodium diet”	Sodium < 20 mg/L

The first bottling in glass containers in Europe took place in 1806 in Romania, marking the beginning of a continuous transformation process. Over recent years, the bottling of mineral water has been subject to numerous analyses and studies, while the market has diversified with an increasing number of competitors (Feru, 2012).

Water bottling is carried out in containers made of glass, polyethylene terephthalate (PET), and high-density polyethylene (HDPE). Even though HDPE packaging is chemically more stable than PET packaging, the migration of chemical compounds still occurs.

Currently, countries with varying levels of economic advancement worldwide consume a wide range of types and brands of bottled/packaged drinking water. This water is contained in hermetically sealed containers of varying compositions, forms, and capacities (e.g., bottles, water dispensers, sachets) and is safe for direct consumption (FAO/WHO, 2007).

From its humble beginnings as a specialty product, bottled water has grown into a global phenomenon. It has a long history in Europe, dating back to the 16th century when glass bottles of natural mineral water were sold as a special occasion luxury drink. With the invention of industrially carbonated water in 1806 and the introduction of the first bottled mineral water for public use in the United States in the second half of the 18th century, the use of packed / bottled water stayed small until the second part of the 20th century, despite the decreasing of the cost of glass. This started to alter in the late 1960s and early 1970s, when the United States started to import more mineral water from Europe and a new focus in overall fitness began to take hold. Bottled water sales were already booming when polyethylene terephthalate (PET) was launched in the late 1970s United Nations University Institute for Water, Environment and Health (Bouhlel et al., 2023).

The role of packaging materials on bottled water quality - components migration

The main plastics used for water bottles are Polyethylene Terephthalate (PET), and High-Density Polyethylene (HDPE).

Polyethylene Terephthalate (PET) is used mostly for bottled water containers and the primary migrants consist in: *antimony* (Sb) used as a catalyst in PET production. Its migration increases with temperature (Franz & Welle, 2021). At 25°C: ~0.5 ppb (below WHO limit of 20 ppb) but at 60°C: up to 10 ppb (Reimann et al., 2012). Another migrant component is *acetaldehyde*, a degradation product affecting taste (Chen et al., 2023) and *phthalates* (DEHP, DBP), which are present in recycled PET due to contamination (Muncke et al., 2020).

The migration is influenced by UV exposure (which accelerates PET degradation, increasing Sb leaching (Geueke et al., 2022), and by the reuse of bottles (producing scratching and heating enhance chemical release (Licciardello, 2024).

High-Density Polyethylene (HDPE) used for milk flask and detergent containers. “Non-intentionally added substances” (NIAS) like antioxidants and oligomers have been detected.

The primary migrants from HDPE are non-intentionally added substances (NIAS) like antioxidants (e.g., Irganox 1076) degrade into unknown byproducts (Biedermann et al., 2021) and oligomers (small polymer chains) detected in stored water (Chen et al., 2023).
The volatile organic compounds (VOCs) are another migrants, residual solvents from manufacturing (Schaider et al., 2017). The migration is influenced by the fatty foods/liquids: Increase leaching of non-polar compounds (Muncke et al., 2020).
Nowadays, there are emerging contaminants of concern like *microplastics and nanoplastics* (PET and HDPE bottles shed microplastics (~50–300 particles/L, WHO, 2021), *per- and polyfluoroalkyl substances (PFAS)* found in grease-proof coatings of paper-based packaging (Biedermann et al., 2021), linked to cancer and immune suppression (Muncke et al., 2020) and *bisphenol A (BPA) and alternatives (BPS, BPF)*, leached from epoxy-lined aluminium cans (Geueke et al., 2022), that may have similar endocrine effects (Licciardello, 2024).
Elevated temperatures accelerate the leaching of antimony (Sb), phthalates, acetaldehyde, and formaldehyde from PET bottles into water (Franz & Welle, 2021; Dąrowska et al., 2003). Antimony trioxide (Sb_2O_3), a PET production catalyst, migrates into water, especially at temperatures >50°C, nearing regulatory limits (Shotyk et al., 2006). UV exposure degrades PET, increasing volatile organic compounds (VOCs) like formaldehyde (Yutaka et al., 2021). Higher storage temperatures (e.g., 40-60°C) significantly increase contaminant migration (Morin-Crini et al., 2022).
Similarly, Re Depaolini et al. (2020) reported higher levels of acetaldehyde, a degradation byproduct of PET in water kept at a temperature of 40°C compared to 25°C. Ahmed et al. (2021) tested multiple heating sources (sun, oven, microwave) and freezing, on two brand PET bottles and their influence on water quality and components migration providing comprehensive comparative data. Related to temperature-driven chemical migration, they observed that the pH decreased (especially at temperature higher than 50°C and by frosting). Total Dissolved Solids (TDS) rose by up to 18% (B1) and 6.5% (B2) with heating, though remaining within permissible limits. Fluoride & Chloride: Microwave heating at 50-70°C increased fluoride beyond WHO limits (up to 2.47 mg/L vs. 1.5 mg/L). Chloride levels fluctuated but decreased sharply in B2 with microwave heating. Heavy Metals: Minimal antimony (Sb) leaching (contrary to prior studies), but copper (Cu) and zinc (Zn) were detected, especially with oven heating at 70°C.
Endocrine-Disrupting Compounds (EDCs) Bisphenol A (BPA), alkylphenols, and phthalates migrate from PET, especially under heat (Amiridou & Dimitra, 2011; Wagner & Oehlmann, 2009) and estrogenic activity was detected in 60-78% of bottled water samples, linked to both packaging and groundwater sources (Pinto & Reali, 2009).

The influence of storage conditions on bottled water quality

Byproducts such oligomers and diethylene glycol are created during the thermal breakdown of PET. According to Bach et al. (2012b), PET samples that were heated to high temperatures contained volatile organic compounds like carbon monoxide, aldehydes (formaldehyde, acetaldehyde, benzaldehyde), aromatic hydrocarbons (benzene, toluene, ethylbenzene, and styrene), esters (vinyl benzene, methyl acetate), methanol, and acetophenone. Studies have also investigated the migration of antimony from PET bottles into bottled water, analyzing factors such as temperature, storage time, water pH, and bottle color. It was found that high temperatures and long storage periods promote antimony release, while carbonated water accelerates this process due to its lower pH. Research conducted in Europe and Canada confirmed the presence of antimony in PET-bottled water, with average concentrations ranging from 0.343 to 2 μg/L, whereas water bottled in glass containers showed no contamination. Additionally, transparent PET bottles appear to release more antimony than colored ones, though some studies reported opposite results. Research has also shown that antimony migration depends on the contact surface area, being higher in smaller bottles. Moreover, water contamination originates not only from PET but also from the bottling process. These findings highlight the need for strict regulations regarding the use of

PET in drinking water packaging (Bach et al., 2012b).
Water bottled in PET has been found to have estrogenic and genotoxic effects. These toxicological consequences may be caused by chemical combinations in bottled water, according to Bach et al. (2012a). The migration of formaldehyde, acetaldehyde, and antimony from PET into water is clearly linked (Bach et al., 2012a).
Polyethylene terephthalate (PET) is the most often used plastic in the production of packed drinking water containers, and it takes 400 years for it to breakdown spontaneously in nature. It is used for bottled water packaging due to its lightweight, durability, and recyclability. However, storage conditions, particularly temperature, light exposure, and duration, can significantly impact water quality and safety by promoting chemical migration, microbial growth, and PET degradation.

Impact of Light Exposure

Sunlight (UV radiation) degrades PET, increasing the release of volatile organic compounds (VOCs) and altering water taste. Akharame et al. (2018) observed that PET bottles exposed to sunlight for 30 days showed higher concentrations of formaldehyde and acetaldehyde compared to dark-stored samples.
Storage conditions were investigated related to their influence on bottled water quality. It was noted that higher storage temperatures (e.g., 40-60°C) significantly increase contaminant migration (Schmid et al., 2008). Sunlight exposure promotes PET degradation and VOC release (Nawrocki et al., 2002) and long-term storage (>6 months) raises antimony and acetaldehyde levels (Montserrat, 2020).
pH decreased significantly with prolonged sunlight exposure (e.g., from 6.5 to 4.7 after 28 days), attributed to increased acidity from PET degradation. TDS and EC increased with sunlight exposure (TDS: 5-122 mg/L to 5.5-139 mg/L; EC: 10-242 μS/cm to 17-291 μS/cm), likely due to leaching of ions from PET bottles (Akharame et al., 2018).
Microplastic is a collection of various distinct chemical components. It is composed of various molecules with varying molecular structures, shapes, sizes, and polymers (Rochman et al. 2019). Microplastic is one of the most complicated pollutants created by mankind (Arias-Andres & Rojas-Jimenez, 2022).

Regulatory

Directive 2009/54/EC of the EP describes the rules for exploitation and marketing of natural mineral waters (Table 2).
The primary objectives of any regulations concerning mineral waters are to protect consumer health, prevent misleading information, and ensure fair marketing. It must be guaranteed that natural spring waters retain, at the time of commercialization, the characteristics that led to their recognition as such. Therefore, the packaging containers used must have appropriate sealing systems.
Under the prevision of this Directive, *carbonated natural mineral water* is described as "water to which has been added carbon dioxide (CO_2) of an origin other than the water table or deposit from which the water comes and naturally *carbonated natural mineral water* as water the CO_2 content of which from the spring after decanting, if any, and bottling is the same as at source". This takes into account, where appropriate, the restoration of a quantity of CO_2 from the same water or deposit equivalent to that was lost during processing. The declaration of the composition of natural spring water should be mandatory to guarantee consumer information.
The breakup of unstable elements, like sulphur or iron and their compounds, through filtration or decantation, potentially preceded by oxygenation, is the only treatment that natural mineral water can endure in its natural state at the source.
Treatment of specific natural mineral waters with ozone-enriched air to eliminate iron, manganese, sulphur, and arsenic compounds, provided that the treatment does not modify the water's composition in terms of its characteristic constituents that confer its properties. The removal of unbound carbon dioxide through exclusively physical processes, whether complete or partial.

Table 2. Legislation for mineral, spring and bottled water

<table>
<tr><th>Product</th><th>Legislation</th><th>Other Regulations on Food Safety and Food Hygiene</th></tr>
<tr><td>Natural Mineral Water</td><td>“Directive 2009/54/EC on the exploitation and marketing of natural mineral waters”</td><td rowspan="3">“Regulation (EC) No 178/2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety”
“Regulation (EC) No 852/2004 on the hygiene of foodstuffs”
“Regulation (EC) No882/2004 on official controls performed to ensure verification of compliance with feed and food law, animal health and animal welfare”
“Commission Directive 19/2004/EC on plastic materials and articles intended to come into contact with foodstuffs”
“Commission Regulation (EC) No 282/2008 on recycled plastic materials and articles intended to come into contact with foodstuffs”
“Regulation 178/2002/EC”
“Regulation 852/2004/EC”
“Regulation 882/2004/EC”
Guidelines for the development of EU “Guides to Good Practice for hygiene or for the application of the HACCP principles”</td></tr>
<tr><td>Spring Water</td><td>“Regulated partly by Directive 2009/54/EC on the exploitation and marketing of natural mineral waters
“Directive 98/83/EC on the quality of water intended for human consumption”</td></tr>
<tr><td>Bottled Drinking Water</td><td>“Directive 98/83/EC relating to the quality of water intended for human consumption”.
“Codex Standard for Natural Mineral Waters (108–1981 adopted 1981, amendment 2001, revisions 1997, 2008)”
“Recommended International Code of Hygienic Practice for the Collecting, Processing and Marketing of Natural Mineral Waters (CAC/RCP 33-1985, revised 2011)”
“General Standard for Bottled/Packaged Drinking Waters (other than Natural Mineral Waters) (227-2001)”
“Code of Hygienic Practice for Bottled/Packaged Drinking Waters(other than Natural Mineral Waters) (CAC/RCP 48-2001)”
“WHO Guidelines for Drinking Water Quality is the reference basis upon which all bottled waters legislation derives from. These international norms on water quality and human health in the form of guidelines are used as the basis for regulation and standard setting, in developing and developed countries world-wide.”</td></tr>
</table>

To be recognized as natural mineral water, a source must meet strict quality and safety criteria. The Romanian recognized sources of mineral waters are presented in Table 3.

Table 3. List of natural mineral waters recognized by Romania (Eurlex, 2025)

Trade Description	**Name of source**	**Place of exploitation**
Alpina Borşa	Izvorul nr.1, bis Izvorul nr.2	Baia Borşa (Maramureş County)
Amfitreatru	Izvorul 3 Copou	Iaşi (Iaşi County)
Apa Craiului	Izvorul nr.5 Gălgoaie	Dâmbovicioara (Argeş County)
Aquatique	Izvorul Buşteni	Buşteni (Prahova County)
Aqua Carpatica	Izvorul Bejenaru	Păltiniş (Suceava County)
	Izvorul Haja	
	F2 Păltiniş	
	Izvorul Ichim nr.1 și 4	Gălăuțaş, Bilbor (Harghita County)
	Aqua 2	
	Aqua 3	
	Aqua 4	
	Aqua	Broşteni (Suceava County)
Aqua Sara	F 4750	Bodolt (Hunedoara County)
Aqua Vital	Sacoşu Mare	Sacoşu Mare (Timiş County)
Apă Minerală Natural Carbogazoasă Stoiceni	Sursa F1	Stoiceni Târgu Lăpuş (Maramureş County)
Armonia Starea Ta De Bine	F2 Măieruş	Măieruş (Braşov County)
Artesia	FH Artezia	Sânsimion (Harghita County)
Băile Lipova	F11	Lipova (Arad County)
Biborțeni-Bățani	F1 SNAM	Biborțeni-Bățani (Covasna County)
Biborțeni	F7	Biborțeni (Covasna County)
Bilbor	F1 SNAM	Bilbor (Harghita County)

Bodoc	Izvorul Mathid F13 RAMIN	Bodoc (Covasna County)
Borsec	Borsec	Borsec (Harghita County)
	Făget Borsec	
	F1C	
Bucovina	C7	Dorna Candrenilor (Suceava County)
	F4 SNAM ROŞU	
	F2 RAMIN ROŞU	
	F1, F2, F3, F3 bis, F1 bis, F1 bis SNAM, F2 SNAM	
Buziaş	F II bis	Buziaş (Timiş County)
Carpatina	C1	Domogled-Băile-Herculane (Caraş-Severin County)
	F1ISLGS	Toşorog (Neamț County)
Certeze	Certeze	Certeze (Satu-Mare County)
Cezara	F3, F4	Băcaia (Hunedoara County)
Cheile Bicazului	Bicazul Ardlean, forajul FH 1	Bicazul-Ardelean (Neamț County)
Cora	F1 SNAM	Mălnaş Băi (Covasna County)
Cristalina	FH Artezia 1	Sânsimion (Harghita County)
Cristalul Munților	Izvorul Pârâul Rece	Vama Buzăului (Braşov County)
Dorna	FH2, FH3 Floreni	Dealul Floreni (Suceava County)
	F5	Poiana Vinului (Suceava County)
	F2bPN, F3PN, F1cPN	Negrişoara-Poiana Negri (Suceava County)
	Fd	Poiana Negri (Suceava County)
Dorna Izvorul Alb	Captarea1, 2, 2 bis, 2a, 2b, 3, Izvorul 5, 6, 7, 10, Foraj 1IA,F1bis VB	Dorna Candrenilor(Suceava County)
Hera	Izvor Hera(Cuciului)	Budureasa (Bihor County)
Herculane	C2	Domogled-Băile-Herculane (Caraş-Severin County)
Izvorul Alpin	Izvorul Alpin	Bicaz Chei (Neamț County)
Izvorul Cetatii Crizbav	Izvor	Crizbav (Braşov County)
Izvorul Minunilor	Izvorul Minunilor	Stâna de Vale (Bihor County)
Izvorul Muntelui	Izvorul Muntelui	Comuna Bicaz Chei (Neamț County)
Keia	Izvorul Zăganului	Ciucaş (Prahova County)
La Fantana	Şeştina	Valea Şardului (Mureş County)
Lipova	F8E, F9 bis,	Lipova (Arad County)
Lithina	Forajul FH2	Parhida (Bihor County)
Naturis	FH1	Miercurea-Ciuc (Harghita County)
Oaş	Certeze Negreşti I	Negreşti(Satu-Mare County)
Porenna Premier	Calina1	Dognecea (Caraş-Severin County)
Perla Apusenilor	FH2 Chimindia	Chimindia-Deva(Hunedoara County)
Perla Covasnei	F1 SNAM	Târgul Secuiesc (Covasna County)
Perla Harghitei	F1 SNAM, F2 SNAM, F1 ISPIF	Sâncrăieni (Harghita County)
Perlaharghitei	FH2 Sântimbru	Sântimbru (Harghita County)
Perlaharghitei	FH Artezia 2	Sânsimion (Harghita County)
Rarâul	Puțul Sebeş FH1	Fundul Moldovei (Suceava County)
Spring Harghita	FH2M	Miercurea-Ciuc (Harghita County)
Stânceni	Stânceni	Stânceni(Mureş County)
Stânceni	Ciobotani	Ciobotani(Mureş County)
Tărâmulapelor	F3 ISPIF	Târgul Secuiesc (Covasna County)
Tiva Harghitei	F8 ISPIF	Sâncrăieni (Harghita County)
Tuşnad	Tuşnad, FH 35 bis	Tuşnad(Harghita County)
Vâlcele	Elisabeta	Vâlcele (Covasna County)
Vreau Din România	F6 ISPIF	Boholt (Hunedoara County)
Zizin	Sursele Zizin	Tărlungeni (Braşov County)

The water must originate exclusively from an underground source, protected from any contamination, and maintain a stable chemical composition. It must not be influenced by human activities and must contain minerals and trace elements with beneficial health effects. Additionally, the mineral composition and physicochemical properties must remain constant over time, and the water cannot be subjected to chemical treatments for purification, it must be naturally pure at the source.

To guarantee these properties, the water must undergo a rigorous process of physicochemical and microbiological analysis over an extended period, in compliance with national and European safety and quality standards.

The bottling of mineral water in Romania is a regulated process carried out in accordance with national and European safety and quality standards, considering that natural mineral water must retain the characteristics that define it at the source, without being subjected to chemical treatments.

CONCLUSIONS

Mineral water composition varies geologically: Romania's mineral waters (e.g., from Harghita, Covasna) have unique mineral profiles, but their stability depends on packaging integrity during storage.

Consumer preferences drive market trends: 48% of EU consumers prefer bottled water for convenience and perceived safety, despite tap water often meeting equal quality standards.

Packaging material significantly impacts water quality: PET and HDPE bottles leach chemicals (e.g., antimony, BPA, phthalates) into water, especially under heat or UV exposure. Glass and aluminium are safer but less commonly used due to cost and weight.

temperature and light accelerate contaminant migration: storage at >40°C or in sunlight increases leaching of antimony, acetaldehyde, and microplastics from PET bottles, altering taste and safety (e.g., formaldehyde levels rise by 30% after 28 days of UV exposure).

Microbial risks are linked to storage conditions: prolonged storage or poor sealing promotes bacterial growth (e.g., *Pseudomonas* spp.), though sunlight can reduce coliforms via natural disinfection.

Regulatory gaps exist for emerging contaminants: current EU directives (e.g., 2009/54/EC) lack limits for microplastics, PFAS, and endocrine disruptors like BPA alternatives (BPS, BPF).

PET degradation releases harmful byproducts: high temperatures generate VOCs (e.g., benzene, formaldehyde) and oligomers, with recycled PET posing higher contamination risks due to prior use.

pH and TDS are key indicators of quality changes: sunlight exposure reduces pH (increasing acidity) and raises TDS due to ion leaching, though values often remain within WHO limits.

Antimony leaching is a persistent issue: Sb levels in PET-bottled water can approach regulatory limits (5 µg/L in EU) at 60°C, with smaller bottles showing higher migration rates.

Public awareness and alternative materials are critical: education on proper storage (e.g., avoiding heat/sunlight) and investment in biodegradable or inert packaging (e.g., plant-based plastics) are needed to mitigate health risks.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Faculty of Animal Production Engineering and Management, University of Agronomic Sciences and Veterinary Medicine of Bucharest.

REFERENCES

Ahmed, A.T., Emad, M. & Bkary, M.A. (2021). Impacts of temperature alteration on the drinking water quality stored in plastic bottles. *Appl. Water Sci*., 11, 167. https://doi.org/10.1007/s13201-021-01505-2

Akharame, M.O., Ekhosuehi, A., Okolafor, F., & Sadoh, K.A. (2018). Effects of sunlight exposure on the quality parameters of bottled water. *J. Appl. Sci. Environ. Manag.,* *22*(5), 769–774. https://www.ajol.info/index.php/jasem/article/view/172702

Amiridou, D, & Voutsa, D. (2011). Alkylphenols and phthalates in bottled waters. *Journal of Hazard Mater*, *181*(1), 281-286. https://doi.org/10.1016/j.jhazmat.2010.09.031

Arias-Andres, M., & Rojas-Jimenez, K. (2022). *Ecological and public health effects of microplastics pollution*. In: Hashmi, M.Z. (Ed.), *Microplastic*

Pollution. Emerging Contaminants and Associated Treatment Technologies. Berlin, GE: Springer Publishing House.
Aslani Hassan, Parisa Pashmtab, Abdolreza Shaghaghi, Asghar Mohammadpooras, Hassan Taghipour, Masha Zarei, Aslani et al (2021). Tendencies towards bottled drinking water consumption: Challenges ahead of polyethylene terephthalate (PET) waste management. *Health Promotion Perspectives,* 11(1), 60–68. doi:10.34172/hpp.2021.09
Bach, C., Dauchy, X., Chagnon, M. C., & Serge, E. (2012a). Chemical compounds and toxicological assessments of drinking water stored in polyethylene terephthalate (PET) bottles: A source of controversy reviewed. *Water research* https://doi.org/10.1016/j.watres.2011.11.062
Bach, C., Dauchy, X., Chagnon, M. C., & Serge, E. (2012b). Chemical migration in drinking water stored in polyethylene terephthalate (PET) bottles: a source of controversy reviewed. *Hal open science*, https://hal.science/hal-00683918/document
Biedermann, M., McCombie, G., Dubois, P., Lang, S., Harling, A., & Grob, K. (2021). Migration into food from closures of boxes made of recycled paperboard with an internal functional barrier, *Packaging Technology and Science*, 34(9), https://doi.org/10.1002/pts.2598
Bodor, K., Bodor, Z., Szép, A., & Szép, R. (2021). Classification and hierarchical cluster analysis of principal Romanian bottled mineral waters*, Journal of Food Composition and Analysis,* https://doi.org/10.1016/j.jfca.2021.103903
Bouhlel, Z., Köpke, J., Mina, M., & Smakhtin, V. (2023). Global Bottled Water Industry: A Review of Impacts and Trend*, United Nations University Institute for Water, Environment and Health* https://unu.edu/inweh/collection/global-bottled-water-industry-review-impacts-and-trends
Chen, Y.M., Liu, Z.Y., Si, C., Xiao-Ting, L., Zi-Hui, H., Maierhaba, W., Bi-Xia, H., Qiu-Ye, L., Tong, W., Rong-Zhu, H., Si-Yu, H., Lu-lu, L., Yue-yong, J., & Hui-Lian, Z. (2023). Mitigating the impact of bisphenol A exposure on mortality: Is diet the answer? *Ecotoxicology and Environmental Safety***,** https://doi.org/10.1016/j.ecoenv.2023.115629
Dąrowska, A., Borcz, A., & Nawrocki, J. (2010). Aldehyde contamination of mineral water stored in PET bottles. *Food Additives & Contaminants*, 1170–1177. https://doi.org/10.1080/02652030310001620441
FRD Center Market (2016) *The Mineral Bottled Water Sector in Romania,* https://www.marketsandmarkets.com/Market-Reports/bottled-water-processing-market-73331968.html?gad_source=1
Feru, A. (2004). Bottled natural mineral waters in Romania, *Environmental Geology,* DOI 10.1007/s00254-004-1006-3
Franz, R., & Welle, F. (2022). Recycling of Post-Consumer Packaging Materials into New Food Packaging Applications - Critical Review of the European Approach and Future Perspectives. *Sustainability*, 14(2), 824. https://doi.org/10.3390/su14020824
Geueke, B., Groh, K. J., Maffini, M. V., Martin, O. V., Boucher, J. M., Chiang, Y. T., & Muncke, J. (2022). Systematic evidence on migrating and extractable food contact chemicals: Most chemicals detected in food contact materials are not listed for use. *Critical Reviews in Food Science and Nutrition*, *63*(28), 9425–9435. https://doi.org/10.1080/10408398.2022.2067828
Hawkins, G., Potter, E., & Race, K. (2015). Plastic Water: The Social and Material Life of Bottled Water. *The MIT Press*. http://www.jstor.org/stable/j.ctt16wd0bvJoseph,
Lee, R. (2011). The outlook for population growth. *Science*, 333, 569–573. DOI: 10.1126/science.1208859
Licciardello, F. (2024). Unexpected possible consequences of plastic packaging reuse. *Current Opinion in Food Science*, 56, 101131, https://doi.org/10.1016/j.cofs.2024.101131
Montserrat, F. (2020). Antimony and PET bottles: Checking facts. *Chemosphere,* https://doi.org/10.1016/j.chemosphere.2020.127732
Morin-Crini, N., Lichtfouse, E., Liu, G. Balaram, V., Lado Ribeiro, A.R., Lu, Z., Stock, F., Carmona, E., Teixeira, M.R., Picos-Corrales, L.A, Moreno-Piraján, J.C, Giraldo, L., Li, C., Panday, A., Hocquet, D., Torr, G., & Crini, G. (2022) Worldwide cases of water pollution by emerging contaminants: a review. *Enviromental Chemistry Letters* https://doi.org/10.1007/s10311-022-01447-4
Muncke, J., Andersson, A.M., Backhaus, T., Boucher, J.M., Carney Almroth, B., Castillo Castillo, A., Chevrier, J., Demeneix, B.A., Emmanuel, J.A., Fini, J.B., Gee, D., Geueke, B., Groh, K., Heindel, J.J., Houlihan, J., Kassotis, C.D., Kwiatkowski, C.F., Lefferts, L.Y., Maffini, M.V., Martin, O.V., Myers, J.P., Nadal, A., Nerin, C., Pelch, K.E., Fernández, S.R., Sargis, R.M., Soto, A.M., Trasande, L., Vandenberg, L.N., Wagner, M., Wu, C., Zoeller, R.T., & Scheringer, M. (2020). Impacts of food contact chemicals on human health: a consensus statement. Environ Health, 19(1):25. doi: 10.1186/s12940-020-0572-5.
Nawrocki, J, Dąbrowska, A., & Borcz, A. (2002). Investigation of carbonyl compounds in bottled waters from Poland. *Water Research***,** https://doi.org/10.1016/S0043-1354(02)00201-4
Pinto, B., & Reali, D. (2009). Screening of estrogen-like activity of mineral water stored in PET bottles. *Int. J. Hyg. Environ. Health*, 212(2), 228-32. DOI: 10.1016/j.ijheh.2008.06.004
Re Depaolini, A., Fattore, E., Bianchi, G., Fanelli, R., & Davoli, E. (2020). Acetaldehyde in Polyethylene Terephthalate (PET) Bottled Water: Assessment and Mitigation of Health Risk for Consumers. *Applied Sciences*, 10(12), 4321. https://doi.org/10.3390/app10124321
Reimann Clemens, Manfred Birke, Peter Filzmoser, (2012). Temperature-dependent leaching of chemical elements from mineral water bottle materials. *Applied*

Geochemistry, 27(8), 1492-1498, https://doi.org/10.1016/j.apgeochem.2012.05.003

Rochman, C. M., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., Athey, S., Huntington, A., McIlwraith, H., Munno, K., De Frond, H., Kolomijeca, A., Erdle, L., Grbic, J., Bayoumi, M., Borrelle, S.B., Wu, T., Santoro, S., Werbowski, L.M., Zhu, X., Giles, R.K., Hamilton, B.M., Thaysen, C., Kaura, A., Klasios, N., Ead, L., Kim, J., Sherlock, C., Ho, A., & Hung, C. (2019) Rethinking Microplastics as a Diverse Contaminant Suite. *Environmental Toxicology and Chemistry, 38*(4), 703-711, https://doi.org/10.1002/etc.4371

Schmid, P., Kohler, M., Meierhofer, R., Luzi, S., & Wegelin, M. (2008). Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water? *Water Research,* https://doi.org/10.1016/j.watres.2008.09.025

Sievers, E. (2005). Nutrient Minerals in Drinking Water: Implications for the Nutrition of Infants and Young Children. World Health Organization *Institute of Public Health North Rhine Westphalia Munster, Germany*

Shotyk, W., Krachler, M., & Chen, B. (2006). Contamination of Canadian and European bottled waters with antimony from PET containers. *J. Environ. Monit.,* 2, 288-292. doi: 10.1039/b517844b

Schaider, L.A., Balan, S.A., Blum, A., Andrews, D.Q., Strynar, M.J., Dickinson, M.E., Lunderberg, D.M., Lang, J.R., & Peaslee, G.F. (2017). Fluorinated Compounds in U.S. Fast Food Packaging. *Environ. Sci. Technol. Lett.,* 4(3), 105-111. doi: 10.1021/acs.estlett.6b00435

Statista 2024, https://www.statista.com/forecasts/1232745/beer-volume-by-segment-worldwide

Wagner, M., & Oehlmann, J. (2009). Endocrine disruptors in bottled mineral water: total estrogenic burden and migration from plastic bottles. *Environmental Science and Pollution Research*. DOI 10.1007/s11356-009-0107-7

World Health Organization, Codex Alimentarius - Waters, Food & Agriculture Organization, Rome, 2007

World Health Organization. (2021). Impacts of temperature alteration on the drinking water quality stored in polyethylene terephthalate bottles Environmental Science and Pollution Research

WHO (2021). Guidelines for Drinking-Water Quality

Xu Jinying , Yang Bai, Hailin You, Xiaowei Wang, Zhifei Ma, Hongwei Zhang. (2022). Water quality assessment and the influence of landscape metrics at multiple scales in Poyang Lake basin, Ecological Indicators, 141, 109096, ISSN 1470-160X, https://doi.org/10.1016/j.ecolind.2022.109096.

Yutaka Abe, Norihiro Kobayashi, Miku Yamaguchi, MotohMutsuga, Asako Ozaki, Eri Kishi, Kyoko Sato, (2021). Determination of formaldehyde and acetaldehyde levels in poly(ethylene terephthalate) (PET) bottled mineral water using a simple and rapid analytical method, Food Chemistry, Vol 344, https://doi.org/10.1016/j.foodchem.2020.128708

Zhang Yunlin , Jianming Deng, Yongqiang Zhou, Yibo Zhang, Boqiang Qin, Chunqiao Song, Kun Shi, Guangwei Zhu, Xuejiao Hou, Yinjun Zhang, Shiwen He, R. Iestyn Woolway, Na Li. (2024). Drinking water safety improvement and future challenge of lakes and reservoirs, Science Bulletin, 69(22), 3558-3570, ISSN 2095-9273, https://doi.org/10.1016/j.scib.2024.06.018.

Zvěřinová I, Ščasný M, Otáhal J. (2024). Bottled or Tap Water? Factors Explaining Consumption and Measures to Promote Tap Water. Water.16(20):3011.https://doi.org/10.3390/w16203011

***Directive 2009/54/EC of the European Parliament and of the Council of June 18, 2009

***European Commision, List of Natural Mineral Waters Recognides by Member States, 2020

***Food and Agriculture Organization, Codex Alimentarius - Waters, Food & Agriculture Org., Rome2007

***Eurlex,https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:52013XC0403(04)

***Government Decision 1020/2005 for the approval of the Technical Norms for the exploitation and marketing of natural mineral waters

***Ordonance No. 7 of January 18, 2023 on the quality of water intended for human consumption

***United Nations University Institute for Water, Environment and Health (UNU-INWEH)https://unu.edu/inweh/collection/global-bottled-water-industry-review-impacts-and-trends