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Microplastic pollution in drinking water

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Abstract
Scientists have demonstrated the presence of microplastics (MPs) in tap and bottled water at various locations. On a global scale, there is still very limited information on MP pollution in drinking water. There are huge differences in reported MP concentration, but no clear conclusion can be drawn if MP content is higher in tap or bottled water. Up to date, it is not clear if these discrepancies arise from differences between the examined systems or from differences in quantification limits, the accuracy of the applied analytical techniques, or contamination during sampling, processing, and analysis. Furthermore, information on MP uptake and fate gained through animal and cell toxicity studies is very limited. To define a limit of tolerance for plastic pollution in drinking water, comparable data resulting from quality assured and controlled methods and more information on the potential uptake and fate of MPs in the human body are still needed.

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Microplastic analysis, Tap water, Bottled water, Human health.

Introduction

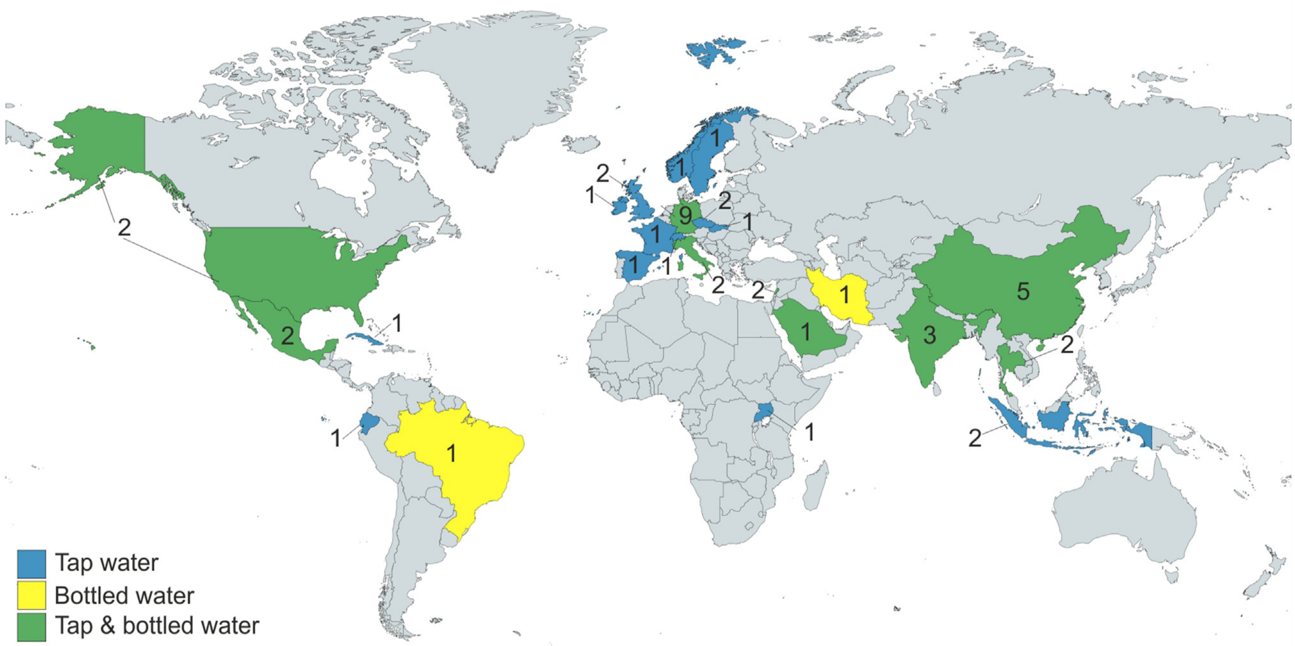
The omnipresence of plastics in all aspects of human life means that humans are inevitably exposed to microplastics (MPs) on a daily basis. Over the past recent years, scientists all over the globe have demonstrated the presence of MPs in tap water originating from different sources (ground, surface, or desalinated water) [1–15] and bottled water in various packaging (single-use plastic, reusable plastic, beverage carton, and glass) [1,16–24] at various locations. The exposure to MPs via drinking water led to growing concerns for the potential associated risks to human health. Because accessible clean drinking water is one of the Sustainable Development Goals of the United Nations [25], it is of utmost importance to reliably assess MPs and associated risks for human health from the consumption of drinking water. Hence, to address the growing public concern related to MPs and their implications for human health, for example, the European Drinking Water Directive (DWD) aims to include MPs on 'the watch list' of emerging compounds by 2024 [26].

The World Health Organization differentiates the potential human health risks associated with MPs into potential hazards associated with particles and chemicals and potential human health risks associated with biofilms attached to MPs [25]. In the present review, we focus on MP pollution in drinking water. To assess the current state of knowledge, we reviewed peer-reviewed studies on MPs in tap and bottled drinking water published in the years 2018–2021. The literature was selected using Scopus with the search string 'TITLE-ABS-KEY (microplastic AND drinking AND water AND bottle OR tap).' In addition, we screened for the relevant literature using respective keywords in Google scholar. Our search resulted in 26 selected studies on MPs in drinking water. Our aim in the present review was to highlight major knowledge gaps, pitfalls, and key questions in MP drinking water research that need to be addressed to understand and evaluate the risks related to human health in the future.

Microplastics in drinking water — tap versus bottled water

Since 2018, an increasing number of scientists investigated tap [1–14] and bottled water [1,16–24] originating from various locations around the globe (Fig. 1). However, on a global scale, there is still very limited information on plastic pollution in drinking water (Fig. 1). Considering peer-reviewed studies up till now, MPs in drinking water were analyzed in only 24 countries (Fig. 1), with an overall limited number of studies (1–9) addressing drinking water in any country. The highest number of studies addressed drinking water in Germany (9) [7,14,16,19–22,27], followed by studies addressing drinking water in China (5) [6,12,13,27,28]. Furthermore, of 26 studies, eight investigated bottled water [16,18–24], 16 investigated tap water [2–15], and two studies investigated both [1,17] (Fig. 1). However, to understand and evaluate the potentially

Figure 1



MPs in drinking water - globally. Global map indicating countries in which MPs in tap water (blue), in bottled water (yellow), or both (green) were investigated. Numbers indicate the number of different studies addressing MPs in drinking water in a respective country. The map was created using mapchart.net and subsequently edited. We considered peer-reviewed studies on MPs in tap and bottled drinking water published in the years 2018–2021 using Scopus, search string, TITLE-ABS-KEY (microplastic AND drinking AND water AND bottle OR tap) and additionally screening for the relevant literature using respective keywords in Google scholar. Our search resulted in 26 currently published studies on MPs in drinking water designated for human consumption. MP, microplastic.

related risks to human health, we need to draw a more complete global picture.

The MP numbers reported in bottled water vary from 1.4 MP/L to 5.42E+07 MP/L (Fig. 2a). However, the latter value originates from a study that used nonvalidated methods for MP quantification [29,30]. MP numbers reported in tap water vary by six orders of magnitude, from 0.0001 to 930 MP/L (Fig. 2b). Generally, it appears that higher MP concentrations were found in bottled water compared with tap water (Fig. 2a). However, there is no clear conclusion to draw as also low and very low MP numbers were reported for drinking water packed in glass and PET bottles (Fig. 2a). Comparing studies, diverse types of drinking water (bottled or tap) were investigated in various countries (Fig. 1) originating from different sources, packed in single-use plastic, reuseable plastic, glass, or beverage cartons (Fig. 2a) by various manufacturers or sampled at diverse locations from public taps, household taps, waterworks, or distribution networks (Fig. 2b). Hence, the high variation in reported MP counts might be related to geographic location, seasonality, source water, processing and production, packaging, and transport. However, many studies on MP occurrences are not considered fully reliable [31], and we want to draw specific attention that across all reviewed studies diverse analytical methods were used (Fig. 2) for MP qualification and quantification, which in our opinion represents one of the greatest pitfalls in MP analysis of drinking water.

From sampling to analytics — pitfalls in drinking water microplastic analysis

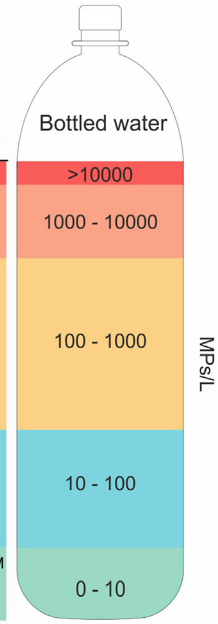
The literature clearly indicates that we currently face a lack of standardized or harmonized methods for sampling, extraction, and analysis of MPs in drinking water, making a comparison of results across studies challenging, if not impossible (Fig. 2). Furthermore, several studies do not meet rigorous quality standards and are hence not fully reliable [25,31].

The field of MP analysis, that is, the branch of analytical chemistry that deals with quantifying the group of particles termed 'microplastics,' has developed from a practical need to quantify MPs in various science fields, and not from other branches of analytical chemistry. This may be the reason why there historically has been little focus on documenting analytical methods including rigors Quality assurance/Quality control, aspects which long have been mandatory in analytical chemistry. Over the later years, there has been a strong trend to remedy this and introduce accurate analytical methods and protocols [32,33]. Today a consensus

Figure 2

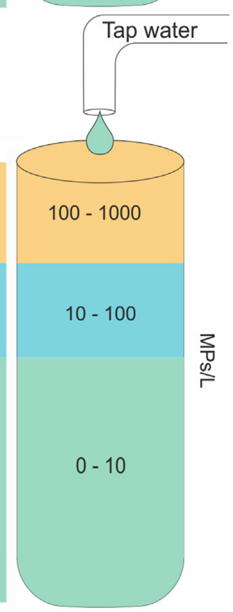
a)

Reference	Sample type	MPs/L	Quanti-/Qualification
Zuccarello et al., 2019	PET s.u.	5.42E+07 ± 1.95E+07	SEM-EDX
Oßmann et al., 2018	glass	6292 ± 10521	RM
Oßmann et al., 2018	PET r.u.	4889 ± 5432	RM
Oßmann et al., 2018	PET s.u.	2649 ± 2857	RM
Winkler et al., 2019	PET	980 ± 320	SEM, EDS
Mason et al., 2018	PET s.u.	325	Nile Red; μ-FTIR
Weisser et al., 2021	glass	317 ± 257	μFTIR
Giese et al., 2021	PET r.u.	242 ± 64	RM
Kankanige & Babel, 2020	PET s.u.	140 ± 19	Nile Red; ATR-FTIR; RM
Giese et al., 2021	PET r.u.	131 ± 25	RM
Schymanski et al. 2018	PET r.u.	118 ± 88	RM
Kankanige & Babel, 2020	glass	52 ± 4	Nile Red; ATR-FTIR; RM
Schymanski et al. 2018	glass	50 ± 52	RM
Almaiman et al., 2021	PET s.u., PC	<LOQ - 26	μFTIR
Schymanski et al. 2018	PET s.u.	14 ± 14	RM
Schymanski et al. 2018	beverage carton	11 ± 8	RM
Makhdoumi et al., 2021	PET	8.5 ± 10.2	hot needle; ATR-FTIR; RM
Almaiman et al., 2021	glass	1.8	μFTIR
Mason et al., 2018	glass	1.41	Nile Red; μ-FTIR



b)

Reference	Sample type	MPs/L	Quanti-/Qualification
Wang et al., 2020	DWTP	930	SEM; RM
Pivokonsky et al., 2018	DWTP	338 ± 76 - 628 ± 28	SEM; μ-FTIR; RM
Tong et al., 2020	houshold	440 ± 275	Nile red; RM
Pivokonský et al., 2021	DWTP	151 ± 4	SEM; μFTIR; RM
Kosuth et al., 2018	houshold	0 - 61	Rose Bengal; spatula tes
Kankanige & Babel, 2020	houshold	56 ± 14; 21 ± 7; 13 ± 5; 6 ± 3 (dif. Size)	Nile Red; ATR-FTIR; RM
Shruti et al., 2020	public drinking water fountains	18 ± 7	SEM-EDX; RM
Pivokonský et al., 2021	DWTP	14 ± 1	SEM; μFTIR; RM
Sarkar et al., 2021	DWTP	2.75 ± 0.92	Nile Red; ATR-FTIR
Zhang et al., 2020	houshold	0.7 ± 0.6	ATR-μFTIR
Lam et al., 2020	houshold	2.181 ± 0.165	Rose Bengal
Kirstein et al., 2021	DWTP; pumping station; hydrant	0.174 ± 0.405	Py-GCMS; μFTIR
Dalmau-Soler et al., 2021	DWTP	0.06 ± 0.04	μFTIR
Pittroff et al., 2021	DWTP, houshold	0,066 ± 0,076	RM
Johnson et al., 2020	DWTP	0.00011	μFTIR
Mintenig et al., 2019	DWTP	0.0007	μFTIR
Almaiman et al., 2021	n.i.	<LOQ	μFTIR
Weber et al., 2021	houshold; transfer station	0	RM
Gomiero et al. 2021	DWTP	n.a. [0.0061 - 0.0931 μg/L]	Py-GCMS
Kirstein et al., 2021	DWTP; pumping station; hydrant	n.a. [0.0014 - 0.00543 μg/L]	Py-GCMS; μFTIR



MPs in drinking water - tap vs. bottled water. Summary of peer-reviewed studies investigating MPs in bottled (**a**) and tap (**b**) water. Summarized are sample type, MP concentration (as average if provided in the study), and quanti-qualification method. Studies are sorted by the reported MP concentration ranges. S.u. = single-use; r.u. = reusable; n.a. = not applicable; n.i. = not identified. MPs, microplastics.

seems to be developing that any protocol for analyzing MPs in the environment should meet a set of requirements including but not limited to the following:

- Representative sampling. Sufficient volume must be sampled to ensure an adequate number of collected MPs. To achieve a reliable analysis, the amount must be above the quantification limit of the applied protocol. Variation in time and space must furthermore be considered.
- Contamination during sampling, sample preparation, and analysis must be documented and taken into account. MPs are ubiquitous and contamination unavoidable even when applying strict avoidance measures.

- Limit of quantification related among others to MP size and polymer type must be documented. A combined quantification limit would hence include the smallest size down to which MPs of certain types can reliably be quantified above the contamination background.
- False positives and false negatives must be considered as no analytical technique is able to distinguish all polymer types, all techniques will overlook some MPs, and all techniques will, to some degree, confuse natural particles with MPs. Furthermore, the number of false positives and false negatives will among others depends on the matrix, particle size, and polymer type.
- Recovery of analytes. The loss of MPs during extracting from a sample must be addressed.

Not all analytical methods applied to study MPs in drinking water are equally good at detecting them. Whether or not a method is suited is not always clear-cut as it depends on the analyzed matrix and the objective of the study. Hence, it must be ensured that the applied method is up to the envisioned task [34]. Contrary to many other micropollutants, MPs are not a single well-defined chemical substance or group of such substances but rather particles made of materials consisting of or containing specific families of polymeric substances. This makes analysis challenging, as these have different properties and structures, sometimes are combined for improved effectiveness, and materials made off them can contain additives in various amounts. MP analysis hence calls for methods which can reliably identify MP polymer type and yield additional information such as MP size, morphology, and mass. No one technique can do it all, and a combination is hence called for. Polymer types are commonly detected by Fourier Transform Infrared (FTIR) spectroscopy, Raman spectroscopy, pyrolysis-Gas Chromatography-Mass Spectrometry (GC/MS), or thermogravimetric GC/MS [24,30], whereas MP size and morphology are quantified by imaging, microscopy, or size fractionation.

Viewing the results of the published drinking water studies (Fig. 2) hence leaves the question of whether the huge differences in reported MP content are owing to actual differences between the examined systems or simply differences in quantification limits, the accuracy of the applied analytical techniques, contamination during sampling, sample preparation, analysis, and so on.

Implications for human health — a ‘black hole’ in microplastic research

The potential risks for human health resulting from MP ingestion are hardly understood, and information on MP uptake and fate gained through animal and cell toxicity studies is very limited. However, the fate and uptake rate of MPs into different organs are supposedly dependent on the size and polymer type. The European Food Safety Authority classified the absorption of MPs larger than 150 μm as unlikely, and the absorption and uptake of MPs smaller than 20 μm into organs as overall limited [35]. However, the European DWD aims to include MPs on ‘the watch list’ by 2024 [26], allowing member states to take preventive measures to reduce MPs in case too high numbers are reported. But what are ‘too high numbers’?

Putting the consumption of MPs in drinking water into a broader perspective based on the data currently available, drinking water may be not the main source of MP uptake for a human being. Despite ingestion is considered the major route of human exposure to MPs, other pathways such as inhalation and dermal contact represent relevant sources of exposure. Based on the consumption of foodstuff via plastic-contaminated seafood (fish and shellfish), beer, table salt, sugar, and honey, an uptake of 12,000−204,000 particles per person and per year is estimated [36−38]. MPs may reach the gastrointestinal system through contaminated foodstuff possibly leading to inflammatory response, increased permeability, cell function disruption, increased oxidative stress, and changes in gut microbe composition and metabolism [38,39]. After digestion, MPs could be adsorbed in the intestine wall by dedicated M-cells [40], whereas the ‘corona’ effect may help MP particles to penetrate the intestinal mucus by an increase in solubility or simply by their small sizes [41]. MPs could be subjected to these same mechanisms as their translocation to the circulatory system after oral administration has been demonstrated *in vivo* [42].

After exposure, MPs may act at a local level in the tissue or translocate to other tissues, as e.g. inflammation tends to increase the permeability of epithelial barriers. Circulating MPs are also reported to cause hypertension [43], blood clots [44], improved coagulability [45,46], and blood cell cytotoxicity [47]. Owing to the high surface area, MPs may act as carriers of oxidizing species adsorbed to their surface (e.g. metals and Reactive oxygen species (ROS) inducers). Oxidative stress after exposure to MPs has been reported in fish and mammalians [48,49]. However, the risk of ingesting MPs is not known because little research has been conducted on estimating the overall human exposure and its effects.

Public awareness and engagement have increased in response to concerns about the impact of plastic and microplastic pollution. In parallel, political commitment is also growing as the governmental representatives of several countries in the world, including the European Commission, committed to significantly reduce single-use plastic products within the next 10 years and the importance of long-term elimination of MPs from the oceans [50,51]. In the context of the

DWD, the European Union points out the urgent need for standard sampling methods of MPs, for the purpose of monitoring and investigating water quality in all water bodies, from lakes, rivers, and streams to pressurized water systems, drinking water, and wastewater. Robust and consistent methodology is now starting to emerge, but no general protocol for the sampling of these pollutants in water currently exists. Furthermore, to define the limit of tolerance of MPs in drinking water, the fate, uptake rate, and effects of MPs for human health need to be addressed.

Conclusion

In our opinion, the best chance to evaluate the potential risks and to define the limit of tolerance for plastic pollution in drinking water is the combination and stepwise approach of 1. quality assurance/control of harmonized methods, 2. collection of resulting comparable quality data, 3. the further development of analytical techniques to increase sensitivity and, for example, reliably assess ever smaller plastic particles, and 4. data collection on the uptake and fate of plastic particles via toxicity studies. Hence, defining the limit of tolerance for plastic pollution in drinking water will take time. In the meantime, more research should focus on the development of new technical innovations on removal techniques of MPs/NPs (nanoplastic) in drinking water treatment plants which can function as a preventive measure.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest

1. Almaiman L, Aljomah A, Bineid M, Aljeldah FM, Aldawsari F, Liebmann B, Lomako I, Sexlinger K, Alarfaj R: **The occurrence and dietary intake related to the presence of microplastics in drinking water in Saudi Arabia**. *Environ Monit Assess* 2021, **193**:1–13.

2. Dalmau-Soler J, Ballesteros-Cano R, Boleda MR, Paraira M, Ferrer N, Lacorte S: **Microplastics from headwaters to tap water: occurrence and removal in a drinking water treatment plant in Barcelona Metropolitan area (Catalonia, NE Spain)**. *Environ Sci Pollut Control Ser* 2021:1–11.

3. Gomiero A, Øysæd KB, Palmas L, Skogerbø G: **Application of GCMS-pyrolysis to estimate the levels of microplastics in a drinking water supply system**. *J Hazard Mater* 2021, **416**: 125708.

4. Johnson AC, Ball H, Cross R, Horton AA, Jurgens MD, Read DS, Vollertsen J, Svendsen C: **Identification and quantification of microplastics in potable water and their sources within water treatment works in England and Wales**. *Environ Sci Technol* 2020, **54**:12326–12334.

5. * Kirstein IV, Hensel F, Gomiero A, Iordachescu L, Vianello A, Wittgren HB, Vollertsen J: **Drinking plastics?–Quantification and qualification of microplastics in drinking water distribution systems by μFTIR and Py-GCMS**. *Water Res* 2021, **188**: 116519.

This is the first study analyzing MP in drinking water sub-samples by two of the most validated and complementary analytical techniques: μFTIR imaging and Py-GCMS.

6. Lam TWL, Ho HT, Ma AT, Fok L: **Microplastic contamination of surface water-sourced tap water in Hong Kong—a preliminary study**. *Appl Sci* 2020, **10**:3463.

7. Mintenig S, Löder M, Primpke S, Gerdts G: **Low numbers of microplastics detected in drinking water from ground water sources**. *Sci Total Environ* 2019, **648**:631–635.

8. Pivokonsky M, Cermakova L, Novotna K, Peer P, Cajthaml T, Janda, V. J. S. o. T. T. E.: *Occurrence of microplastics in raw and treated drinking water*, **643**; 2018:1644–1651.

9. Pivokonský M, Pivokonská L, Novotná K, Čermáková L, Klimtová M: **Occurrence and fate of microplastics at two different drinking water treatment plants within a river catchment**. *Sci Total Environ* 2020, **741**:140236.

10. Sarkar DJ, Sarkar SD, Das BK, Praharaj JK, Mahajan DK, Purokait B, Mohanty TR, Mohanty D, Gogoi P, Kumar S: **Microplastics removal efficiency of drinking water treatment plant with pulse clarifier**. *J Hazard Mater* 2021, **413**:125347.

11. Shruti V, Pérez-Guevara F, Kutralam-Muniasamy G: **Metro station free drinking water fountain-A potential "microplastics hotspot" for human consumption**. *Environ Pollut* 2020, **261**:114227.

12. Zhang M, Li J, Ding H, Ding J, Jiang F, Ding NX, Sun C: **Distribution characteristics and influencing factors of microplastics in urban tap water and water sources in Qingdao, China**. *Anal Lett* 2020, **53**:1312–1327.

13. Wang Z, Lin T, Chen W: **Occurrence and removal of microplastics in an advanced drinking water treatment plant (ADWTP)**. *Sci Total Environ* 2020, **700**:134520.

14. Weber F, Kerpen J, Wolff S, Langer R, Eschweiler V: **Investigation of microplastics contamination in drinking water of a German city**. *Sci Total Environ* 2021, **755**:143421.

15. Pittroff M, Müller YK, Witzig CS, Scheurer M, Storck FR, Zumbülte N: **Microplastic analysis in drinking water based on fractionated filtration sampling and Raman microspectroscopy**. *Environ Sci Pollut Control Ser* 2021:1–13.

16. Giese A, Kerpen J, Weber F, Prediger Jr: **A preliminary study of microplastic abrasion from the screw cap system of reusable plastic bottles by Raman microspectroscopy**. *ACS ES&T Water* 2021, **1**:1363–1368.

17. Kankanige D, Babel S: **Smaller-sized micro-plastics (MPs) contamination in single-use PET-bottled water in Thailand**. *Sci Total Environ* 2020, **717**:137232.

18. Makhdoumi P, Amin AA, Karimi H, Pirsaheb M, Kim H, Hossini H: **Occurrence of microplastic particles in the most popular Iranian bottled mineral water brands and an assessment of human exposure**. *Journal of Water Process Engineering* 2021, **39**:101708.

19. Mason SA, Welch VG, Neratko J: **Synthetic polymer contamination in bottled water**. *Frontiers in chemistry* 2018, **6**:407.

20. Oßmann BE, Sarau G, Holtmannspötter H, Pischetsrieder M, Christiansen SH, Dicke W: **Small-sized microplastics and pigmented particles in bottled mineral water**. *Water Res* 2018, **141**:307–316.

21. Schymanski D, Goldbeck C, Humpf H-U, Fürst P: **Analysis of microplastics in water by micro-Raman spectroscopy: release of plastic particles from different packaging into mineral water**. *Water Res* 2018, **129**:154–162.

22. Weisser J, Beer I, Hufnagl B, Hofmann T, Lohninger H, Ivleva NP, Glas K: **From the well to the bottle: identifying sources of microplastics in mineral water**. *Water* 2021, **13**:841.

23. Winkler A, Santo N, Ortenzi MA, Bolzoni E, Bacchetta R, Tremolada P: **Does mechanical stress cause microplastic release from plastic water bottles?** *Water Res* 2019, **166**: 115082.

24. Zuccarello P, Ferrante M, Cristaldi A, Copat C, Grasso A, Sangregorio D, Fiore M, Conti GO: **Exposure to microplastics (< 10 μm) associated to plastic bottles mineral water consumption: the first quantitative study**. *Water Res* 2019, **157**:365–371.

25. WHO: *Microplastics in drinking-water*. Geneva: World Health Organization; 2019. Licence: CC BY-NC-SA 3.0 IG. **2019**.

26. (EU) DWD: **Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (Text with EEA relevance)**. *Orkesterjournalen L* 2020, **435**:1–62.

27. Kosuth M, Mason SA, Wattenberg EV: **Anthropogenic contamination of tap water, beer, and sea salt**. *PLoS One* 2018, **13**, e0194970.

28. Tong H, Jiang Q, Hu X, Zhong X: **Occurrence and identification of microplastics in tap water from China**. *Chemosphere* 2020, **252**:126493.

29. * Oßmann BE: **Microplastics in drinking water? Present state of knowledge and open questions**. *Current Opinion in Food Science* 2021.
This recent review gives a good overview on the current state of knowledge regarding microplastics in drinking water.

30. * Danopoulos E, Twiddy M, Rotchell JM: **Microplastic contamination of drinking water: a systematic review**. *PLoS One* 2020, **15**, e0236838.
The authors reviewed studies on microplastics in drinking water, excluding all studies using "non-validated processes for the identification of microparticle composition."

31. Koelmans AA, Nor NHM, Hermsen E, Kooi M, Mintenig SM, De France J: **Microplastics in freshwaters and drinking water: critical review and assessment of data quality**. *Water Res* 2019, **155**:410–422.

32. Miller E, Sedlak M, Lin D, Box C, Holleman C, Rochman CM, Sutton R: **Recommended best practices for collecting, analyzing, and reporting microplastics in environmental media: lessons learned from comprehensive monitoring of San Francisco Bay**. *J Hazard Mater* 2021, **409**:124770.

33. Brander SM, Renick VC, Foley MM, Steele C, Woo M, Lusher A, Carr S, Helm P, Box C, Cherniak S: **Sampling and quality assurance and quality control: a guide for scientists investigating the occurrence of microplastics across matrices**. *Appl Spectrosc* 2020, **74**:1099–1125.

34. * Primpke S, Christiansen SH, Cowger W, De Frond H, Deshpande A, Fischer M, Holland EB, Meyns M, O'Donnell BA, Ossmann BE: **Critical assessment of analytical methods for the harmonized and cost-efficient analysis of microplastics**. *Appl Spectrosc* 2020, **74**:1012–1047.
The authors focuss in this review, to evaluate the state of the currently applied identification and quantification tools for microplastics and provide a harmonized guideline for future standardized operational protocols.

35. *EFSA* Statement on the presence of microplastics and nanoplastics in food, with particular focus on seafood. (EFSA Panel on Contaminants in the Food Chain); 2016:1830–5458.

36. Cox KD, Covernton GA, Davies HL, Dower JF, Juanes F, Dudas SE: **Human consumption of microplastics**. *Environ Sci Technol* 2019, **53**:7068–7074.

37. * Senathirajah K, Attwood S, Bhagwat G, Carbery M, Wilson S, Palanisami T: **Estimation of the mass of microplastics ingested–A pivotal first step towards human health risk assessment**. *J Hazard Mater* 2021, **404**:124004.
The authors attempt to transform microplastic counts into a mass value relevant to human toxicology assessment.

38. * Prata JC, da Costa JP, Lopes I, Duarte AC, Rocha-Santos T: **Environmental exposure to microplastics: an overview on possible human health effects**. *Sci Total Environ* 2020, **702**: 134455.
The authors reviewed possible routes of exposures linking exposure to a pattern of potential biological effects on humans.

39. Salim SY, Kaplan GG, Madsen KL: **Air pollution effects on the gut microbiota: a link between exposure and inflammatory disease**. *Gut Microb* 2014, **5**:215–219.

40. Ensign LM, Cone R, Hanes J: **Oral drug delivery with polymeric nanoparticles: the gastrointestinal mucus barriers**. *Adv Drug Deliv Rev* 2012, **64**:557–570.

41. Paul MB, Stock V, Cara-Carmona J, Lisicki E, Shopova S, Fessard V, Braeuning A, Sieg H, Böhmert L: **Micro-and nanoplastics–current state of knowledge with the focus on oral uptake and toxicity**. *Nanoscale Advances* 2020, **2**: 4350–4367.

42. Wright SL, Kelly FJ: **Plastic and human health: a micro issue?** *Environ Sci Technol* 2017, **51**:6634–6647.

43. Amabile N, Heiss C, Real WM, Minasi P, McGlothlin D, Rame EJ, Grossman W, De Marco T, Yeghiazarians Y: **Circulating endothelial microparticle levels predict hemodynamic severity of pulmonary hypertension**. *Am J Respir Crit Care Med* 2008, **177**: 1268–1275.

44. Jones AE, Watts JA, Debelak JP, Thornton LR, Younger JG, Kline JA: **Inhibition of prostaglandin synthesis during polystyrene microsphere-induced pulmonary embolism in the rat**. *Am J Physiol Lung Cell Mol Physiol* 2003, **284**:L1072–L1081.

45. Dong C-D, Chen C-W, Chen Y-C, Chen H-H, Lee J-S, Lin C-H: **Polystyrene microplastic particles: in vitro pulmonary toxicity assessment**. *J Hazard Mater* 2020, **385**:121575.

46. Banaee M, Gholamhosseini A, Sureda A, Soltanian S, Fereidouni MS, Ibrahim ATA: **Effects of microplastic exposure on the blood biochemical parameters in the pond turtle (Emys orbicularis)**. *Environ Sci Pollut Control Ser* 2021, **28**: 9221–9234.

47. Çobanoğlu H, Belivermiş M, Sõkdokur E, Kõlõç Ö, Çayõr A: **Genotoxic and cytotoxic effects of polyethylene microplastics on human peripheral blood lymphocytes**. *Chemosphere* 2021, **272**:129805.

48. Lu Y, Zhang Y, Deng Y, Jiang W, Zhao Y, Geng J, Ding L, Ren H: **Uptake and accumulation of polystyrene microplastics in zebrafish (Danio rerio) and toxic effects in liver**. *Environ Sci Technol* 2016, **50**:4054–4060.

49. Deng Y, Zhang Y, Lemos B, Ren H: **Tissue accumulation of microplastics in mice and biomarker responses suggest widespread health risks of exposure**. *Sci Rep* 2017, **7**:46687.

50. UNEP: *Ministerial declaration of the united Nations environment assembly at its fourth session*. Nairobi: United Nations Environment Programme; 2019 (UNEP/EA.4/HLS.1, http://web.unep.org/environmentassembly/ministerial-declaration-resolutions-and-decisions-unea-4. Accessed 18 June 2019. accessed.

51. ECHA: *Proposal for a restriction: intentionally added microplastics*. European Chemicals Agency; 2019 (Annex XV restriction report: Version 1.1, https://echa.europa.eu/documents/10162/12414bc7-6bb2-17e7-c9ec-652a20fa43fc. Accessed 1 July 2019. accessed.