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Trace elements concentrations in drinking water – is there a risk for neurological or psychiatric disorders?

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Abstract

Introduction: Drinking water contaminated with heavy metals like arsenic, cadmium, nickel, mercury, chromium, zinc, lead, etc. is becoming a major health concern. Some trace elements have been linked to neurotoxic effects and an increased risk of neurodevelopmental disorders, although there is still an area for further investigations on how they may affect neurological and psychiatric illnesses. It is widely acknowledged that the generation of reactive oxygen species causes oxidative damage and other detrimental health effects, and is the main mechanism underlying heavy metal-induced toxicity in contaminated drinking water.

Material and method: The available literature was reviewed using PubMed, Scopus, and Web of Sciences platforms. The analysis included both reviews and original studies.

The aim: The main objective of this narrative review was to summarize the current knowledge regarding the concentrations of chosen trace elements in drinking water and their possible relationship with neurological and psychiatric disorders.

Discussion: Some elements such as aluminum, arsenic, lithium, or nickel have been suggested to be risk factors for psychoneurological disorders. Further, studies suggest that some neurobehavioral disorders might be due to the collective action of metals in drinking water.

Keywords: trace elements; drinking water; contamination; neurological disorder; psychiatric disorder

Streszczenie

Wstęp: Woda pitna zanieczyszczona metalami ciężkimi, takimi jak arsen, kadm, nikiel, rtęć, chrom, cynk, ołów itp. staje się poważnym problemem zdrowotnym. Niektóre pierwiastki śladowe zostały powiązane z efektami neurotoksycznymi i

zwiększonym ryzykiem zaburzeń neurorozwojowych, chociaż nadal istnieje obszar do dalszych badań nad ich wpływem na choroby neurologiczne i psychiczne. Powszechnie uznaje się, że wytwarzanie reaktywnych form tlenu powoduje uszkodzenia oksydacyjne i inne szkodliwe skutki zdrowotne oraz jest głównym mechanizmem leżącym u podstaw toksyczności wywołanej metalami ciężkimi w zanieczyszczonej wodzie pitnej. W artykule omówiono liczne zagrożenia dla zdrowia związane z mechanizmami i działaniem pierwiastków śladowych, w szczególności metali ciężkich występujących w zanieczyszczonej wodzie. Sugeruje się, że niektóre pierwiastki śladowe są czynnikami ryzyka zaburzeń psychoneurologicznych.

Materiał i metoda: Dokonano przeglądu literatury za pomocą platform PubMed, Scopus i Web of Sciences. Analiza obejmowała zarówno prace przeglądowe, jak i oryginalne.

Dyskusja: W niniejszym przeglądzie omówiono potencjalne mechanizmy i skutki wpływu pierwiastków śladowych w celu oceny zagrożeń związanych ze spożyciem zanieczyszczonej wody i podniesienia świadomości na temat potencjalnej roli w kwestiach zdrowotnych, w szczególności w zaburzeniach neuropsychologicznych. Omówiono procesy powodujące objawy ostrych i przewlekłych zatruć.

Wnioski: Sugeruje się, że niektóre pierwiastki takie jak glin, arsen, lit lub nikiel, są czynnikami ryzyka zaburzeń psychoneurologicznych. Ponadto badania sugerują, że niektóre zaburzenia neurobehawioralne mogą być spowodowane zbiorowym działaniem różnych metali w wodzie pitnej.

Słowa kluczowe: zanieczyszczenia, pierwiastki śladowe, woda pitna, choroby neurologiczne, choroby psychiczne

1. Introduction

The unit that forms the basis of life and the functioning of living organisms is water. Its quality has a significant impact on human health – both physical and mental [1]. Maintaining the proper hydration of the body is an important factor in ensuring homeostasis, which has a positive effect on the prevention of diseases or bothersome symptoms. The current drinking water regulations define the highest so far allowable levels of toxic metals, and the presence of harmful bacteria or organic pollutants [2].

The demand for water shows high interindividual variability, depending on the diet, temperature, and physical activity [3]. This demand will be increased at elevated temperatures, lowered ambient humidity, high altitudes, and increased physical activity [4]. People consume water in various forms i.e., plain drinking water, water contained in other beverages such as coffee, water contained in food, and water obtained from food metabolism. Small amounts of water (200-300 ml/d) are formed in the body because of the metabolism of nutrients, as shown in Table 1.

Table 1.

	1 g of fat	1 g of carbohydrates	1 g of protein
The amount of water obtained from the metabolism of individual nutrients	1.07 g	0.6 g	0.4 g

In general, 1/3 of the average daily fluid intake comes from food. The remaining 2/3 should be met through the proper fluid intake. Water can contain up to 70 different minerals. In this broad group, the most important are magnesium, calcium, chlorides, sodium, iodides, iron, and carbon dioxide. The micronutrients are also present in water but in smaller amounts, so it is preferable to supply them with food. It is best to choose water where 1 liter contains more than 15% of the daily requirement of a given element [5].

Overall, in addition to the beneficial effects of drinking water on individual systems, we have mounting evidence of a positive association between the consumption of water and the occurrence of a mental disorder [6]. The beneficial effects of water on the signaling pathway and by delivering nutrients to the brain, and removing toxins and inflammatory markers, translate into better, more effective brain activity [7]. Several studies indicate that the lack of adequate water quality is associated with distress and mental anxiety [8,9]. Mainly the female population is exposed, particularly those who live in poor environments (like Ethiopia or Nepal), as they are responsible for water resources [10]. In a study by Haghighatdoost et al. lower daily clean water consumption has been linked to an increased risk of depression [6]. Earlier works related water consumption to civilization diseases (obesity, diabetes, coronary diseases), cancer, or mortality [11-13]. Considering the beneficial effect of drinking water, and the two-way relationship between metabolic balance, and mental health, it can be assumed that water consumption may affect the risk of mental disorders by influencing the metabolic state [6].

Demineralized water/deionized water is water devoid of mineral salts by reverse osmosis, nanofiltration, electrodialysis, ion exchange, or other technology. Additionally, it does not contain foreign ions and pollutants, but it contains gases such as nitrogen, oxygen, or carbon dioxide [14]. Considering its specific properties, it has found its application in many industries such as pharmacy, cosmetology, and cleaning agents. These technologies were more widely used in drinking water treatment in the 1960s' due to the limited sources of drinking water in some dry coastal and inland arid areas not being able to ensure adequate water demand, industrial development, growing tourism, and an increased standard of living [15]. In the late 1970s' the WHO (World Health Organization) commissioned a skilled team to conduct a study on basic standards for demineralized water. A study by Sidorenko and Rakhmanin proved that distillate, i.e., fully demineralized water, has unfavorable organoleptic properties and has an adverse effect on the body [16]. The final report provided by the above-mentioned team also included recommendations for optimal levels of substances such as salts, and bicarbonate ions and recommendations for the maximum level of alkalinity [16]. The research carried out by Kondratiuk also confirms the negative aspect of the supply of demineralized water [17]. The above 6-month-long study, which was carried out on rats, suggested an unfavorable effect of demineralized water on the blood formation process (mean hemoglobin content in erythrocytes was approx. 19% lower). The water in the human body contains electrolytes i.e., Na, K thus when consuming demineralized water, the intestines must obtain electrolytes from the body's reserves [18]. Then symptoms of low electrolyte levels may appear e.g., headache, fatigue, weakness. Introducing this type of water into the body leads to changes in extracellular osmolality, which may in some way compensate for osmoregulatory mechanisms such as: maintaining cell volume, ion transport, organic osmolyte concentration, etc. [19].

Contrarily, mineral water contains large amounts of dissolved minerals containing high quantities of magnesium sulfate, calcium carbonate, potassium, and sodium sulfate. Mineral water might undergo various processes that aim to eliminate toxic substances or elements such as arsenic for instance. Drinking mineral water is beneficial for human organism as it is a good source of magnesium and calcium, it promotes digestive health, and regulates blood circulation as well. This type of water isf generally considered safe to drink, but the amount of research regarding its disadvantages is increasing. The most alarming threat regarding mineral water is the fact that this type of water is usually bottled and therefore might contain specific contaminants including microplastic.

Another type of water is tap water obtained directly from the tap or faucet. Regulations regarding the tap water are provided by the Environmental Protection Agency (EPA). There are various risks while drinking this type of water because of the presence of chlorine and fluoride that can significantly affect human health including the onset of cardiovascular, reproductive, or neurological problems. Tap water might also be contaminated with arsenic or heavy metals like copper, chromium, lead, mercury, aluminium, and cadmium, which that eventually might be associated with such conditions as dementia, Alzheimer's, and Parkinson's diseases [20,21].

2. Material and method

The available literature was reviewed using PubMed, Scopus, and Web of Sciences databases in May 2023. The analysis included both reviews and original studies. The literature search included both human and animal studies. There were no restrictions regarding the year of publication nor the language of searched articles but overally only articles in English were included.

3. The aim

This narrative review aims to summarize the current knowledge regarding the concentrations of chosen trace elements in drinking water and their possible relationship with neurological and psychiatric disorders. This review discusses the potential mechanisms and effects of trace elements to assess the hazard associated with the consumption of contaminated water and to raise awareness about the potential role in health-related issues, specifically neuropsychological disorders. The processes causing such toxicities as well as the acute and chronic poisoning symptoms have been discussed.

4. Aluminium

The neurotoxic effect exerted by aluminium (Al) environmental exposure is currently well established [22,23]. Naturally present in the environment and widely used in the industry elementary body, aluminium indispensably affects human beings [23]. Interestingly, aluminium does not exert any important or necessary role in the biochemical processes of any existing organisms that may be a consequence of a productive cycling of this metal within the lithosphere, ruling it probably out from biochemical evolution [24,25]. The increasing burden of the Al in the biosphere and its impact on humankind appear as a result of human activity that affects the lithospheric cycling [25]. Aluminium exposition appears through diverse routes, including food, water, and air. Food additives, pharmaceuticals, or cosmetics, every day utilized by humans, are rich in Al-based compounds

[23,26].

The fourth edition of the Guidelines for drinking-water quality by the World Health Organization (WHO) indicates that provisional tolerable weekly intake for aluminium should not exceed 1 mg/kg body weight, from all sources. Whereas drinking water contributes to approximately 5% of the total oral intake of aluminium [27].

Regarding neurological disorders, Al content in the brain tissue of patients with Alzheimer's disease (AD), Dialysis dementia syndrome (DDS,) and Down syndrome was investigated to be significantly elevated [28]. Furthermore, neurobehavioral changes associated with Al exposure were reported [23]. However, data on Al exposition through drinking water reveals some discrepancies [26].

Campdelacreu (2014) indicates that there is weak evidence suggesting an increased risk of AD related to the intake of Al-containing water [29]. A large study by Van Dyke et al. (2021) showed no significant association between AD incidence and Al exposure through drinking water both minimally (considering only age with stratification by gender) and completely (considering confounding factors, including previous history of stroke, blood pressure, education, and age, with stratification by gender) adjusted models. No significant association was found even at the highest Al exposure category (Al concentrations ≥ 433.3 μg/L). The mean Al concentration in the water was 134.1 μg/L. However, the authors revealed a positive linear trend regarding the relationship between AD and Al levels in the drinking water in the adjusted for ApoE-ε4 allele status model that should warrant subsequent investigations [30]. Rondeau et al. (2009) revealed that high daily consumption of Al through drinking water (defined as Al intake ≥ 0.1 mg per day) is significantly related to a higher risk of dementia and it is associated with greater cognitive decline. Moreover, the authors suggested in their multivariate analysis that consumption of water with high Al content may be considered a risk factor for AD [20].

An apparent relationship between Al in drinking water and the risk of AD was demonstrated by Martyn et al. in 1989. Al concentration exceeding 110 μg/L implied a 1.5 times higher risk of AD than in the group where Al concentrations were found to not exceed 10 μg/L [31]. Furthermore, a recent study by Russ et al. (2020) showed higher dementia risk in both women and men exposed to increased Al levels in drinking water. The same results were observed in the case of fluoride. The inclusion of both aluminium and fluoride in the studying model and exploration of the synergistic influence did not reveal any statistical significance. Interestingly, Al and fluoride levels in drinking water appeared to be relatively low (mean Al concentrations were 37.4 μg/L, range 10.5-92.8 μg/L; mean fluoride concentrations were 53.4 μg/L, range 23.8-181.1 μg/L) [32].

Notably, Al from drinking water constitutes only a part of total dietary Al exposure which has been emphasized in some studies, indicating difficulties in their interpretation [33]. Notwithstanding, it is speculated that some fraction of aluminium contained in drinking water may exhibit specific bioavailability [33-35]. This possibility arises taking into account studies investigating Al-based antacids users who consumed about 1 g or more of Al per day and did not present a higher risk for Alzheimer's disease [33,36-38]. Indeed, owing to many inconsistencies, further investigations are needed to explore a clear association between neurological disorders and Al in drinking water [33].

5. Ammonia

Denomination ammonia encompasses two species – non-ionized NH3 and ionized form NH4+, named commonly ammonium. NH3 and NH4+ appear as very important compounds in human metabolism, accounting for acid-base regulation or nucleoside biosynthesis [39,40]. Environmental ammonia presence is associated with agriculture, industry, or metabolic processes [40].

Regarding ammonia concentrations in drinking water, the WHO in the fourth edition of the Guidelines for drinking-water quality indicates that NH3 and NH4+ levels present well below quantity that may affect human health, hence guideline value was not established [27].

Daily consumption of ammonia appears to be at level 18 mg, while toxic effects were noted at levels beyond 200 mg/kg body weight. Concentrations in ground and surface water range from less than 0.2 mg/l to 3 mg/l when water contains large amounts of humic substances or iron [27,39,40]. Fu et al. (2012) investigated ammonia contamination in drinking water in China. Depending on the source of drinking water, the highest NH3/NH4+ levels were noted in the river sources, further in lake/reservoir sources with the lowest ammonia concentrations in the groundwater sources. However, the annual mean NH3/NH4+ concentrations in all three types of sources did not exceed 0.5 mg/l. The river drinking water sources are characterized by variable ammonia levels depending on investigated regions and fluctuate seasonally. Variable ammonia concentrations in different regions were also observed in the groundwater sources owing to geological permeability and natural characteristics of regions. Increased ammonia levels were particularly associated with wastewater drainages, and other pollution sources such as outflows from industries, urban sites, or unidentified sites [41].

There remains a lack of studies with robust data

linking ammonia concentrations in drinking water and human health risks, especially concerning NH3/NH4+ neurotoxicity; however, neuropsychiatric complications following hyperammonemia per se are currently well established [39,42,43].

6. Antimony

Antimony (Sb) is a white, friable metal that occurs naturally in the Earth's crust. Sb has an array of industrial applications, including the manufacture of semiconductors, diodes, lead storage batteries, or bearings. It may also be used in fire-retardant specimens for plastics or textiles, as compounds of drugs for the treatment of leishmaniasis and schistosomiasis, or in the production of explosives [44,45]. Sb toxicity is mostly associated with occupational inhalational exposure. It was observed in pulmonary, cardiovascular, gastrointestinal, and dermal alterations.

Sb exhibits also carcinogenic and genotoxic potentials that have been investigated in recent animal studies [45,46]. Guidelines for the drinking water quality provided by the WHO denote that Sb exposure through food or drinking water is very low. A tolerable daily intake of Sb is 6 μg/kg body weight while drinking water concentrations should not exceed 20 μg/l [27].

However, an increasing number of recent analyses have indicated that Sb may be released into drinking water from polyethylene terephthalate (PET) bottles [47,48]. Antimony trioxide (Sb2O3) is used in PET polymers production as a catalyst and it may leach into bottled beverages under inappropriate storage conditions, such as exposition to high temperature or sunlight [47]. Some reports about increased Sb concentrations in bottled water link it with the PET production process that appeared in 2006 and 2007, including a large study by Shotyk and Krachler (2007), investigating 132 brands of bottled water from 28 countries [49,50]; however, the first mentions about this problem occurred in 1988, and further in 1995 and 1997 [48,51-53]. Shotyk and Krachler (2007) noted that releasing Sb from PET materials reveals variable reactivity. Considering bottled water from Europe, Sb concentrations have increased by about 90% after storage at room temperature for half a year, compared to Sb concentrations in bottled water from Canada which have increased by only 19% under the same storage conditions [50].

Qiao et al. (2018) explored Sb concentrations in the bottled drinking water of the 10 famed brands presented in supermarkets in China. The authors concluded that Sb leaches from PET bottles into water irrespective of storage conditions; however, incubation at 70 °C significantly enhanced releasing Sb in the case of all ten brands [54].

Temperature and storage time appear as relevant factors affecting the Sb migration from PET into bottled water [44,47,48,55]. In a recent study, Zmit and Belhaneche-Bensemra (2019) revealed that Sb concentrations are higher in smaller PET bottles (0.33 l) than in bigger (1.5 l) PET bottles, indicating that this occurrence is associated with larger contact surface area concerning water volume. The researchers created a tool for quantification of the migration of Sb into bottled beverages, indicating that temperature, time, and bottle thickness are factors affecting the Sb migration. The proposed model appears to be effective, simple, and fast and may be used for validation of the quality of PET materials as receptacles for drinking water [56].

Xu et al. (2021) indicated that Sb released from PET bottles may be supported by various ingredients of beverages. The authors showed that the pH of solutions affects significantly Sb migration from PET packaging. Carbonated beverages with lower pH presented significantly higher Sb concentrations than other kinds of beverages. Using ian vivo mouse model, Sb relative bioavailability (RBA) in the bottled drinks was assessed. The study exhibited that coffee beverages present the lowest Sb RBA, while protein beverages have the highest Sb RBA. Additionally, Sb RBA values were negatively correlated with iron (Fe) and phosphorus (P) presence in explored beverages, while tartaric acid exhibited a positive correlation with Sb RBA [47].

In most of the conducted studies, Sb concentrations in bottled drinking water appeared to be, however, below adopted by the WHO or European Union limits that present at level 20 μg/l and 5 μg/l, respectively [27,50,56]. Some surveys demonstrated also no health risks associated with the intake of Sb-contaminated bottled water. Results were based on the estimation of chronic daily Sb intake (CDI), using a special equation that considered Sb concentration in PET-bottled water, the average daily consumption of beverages, and body weight [47,54,56].

Notwithstanding, a study by Tanu et al. (2018), involving in vivo experimental mice model, revealed that Sb exposure is associated with neurobehavioral changes in mice, including memory and learning abilities deterioration, and anxiety-like behavior induction. Furthermore, researchers showed that Sb-exposed mice reveal biochemical and histological changes in the liver and kidneys, indicating dysfunction of these organs. The authors suggested that chronic exposure to Sb, inter alia through drinking water, may lead to potential implications for humans [57].

7. Arsenic

Earth's crust is rich in arsenic (As) compounds, presenting heterogeneous oxidative states (-3, 0, +3, and +5). The water contains predominantly arsenate (+5

oxidative form), or arsenite (+3 oxidative form) when exposed to anaerobic conditions. The most important As exposure routes remain food, drinking water, and occupational milieu; however, arsenic in groundwater or drinking water emerges mainly in a more toxic, inorganic form (iAs). Geological conditions with natural sediments or mining activities cause approximately 200 million people all over the world to be exposed to high As concentrations in drinking water, exceeding the recommended by the WHO guideline value by10 μg/l [27,58,59]. As toxicity is associated with inactivation, about 200 enzymes are responsible for DNA synthesis and repair, or cellular energy pathways. The clinical view encompasses acute As poisoning with distinctive nausea, vomiting, abdominal pain, watery diarrhea, and extravagant salivation, and chronic As toxicity that may manifest in all body systems, particularly affecting the liver, kidneys, heart, lung, nervous system, gastrointestinal tract, skin, or muscles. Acute As toxicity may be also associated with psychosis, seizures, peripheral neuropathy, and encephalopathy. Regarding chronic As exposure, it may lead to peripheral neuropathy, alterations in behaviour, cognitive impairment, or memory loss. Notably, As toxicity may cause malignancies [60-62].

Ersbøll et al. (2018) in a cohort study revealed that As exposure through drinking water at relatively low As concentrations (not exceeding 50 μg/l) is associated with an increased incidence rate of ischemic and hemorrhagic stroke in Denmark. The dependence was stronger for ischemic stroke [63]. Similarly, Lisabeth et al. (2010) showed that low-level As exposure through drinking water may cause a higher risk of hospital admissions for ischemic stroke in Michigan. However, the authors noted similar results for duodenal ulcer and hernia (nonvascular outcomes), indicating that an association between low-dose As and stroke may react with unmeasured confounders or it may ensue from ecological bias. On the other hand, the authors revealed that in regions with more raised As concentrations in drinking water, an association between As and stroke incidence was more apparent in adjusted analyses. Furthermore, in these regions associations between As and nonvascular outcomes appeared to be negative [64]. Furthermore, Moon et al. (2012) showed in their analysis an increased risk of stroke following high As levels exposure (As concentrations in drinking water beyond 50 μg/l) [65].

Mochizuki et al. (2019) explored the relationship between peripheral neuropathy and drinking water contamination by low-dose As in Myanmar. Subjective and objective symptoms were investigated [66]. The feeling of weakness, chronic numbness, and pain appeared at very low As levels in drinking water (As concentrations were approximately 10 ppb (parts per billion)), whereas objective disturbances of small and large peripheral nerve fibers as pain and vibration sensations impairment appeared at As levels in drinking water beyond 50 ppb. The authors concluded that a threshold of 10 ppb, set by the WHO has appeared to be relevant to preclude adverse health effects, including peripheral neuropathy. Peripheral neuropathy related to As exposure through drinking water was also reported in other studies [67,68]. As contaminated drinking water may also cause optic neuropathy [69,70].

Li et al. (2020) explored the accumulation of As in various murine tissues, including different regions of the brain. Mice were exposed to 0, 25, 50, 100, and 200 mg/l iAs concentrations in drinking water during 1- and 12-month duration periods. The study revealed that total arsenic (TAs) levels in the tissues increased in a dose-dependent manner during long-term As exposition, while the higher As content was observed in the urinary bladder and further in the brain, lung, liver, and kidneys in descending order with the lowest As content in the spleen. Interestingly, in the hippocampus there were observed exceedingly higher levels of monomethylated acid (MMA) – a metabolite of iAs than in other investigated regions of the brain (cerebral cortex and cerebellum). In both the cerebellum and cerebral cortex iAs and its metabolite - dimethylated acid (DMA) were found, while DMA was the only one As species in the cerebral cortex deposited during 1 month.. Notably, iAs and DMA occurred in all brain regions, while DMA appeared as the prevailing form. The authors concluded that long-term As exposure leads to tissue-specific deposits of iAs and its methylated metabolites, and the brain reveals heterogeneity for arsenic species accumulation within different regions [71].

8. Barium

Barium (Ba) appears to be the 14th most common element in the Earth's crust, occurring naturally as ore deposits and in the rocks. Owing to considerable chemical reactivity, it emerges naturally in the form of salts, never as a free elementary body. Routes of human uptake remain oral exposition (through food and drinking water), inhalation, and skin contact, food being the main source of Ba exposure. However, Ba-contaminated water may significantly influence total Ba intake [27,72].

The WHO recommends a guideline value for Ba in drinking water at a level of 1300 μg/l. However, concentrations measured in drinking water appeared to be generally less than 100 μg/l [27].

Oral Ba exposure may lead to various health complications and cause even death, which has been reported during accidental or intentional consumption of barium salts. Cardiovascular, gastrointestinal,

musculoskeletal, or metabolic disturbances as hypokalemia following Ba intake were noted. Regarding neurological effects, Ba toxicity may manifest in numbness and tingling around the neck and mouth, partial or entire paralysis, and a lack of deep tendon reflexes. Brain congestion and edema following barium sulfide poisoning were also described [72,73]. Nevertheless, animal studies did not reveal any meaningful changes in the brain weight or histopathology of rats exposed to high doses (up to 450000 μg /kg/day) of Ba through drinking water [73].

Ohgami et al. (2012) explored the association between exposition to low-dose Ba by drinking water and hearing loss in mice. The authors revealed that even low Ba dose (ranging from 140 to 1400 μg/kg/day) induced heavy hearing impairment with severe degeneration of inner and outer hair cells, stria vascularis, and spiral ganglion neurons. Morphological analysis showed significantly higher Ba levels in the inner ears of rats exposed to Ba than in the control group. Interestingly, Ba levels in the cerebrum, cerebellum, liver, kidneys, and heart were undetectable in both Ba-exposed and control groups. The authors concluded that consumption of drinking water contaminated by low Ba dose leads to distinctive Ba affinity to murine inner ears that results in heavy ototoxicity [74].

Fenu et al. (2021) described a case of suicide by oral ingestion of a "couple scoops" of barium acetate mingled with water. Exceedingly low potassium level (1.4 mmol/l) following Ba ingestion resulted in fatal arrhythmia with asystolic arrest. A subsequent autopsy revealed histological changes in the liver, heart, lungs, and kidneys, but with no distinctive alterations in the brain. Postmortem peripheral blood analysis revealed Ba concentration at level 13 mg/l (13000 μg/l) [75].

Undoubtedly, Ba exposure through drinking water exerts serious adverse health effects; however, further comprehensive investigations are needed, particularly in the field of neurological problems [76].

9. Beryllium

Beryllium (Be) appears as one of the most toxic human body chemical substances [39]. Earth's crust Be content ranges from 2.8 to 5.0 mg/kg. The presence of Be in the water is mainly associated with industry contamination or weathering of soils and rocks. Beryllium oxides and hydroxides are insoluble in a normal pH range and hence Be content in the water remains at a trace level [27,39,77]. The WHO in the fourth edition of the Guidelines for drinking-water quality (2017) has denoted that Be concentrations in drinking water were below the level causing any health concerns and therefore guideline value has not been established. However, it was mentioned that 12 μg/l might be recognized as a health-based Be concentration value [27]. Be exposure may be through inhalational, oral, or dermal routes. However, there are no solid data regarding oral Be toxicity in humans. Animal studies revealed that the target organs for Be after oral exposition were the skeletal system and gastrointestinal tract [77]. Pulmonary disturbances, including lung cancer, following Be inhalational exposure, were well-established in humans. However, there remains a paucity of any data regarding neurological or psychiatric disorders following Be oral exposure through drinking water [77,78].

10. Lithium

Lithium (Li) as a pure element is the lightest metal and is characterized by high reactivity. Naturally, Li occurs as stable salts and minerals in the pegmatites or brines. Li concentrations in surface waters are usually low (< 0.04 mg/l), while concentrations in drinking water may range from 1 to 10 μg/l (0.001 – 0.01 mg/l). Sources of Li to surface- or groundwater may be associated with human activities such as waste disposal or chemical manufacturing [79].

Lithium salts are commonly used as a remedy in the treatment of bipolar disorder [80].

It was noticed that Li-contained drinking water might play a protective role owing to neuropsychiatric disorders [81]. There is a wide range of studies, strongly indicating that higher Li concentrations in drinking water are associated with lower suicide rates and suicide mortality [82-85]; however, several surveys revealed no association between Li in drinking water and suicide [86,87]. Average Li concentrations in the studies appeared to be between 0.48 and 27.4 μg/l [81]. Additionally, Schrauzer and Shrestha (1990) revealed that incidence rates of not only suicide but also homicide, rape, and other crimes such as burglary, robbery, and theft were significantly elevated in Texas counties where drinking water supplies contained small amounts of Li compared to counties where Li concentrations exceeded 70 μg/l [88]. Similar results were revealed by Kohno et al. (2020) regarding crime rates [89], and Giotakos (2015) regarding homicide incidences [90]. Authors concluded that Li containing drinking water influences suicidal and violent criminal behaviour, and it may affect impulsiveness that mediates aggressiveness and suicidality [88,90].

Kessing et al. (2017) showed a non-linear association between long-term increased Li exposition through drinking water and a reduced incidence rate of dementia. At Li concentrations > 15 μg/l dementia appeared to be significantly less common than in the reference group (Li concentrations ranged from 2.0 to 5.0 μg/l) [91]. However, Parker et al. (2018) found no significant relationship between Li in groundwater (mean Li concentration at level 27.4 μg/l) and dementia or bipolar disorder [92]. Fajardo

et al. (2018) showed a significant increase over time in the age-adjusted Alzheimer's disease mortality rate in Texas, but mortality changes were depreciatingly associated with trace lithium levels. Lithium concentrations ranged from 3 to 539 μg/l. Taking into consideration the median Li concentration of 40 μg/l, the age-adjusted AD mortality rate was significantly elevated when Li levels were < 40 μg/l in comparison to Texas counties where Li levels were above 40 μg/l [93].

Schimodera et al. (2018) explored Li concentrations in tap water concerning psychotic experiences and distress among adolescents in Japan. The study revealed an inverse association between Li levels and psychotic experiences and distress related to these experiences, independently of depressive symptoms. The authors claimed that lithium-rich water consumption might be a virtual public health strategy for the prevention of psychotic symptoms and distress, especially among the population of adolescents [94]. A little before the above-mentioned study, Ando et al. (2017), exploring a population of adolescents, revealed that Li concentrations in tap water were inversely related to depressive symptoms and interpersonal violence [95].

Eyre-Watt et al. (2021) in their meta-analysis found that increased Li concentrations in drinking water were linked with fewer psychiatric hospital admissions [81].

Interestingly, unlike the aforementioned studies, Shullehner (2019) observed a positive correlation between Li levels in drinking water and schizophrenia, and schizophrenia spectrum disorder (SSD), indicating adverse health effects associated with Li exposure through drinking water. Li concentrations in this study ranged from 0.6 to 30.7 μg/l. Furthermore, no association between Li concentrations in drinking water and bipolar disorder was found [96].

Brown et al. (2018) found a quaint hypothesis that psychiatric benefits related to lithium exposure through drinking water may be associated with the alleviation of lead (Pb) neurotoxicity by lithium. Based on the literature review, the authors supported their hypothesis, indicating further investigation is necessary to prove it clearly [97].

11. Manganese

Manganese (Mn) is one of the most common occurring metals in the Earth's crust and it is widely used by humans in the industry. Mn appears as an essential element for the human body, playing an important role in gluconeogenesis, reactive oxygen species (ROS) combating, or ammonia metabolism, especially in the brain, as a component of glutamine synthetase [27,98]. Daily adequate intake of manganese has been established to be at levels 2.3 mg for adult men and 1.8 mg for adult women [99]. Food is the most important source of daily dietary Mn intake [27,98]. Mn is naturally present in surface water and groundwater, especially under anaerobic conditions. Owing to a paucity of health problems at concentrations usually causing permissibility troubles in drinking water, the WHO has not established a formal guideline value for manganese; however, a health-based value at levels of 0.4 mg/l has been proposed. Additionally, back to permissibility troubles, Mn concentrations higher than 0.1 mg/l might cause improper water taste, and blots on laundry or sanitary ware that seem to be immediately noticed by water consumers, and hence suggested value of 0.4 mg/l has appeared to be safe enough [27].

It is currently well established that Mn overexposure, especially through the occupational inhalational route, may lead to neurotoxicity [100-103]. Exposition via drinking water appears to be, however, also an important source of Mn toxicity [104].

Mn overexposure through drinking water might be associated with neurobehavioral disturbances in children [105]. Schullehner et al. (2020) showed that exposition to increasing Mn concentrations in drinking water during childhood was associated with an elevated risk of attention-deficit hyperactivity disorder (ADHD), particularly the ADHD-inattentive subtype. Increased ADHD risk was found to be at Mn concentrations in drinking water below the proposed by the WHO guideline value of 0.4 mg/l [106]. Elevated Mn concentrations are also associated with deficiencies in IQ scores in children [107,108]. Kullar et al. (2019) reported the benchmark concentration (BMC) for Mn in drinking water at a level of 133 μg/l, leading to a reduction of 1% in Performance IQ score, BMC at a level of 266 μg/l led to a reduction of 2%, and reduction of 5% was associated with BMC at the level of 676 μg/l [109]. Rahman et al. (2017) found that increased prenatal Mn exposure through drinking water (but Mn concentrations <3 mg/l) affected positively cognitive function in girls, but boys were unaffected. However, prenatal and early life exposure to increased Mn levels in drinking water was associated with a higher risk of behaviour disturbances at 10 years of age. The median Mn concentrations appeared to be at the level of 0.2 mg/l during pregnancy, and 0.34 mg/l at 10 years of age [110].

Considering the above-mentioned studies and explored Mn concentrations, there appears to be a necessity for establishing formal guideline values for Mn in drinking water, especially to protect children from Mn neurotoxicity [106,109].

12. Bismuth (Bi)

This heavy metal is not crucial to human existence and it is mainly used in tumours treatment. It was reported, that after therapy with Bi, the patient was feeling fatigued, puzzled, apathetic, and forgetful, as well as experienced spasms in his thigh muscles [111]. Both

concentration levels and studies on the effect, that Bi from drinking water has on the human body, are currently not available. Bismuth thiol (BT) was intended to be used in the removal of major contaminants from drinking water [112]. There are no recommended values, but the risk-reducing Bi concentration is suggested to be less than 0.001 mg/L [113,114].

It is suggested, that high levels of cortical intracellular bismuth cause a "cortical inhibition" which initiates suppression of regular electrical brain activity, as well as the absence of EEG paroxysmal phenomena in myoclonic jerks, and explains rare epileptic seizures among such patients [115]. In the described case of rare bismuth encephalopathy after 20-year bismuth subsalicylate therapy, the patient developed subacute encephalopathy and myoclonus. However, due to supportive treatment and bismuth intake cessation, the patient made a full recovery within weeks [116,117].

13. Bromate (BrO3)

The presence of BrO3 is not essential for the human body. It is a powerful oxidizer, and as such it irritates mucous organs and skin. The main targets of this particle isare the kidneys [118]. BrO3 is believed to have a carcinogenic effect on human tissues [113]. Its presence in drinking water is a by-product of bromine oxidation reaction with ozone, and concentrated hypochlorite solutions [119]. When present at levels, that are numerous times higher than its standard concentration, BrO3 can cause sore throat, cough, vomiting, diarrhoea, and possibly even cancer [120]. Bromate reacts forcefully with trihalomethanes (THM) precursors, resulting in creating their final form, that is supposedly causing cancer; furthermore, the relation between THMs, reverse reproductive outcomes, and congenital anomalies are also considered [121-123]. Researchers similarly found a moderate connotation between bladder cancer and average daily consumption, as well as cumulative intake of THMs [124]. The upper concentration level limit for BrO3 is estimated to be less than 0.01 mg/L [113,114].

It has been reported, that exposure to KBrO3 causes behavioural shortages demonstrated as decreases in the maximum speed, total distance travelled, and body rotation of the mice. The toxicity induces the disruption of neuromuscular junction coordination. Moreover, KBrO3 induces oxidative stress in the cerebellum, resulting in significant learning and memory impairments [125].

14. Cadmium (Cd)

Cd, which co-exists with zinc in the Earth's crust, is not an essential bodily element. Exposure to Cd mostly results from consumption of contaminated food, tobacco smoke, or inhalation [126]. Cadmium interacts with several other elements. Its preservation and uptake are reduced by proper iron levels [127]. Cd-induced hypercholesterolemia can be eased with an extra dosage of copper [128]. Because of the fact, that Cd accumulates in the kidneys, high intake can cause renal dysfunction and high blood pressure [129]. Cadmium is highly toxic and highly soluble in water, therefore even low levels of its intake may cause acute gastroenteritis [130], renal tubular dysfunction, and renal cancer [131,132]. Because of Cd's 10-35-year biological half-life, excellent bioavailability, and accumulation, the human body is very susceptible to its acute toxicity [133,134]. Additionally, Cd exposure has non-carcinogenic effects, such as chronic kidney disease, hypertension, diabetes, bone defects, and macular degeneration [135,136]. The WHO classified Cd as a human carcinogen [126]. The suggested upper limit of Cd concentration appears to be less than 0.003 mg/L [113,114].

Cd-dependent neurotoxicity has been associated with neurodegenerative diseases such as Alzheimer's and Parkinson's diseases, amyotrophic lateral sclerosis, and multiple sclerosis. At the cellular level, Cd affects cellular proliferation, as well as differentiation and apoptosis. Cadmium interferences in DNA repair mechanisms and the production of reactive oxygen forms [137]. Studies showed, that patients with ADHD inattentive type (ADHD-I) demonstrated high cadmium levels and that they were negatively correlated with the Full Scale Intelligence Quotient. Therefore, cadmium is associated with susceptibility to ADHD and symptom severity in school-age children [138].

15. Cyanide (CN)

CN intake might have deadly effects on the human body, due to its stable complex with cytochrome oxidase, an enzyme promoting the transport of electrons in the mitochondria during ATP synthesis in the respiratory process. Acute poisoning appears shortly after oral intake. Symptoms of such an incident include anxiety, rapid breathing, nausea, vomiting, headache, spasms, and other neurological outcomes, such as coma [139]. CN can trigger vitamin B12 deficiency, as well as chronic neural and thyroid effects, with hypothyroidism and goiter. CN is sporadically found in drinking water, mainly as a result of industrial contamination. Long-term exposure through drinking water may have a negative impact on the thyroid gland and the nervous system. It can also initiate weight loss and diabetes [140,141]. The WHO introduces a possible short-term health-based guide value of 0.5 mg/L [113].

Neurological manifestations of CN toxicity often occur before CN-induced cardiac arrest. The acute neural displays of this intoxication are very similar to

those observed in hypoxia or anoxia. They consist of sudden coma and seizures with early medullary neuron depression, which is the cause of apnoea and gasping. Long-term nervous sequelae are infrequent and they range from minor cognitive dysfunctions to profound motor, visual, or memory deficits, like the effects of postanoxic injury. The scientists observed that rats with neurological deficits after acute CN intoxication presented lesions affecting areas of the brain akin to those found after ischemia: diffuse lesions of the hippocampus, cerebellum, cortex, and subcortical nuclei. However, those lesions were only present in rats with a clinical deficit [142-144].

16. Germanium (Ge)

Germanium is not a vital particle, with low acute toxicity. Nevertheless, at least 31 reported human cases linked long-term oral intake of germanium with renal failure and even death. Signs of kidney dysfunction, kidney tubular degeneration, and germanium accumulation were observed. Anemia, muscle weakness, and peripheral neuropathy were among other undesirable effects. Renal function recovery is gradual and incomplete even long after ingestion is stopped [145,146]. The azaspiran organogermanium compound, 2-aza-8-germanspiro [114,115] decane-2-propamine-8,8-diethyl-N,N-dimethyl dichloride (spirogermanium), has been found to cause both neurotoxicity and pulmonary toxicity in phase I and II studies examining its potential chemotherapeutic use as an antitumor drug [147]. Scientific studies on Ge in drinking water are not available. The suggested upper limit of Ge concentration is indicated to be less than 0.01 mg/L.

In the cited publication, the authors reported five patients, who have taken inorganic germanium preparations for a prolonged period. In presented cases, the renal function deteriorated without proteinuria or haematuria. Histological examination of the kidneys showed widespread tubular degeneration and interstitial fibrosis with minor glomerular abnormalities. Most patients had gastrointestinal symptoms, such as vomiting, anorexia, and weight loss. Furthermore, one patient suffered from peripheral neuropathy and myopathy. A significant amount of germanium was found in patients' hair or nails. The cases showed that abuse of inorganic germanium compounds can cause renal damage with various extrarenal manifestations [148].

17. Lead (Pb)

Pb is a cumulative toxic substance, that can severely affect the central nervous system, cause high blood pressure, and have a negative impact on red blood cell production. It also disturbs kidney function and decreases bone calcification. When ingested, Pb is easier absorbed in children than in adults and can result in decreased IQ, hyperactivity as well as depression [149-151]. The average daily intake of Pb is estimated around 20–25 µg [152]. Until 1965, Pb pipes were installed in some countries between the mains and the house taps. Low mineralized water is not stable, and because of that, it is highly aggressive to piping materials. Population and toxicokinetic modelling research have linked water lead levels and blood lead levels in children at low levels of lead in drinking water [153]. Pb levels in drinking water can be reduced by flushing before use. Around 25% of domestic dwellings in the EU, except in the Nordic countries, have Pb pipes, potentially putting millions of people at risk of Pb exposure [154]. During the Washington DC "lead crisis" in the years 2000–2004, when the Pb levels in drinking water were the highest, foetal death rates were drastically elevated [155]. Even a low dosage of Pb can cause difficulty in learning, decreased body height, impaired hearing, and impaired formation and function of children's blood cells [156]. Consumption of Pb from drinking water during pregnancy might lead to reduced growth of the foetus or premature birth [157]. The EU and WHO guideline intake value of Pb is 0.01 mg/L. Suggested Pb absorption is said to be less than 0.005 mg/L [113,114].

Scientists claim that low-level exposures and blood lead levels, which were previously considered normal, are causative factors in cognitive dysfunction, neurobehavioral disorders, neurological damage, hypertension, and renal impairment [158]. Lead blood concentrations at or below 10 µg/dL generated neurophysiological and neurobehavioral deficits that could affect academic outcomes. They included: distractibility, memory deficits, decreased verbal and quantitative scores, weakened visual-motor coordination, and extended reaction times [159,160]. Moreover, lead can also affect educational achievement by the increase of behavioural problems. Lead exposure during infancy has long been linked to violent, disruptive, and unpredictable behaviour that contributes to academic failure and school dismissal [161,162]. Furthermore, environmental lead exposure was related to impulsivity among the clinical features of ADHD. As a result, we may associate postnatal exposure with a higher risk of clinical ADHD [163]. Additionally, lead that accumulates over a lifetime generates negative cognitive consequences in the elderly. Pb, stored in bones, is released due to osteoporosis, in the process of decalcification. Studies confirm that lead exposure early in life produces latent cognitive effects that emerge later in life in the form of Alzheimer's disease [164,165].

18. Mercury (Hg)

This heavy metal is not a crucial element in the

human body. Its average daily intake ranges from 2 to 20 μg/day [166]. Hg was formerly used in medicine, but this aspect changed after its devastating poisoning effect on humans and animals was reported. Nowadays, Hg is one of the strongest known neurotoxins, having numerous harmful health effects on animals and humans [167]. Organic Hg compounds are easier to absorb. Food contaminated with methyl mercury (a product of its bacterial conversion) may cause neurological disorders and difficulties in development among children exposed in utero [168,169]. Skin rashes and dermatitis, mood swings, irrationality, memory loss, mental disorders, muscle weakness, gastrointestinal tract, and kidney damage may all be a result of high exposures to inorganic Hg [170]. The heavy metal's natural concentrations in both groundwater and surface water are lower than 0.5 μg/L [171]. Hence, Hg in drinking water is believed to be a minor exposure source. Risk-reducing Hg absorption appears to be less than 0.001 mg/L [113,114].

Mercury pollution in large waterways leads to methylmercury contamination of aquatic organisms, and human intoxication upon their consumption. As for healthcare-related exposures, dental amalgams (often comprised of up to 50% elemental mercury) release mercury vapor which is inhaled and eventually deposited as methylmercury over many years, often leading to clinical manifestations of chronic mercury toxicity. The symptoms can progress from paraesthesia, decreased sense of taste or hearing, fatigue, headaches, hypertension, and immune dysregulation to severe symptoms such as tremors, anaemia, psychoses, renal failure, or Alzheimer's disease [172,173]. In addition, mercury poisoning causes central nervous system damage and demyelinating polyneuropathy. Researchers described a patient with daily exposure to mercury in skin lightening cream and hair dyes who was diagnosed with Guillain-Barre syndrome and then developed nephrotic syndrome because of membranous neuropathy. Mercury components are claimed to have an immunomodulatory activity, which is involved in both peripheral neuropathy and glomerulonephritis [174]. Another study, that involved multivariate linear regression analysis, with adjustment for covariates, was used to assess the relationship between verbal, performance, and total IQ in children and blood mercury levels of mothers during late pregnancy. The results indicated, that a doubling of blood mercury was associated with the decrease in verbal and total IQ. This inverted association remained after adjustment for blood lead concentration. In conclusion, the high maternal blood mercury level is associated with low verbal IQ in children [175].

19. Nickel (Ni)

Nickel is a transition element that is not particularly crucial for the human organism. It can even be toxic because of contamination of water and soil [176]. Ni is an immunotoxic and carcinogenic substance that can have a range of negative health consequences on the body, including contact and spongiotic dermatitis, cardiovascular illness, asthma, lung fibrosis, and respiratory tract cancer, depending on the dose and duration of exposure [177].

One of the primary targets of Ni toxicity is the neurological system; in fact, it can accumulate in the brain [178]. Ni2+ exposure can affect glutamate NMDA receptors and dopamine release (both stimulating and inhibiting it) [179]. Few studies suggest that Ni2+ has an impact on serotonin and GBA neurotransmission. Rodents exposed to Ni2+ experience changes in their motor function, learning, and memory, as well as anxiety and depressive-like symptoms. However, no research on the dose-dependent association between these effects and the concentrations of Ni2+ in the brain, blood, or urine has been made.

What is more, this widely used industry element can induce the process of carcinogenesis because of epigenetic effects that can affect gene expression. Nickel compounds can cause histone hyperphosphorylation, hypermethylation, and hyperubiquitination [180-182]. In vitro studies demonstrated Ni sulphate's ability to cause apoptosis in human hepatoma cells, human T hybridoma cells, and human breast cancer [183-185]. It also affects intestinal microbiota and increases the chances of gastric diseases [186]. There were conducted several studies on rats and hamsters demonstrating toxic effects on the reproductive system [187,188]. Nickel changes Zinc metabolism, which is crucial for sperm quality [189]. However, it is a microelement that participates in the proper functioning of lipid metabolism or the hormonal system [190].

20. Nitrite

Nitrite is a chemical compound that is commonly used in pharmaceutical industries. It also has some benefits for human health. It can prevent civil and lifestyle diseases. Nitrite also plays a crucial role in neonatal development. The content of nitrate in breast milk is counterbalanced by the lack of this endogenic compound during the neonatal period [191]. Nitrite is also important for human health due to its therapeutic influence on hypertension therapy. By being an alternative source of NO (nitric oxide), it has a positive influence on vascular endothelium and the whole cardiovascular system [192]. The generation of NO by the nitrate when endothelial nitric oxide synthase is not able to produce an adequate amount of this crucial compound

could be lifesaving [193]. The possibility of using it in ischemic disease therapy should be highlighted. Because of its positive effect on human endothelium, it can be used in ischemia-reperfusion diseases of the kidneys, heart, liver, or brain [194].

21. Uranium

Uranium (U) is a radioactive element used in the nuclear industry such as power stations or may be potentially a weapon. This element has a huge carcinogenic effect. For instance, workers who were exposed to high U rate, more often died due to cancers and other systemic diseases [195]. The presence of this element in drinking water should be alarming because of the tragic consequences of uranium's influence on the human body. Radiation exposure may lead to kidney diseases or fertility problems [196]. What is more interesting, after such exposure, U may be stored in the human monoaminergic system. However, the exact result and potential toxicity of this radioactive piece are not yet understood [197]. Ma et al. suggest that higher levels of U may be one of the factors linked to the increased risk of schizophrenia in the comparative study [198].

22. Discussion

This article discusses the numerous health hazards associated with the mechanisms and effects of trace elements, specifically heavy metals found in contaminated water. In the following review, we discussed several elements including aluminium, antimony, arsenic, barium, beryllium, lithium, manganese, bismuth, cadmium, lead, mercury, and nickel, along with compounds such as ammonia, bromate, cyanide, and nitrate. Some of the discussed elements, such as aluminum, arsenic, lithium, nickel, and more, have been suggested to be risk factors for psychoneurological disorders. The general mechanism involved in metal-induced toxicity is recognized to be the production of reactive oxygen species resulting in oxidative damage and health-related adverse effects such as changes in the pathological molecular pathways and the onset of various disorders. In our paper, we discussed the results of various studies throughout recent years regarding the relationship between the intake of drinking water, its elemental composition, and the potential onset of neuropsychiatric disorders. Several elements, namely aluminium, cadmium, or lead, have been linked with Alzheimer's disease. Contrarily, high concentrations of lithium might alleviate the symptoms of dementia and even reduce its risk and incidence. Excessive cumulation of manganese or lead might be associated with the onset of ADHD while elevated concentrations of manganese and mercury – with disturbed IQ scores in children.

The elements discussed in this review can be found in drinking water, sometimes even in amounts that exceed the concentrations that are assumed as safe for human health. This is because of the pollution and toxic substances that constitute the growing hazard of the current world. Even though there are restrictions provided by the WHO for example, toxic pollutions significantly affects the quality of drinking water and thus potentially hazardous effects on human health. In fact, the potential threats might not be even yet comprehended for us because we are not truly sure what concentrations can possibly cause changes in our health and whether they are reversible or not. There are also knowledge gaps regarding the mechanism of chosen elements' action in the human organism – whether and if particular elements act agonistically or antagonistically and in what concentrations such actions might appear. We also do not know how the combination of the abovementioned elements in our organism and also what mechanisms might lead to the potential onset of neuropsychiatric disorders.

Furthermore, another problem is the fact that there are discrepancies regarding the concentrations assumed as 'safe' for human health between the organizations such as the WHO or the European Union, indicating that standardization of those values is of great importance to provide credible information for the general public. What i's more, some of the elements in drinking water do not have any reference values, which should also be further evaluated by scientists and afterward provided for the general public. To guarantee the general population access to safe drinking water, contaminated water must be evaluated before its release into the environment. Public education and awareness of exposure routes are crucial for preventing additional exposure and prevention of the potential onset of various psychoneurological disorders. The review highlights the importance of examining water consistency worldwide and the need for further investigations. To ensure that human health is safe from the effects and dangers of heavy metals and other elements, further studies will be required in the future.

Conflict of interest

The authors have declared no conflict of interest.

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