Emergent Materials (2021) 4:1275–1294
https://doi.org/10.1007/s42247-021-00268-5

REVIEW

Origin, fate, and risk assessment of emerging contaminants in groundwater bodies: a holistic review

Yash Vaddoriya[1] · Vishwa Patel[1] · Prit Patel[1] · Maheshree Gohil[1] · Cathrine Gono[1] · Kelvin Mgaiwa[1] · Manan Shah[1]

Received: 25 February 2021 / Accepted: 5 July 2021 / Published online: 26 October 2021

Abstract

Groundwater is one of the primary and most safe sources of freshwater supplies to sustain human life. Emerging contaminants (ECs) including pharmaceutical contaminants (PhACs), personal care products (PCPs), endocrine-disrupting compounds (EDCs), synthetic chemicals, and artificial sweeteners (ASWs) are detected in groundwater supplies in trace amounts, raising concerns about the possible adverse effects on humans and the ecosystem; thus, surveillance of contaminants is important to minimize risks. Therefore, this paper reviews more than 50 studies (2000–2020) that provide accurate and analytical information on PhACs and their composition in groundwater. In specific, detailed data on the occurrence and impact of ECs in various water body matrices are systematically analyzed and classified with respect to distinct groups (PhACs, PCPs, EDCs, ASWs, etc.). The main objective of this study is to (1) evaluate groundwater contamination via depicting occurrence and classification of PhACs as ECs, (2) analyze the health and ecological risk due to emerging PhACs, and (3) showcase challenges faced by industries and future prospects for further research on PhACs. The correlation between the occurrence of PhACs and their related health and ecological risks can be easily understood by this paper, which opens a new gateway to discover analytical strategies for future surveillance research works and to fill in the research gaps found in the existing state of knowledge on PhACs.

Keywords Groundwater · Emerging contaminants · Pharmaceuticals · Personal care products · Health risk · Ecological risk

1 Introduction

Groundwater has been a significant source of water for sustaining human life throughout history [1]. Since the weather patterns are buffered from short-term fluctuations, groundwater is often considered a secure and reliable resource [2]. Groundwater is the most crucial factor and represents about two-thirds of the world's freshwater supplies and, neglecting the polar ice caps and glaciers, groundwater contributes to all freshwater available. Nearly, 70% of the world's groundwater collected is used for cultivation, 38% of irrigated land is fit for groundwater irrigation, and about half of the domestic intake of human water in urban areas is groundwater [2–4]. It is estimated that nearly 90% of the water used for drinking purpose is from groundwater at the area where there is no such plan distributed by the water department of the government or by any of the private water supply companies [5]. In India, currently 60% of freshwater is from groundwater and due to growing population groundwater will be soon at alarming levels which can lead to the water crisis, so in this situation, humans cannot afford contamination of groundwater or any other source, but in the frame of modernization, such issues are neglected and in the long term, it will lead to destructions of mankind [6]. Owing to numerous agricultural processes and anthropogenic sources, a growing number of emerging contaminants (ECs) and anthropogenic compounds are found in groundwater [7–9].

The rise in environmental levels of pharmacological compounds and their possible harmful effects on biological processes are global phenomena that would bring greater challenges to countries with high population growth rates. The insertion of pharmacological agents into animals and habitats poses a risk to genetic diversity, habitat diversity, and population diversity [10]. Thus, the long-term toxicity triggered by these pharmaceutical contaminants (PhACs) could not be overlooked and more precise examinations are needed to examine its side effects on human, aquatic, and animal health by means of detailed surveillance and toxicological studies

---

✉ Manan Shah
manan.shah@spt.pdpu.ac.in

[1] Department of Chemical Engineering, School of Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India 382426

[11–14]. Therefore, this paper reviews more than 50 studies that provide accurate and analytical data on PhACs and their groundwater composition (Tables 1 and 2). Our main objective is (1) evaluating groundwater contamination by providing data on occurrence and classification of PhACs, (2) systematically presenting the impact and risks of PhACs on humans and the environment, and (3) highlighting challenges faced by industries and future scope on further research on PhACs.

Due to rapid urbanization and development, water bodies are prone to be a hub of anthropogenic contaminants including nanograms of PhACs to huge portion of microplastics indicating severe concerns [38, 39]. Subsequently, ECs are nowadays known to be widely spread in a vast array of solid (soil, food, dregs) and liquid (river, ocean, ponds, groundwater, effluent of WWTP and DWTP) matrices exhibiting their unbound transmission [40–53]. A broad variety of chemical substances, primarily from PhACs and pharmaceuticals and personal care products (PPCPs), polymers, dietary supplements, food additives, cleaning products, surfactants, antiseptics, fire retardants, pollutants, and disinfection by-products, are covered by contaminants of emerging concerns [54].

Nearly all ECs are primarily a derivation from the contaminants resulting from the following categories: PhACs, PCPs, endocrine-disrupting compounds (EDCs), and pesticides [8, 40, 41, 43–45, 47, 49, 50, 52, 55–68]. ECs might be of some industrial origin and may come from household, agrarian, medical clinic research facility wastewater,

Table 1 Occurrence of pharmaceutical contaminants according to different therapeutic groups

Groups	Region of CTs	CTs	Occurrence	Conc. in water measured	Impact	References
Antibiotic	Okhla, Delhi	Ciprofloxacin	• Effluent discharged from pharma industries sewage pipes	0.012–1.5 mg/L	• Decline in genetic diversity of algal communities and threat to other aquatic organisms	Wilson et al. [15], Balakrishna et al. [16]
Anti-inflammatory	Pearl River, China	Diclofenac	• Enter water system through hospital sewage pipes and dead vaccinated animals died near water bodies	8.3–114 μg/L	• Extinction of several Asian subcontinent vulture species • Cause heart-related diseases	Peng et al. [17]
Anti-microbial agent, antiseptics, and disinfectants	River, Brazil	Triclosan and tricarban	• Agriculture waste by wash out of soil during to monsoon • Domestic waste through city sewage pipes	4.54–61.3 ng/L	• Growth inhibition of algae • It causes microbial resistance and act as toxic or biotic agents	[19, 133] de Sousa et al. [20]
Anti-inflammatory	Marina Catchment, Singapore	Ibuprofen	• Sewage waste from pharma industries	2–76 μg/L	• It suppressed growth of plant and led root to being shorter • Affects the aquatic life of rivers especially fishes	Xu et al. [21]
Anti-epileptic drug	River, Bangladesh	Carbamazepine	• Pharma waste through pipes	8.8 ng/L	• It is toxic for various invertebrates and other organisms	Li et al. [22, 23]
Blood lipid regulator	Water treatment plant, Iran	Gemfibrozil	• Through hospital sewage pipes and from dumped medic waste in dumping yard	518–3720 ng/L	• Fishes such as Japanese medaka face reduction in viable eggs	Huggett et al. [24]
Anti-inflammatory	Seine River estuary, France	Ketoprofen	• Through hospital sewage system	< 2.4–33.2 μg/L	• It affects human healthNon-targeted terrestrial and aquatic species	Togola and Budzinski [25]
Endocrine-disrupting compound	River, China	Bisphenol A (BPA)	• Effluent from pharma industries	1131 ng/L	• It causes hormonal changes in rats • Such effects lead to breast cancer risk in human • It has androgenic effects that cause side effects in men	Dodds and Lawson (1938) Tan et al. [26]
Anti-inflammatory	Danube River, Hungary	Naproxen	• Veterinary hospital and pharma industrial waste	5.7–62 μg/L	• It is highly non-degradable • Target the lives of organism in a habitat due to long-term exposure	Helenkár et al. [27]

CTs, contaminants

Table 2 Environmental and human health impact of PhACs according to different therapeutic groups

Group	PhACs	Main use	Impact on environment	Impact on human health	References
Antibiotic	Amoxicillin Azithromycin Ciprofloxacin Cephalexin Natamycin Vancomycin Erythromycin Sulfamethoxazole Oxalinic acid	Veterinary Humans Humans Veterinary (dogs) Food additive Veterinary Human Veterinary (cattle, poultry) Veterinary (pigs) Plants Veterinary	• Decline in genetic diversity of algal communities and threat to other aquatic organisms • It affects the ecosystem including conversion of nitrogen to its oxides, methanogenesis, and reduce the amount of sulfate in the environment. • It also affects the micro-ecosystem including hormone alteration, resistance expansion to microbacteria, phylogenetic structure, and other ecological distribution	• It increases the chances of bacteria becoming resistant to medication of antibiotic due to which antibiotics do not affect them when it is needed • Its long-term consumption can affect the liver and stomach • High concentration in water leads to diarrhea and nausea • It also wipes out beneficial bacteria that help to regulate weight.	[28] Phillips et al. [29]
Anti- inflammatory	Ibuprofen Meloxicam Ketoprofen Diclofenac Indomethacin Celecoxib Sulindac piroxicam	Humans Humans Humans Humans Veterinary Humans Humans Humans Humans	• Its long-term exposure can cause chronic toxic effects in organisms • Causes adverse effect on living creatures and accumulation of toxic chemicals in the food chain • It suppressed growth of plants and led to root to being shorter • Diclofenac leads to extinction of several Asian subcontinent vulture species	• It causes kidney damage and cause diabetes and obesity • Its high concentration leads to exacerbating asthma • It contributes to chronic diseases such as heart diseases and blood vessel diseases	Carlsson et al. [30] Tan et al. [31]
Endocrine-disrupting compound	Estrone (E1) Estradiol (E2) Ethynyl-estradiol (EE2) Progesterone (P) Testosterone (T)	Majorly used for humans only	• It causes reproductive problems in various species • Estrogenic abnormalities in fishes and various other aquatic species • It can cause hormonal changes in various species	• It causes problem in reproduction such as decrease in fertility and abnormalities in the reproductive tract of male and female, and disturbs male/female sex ratios, loss of fetus, and menstrual problems • It changes hormonal levels which cause early puberty and several other problems • It also causes brain and behavior problems	Edward archer et al. [32] Malgorzata kajta et al. [33]
Anti-epileptic drug	Carbamazepine Clonazepam Diazepam Gabapentin Lamotrigine Lorazepam Pregabalin Valproic acid	Humans Humans Humans Humans Humans Humans Humans Humans	• Cause oxidation stress in rainbow trout. Carbamazepine is toxic for some algae, bacteria, invertebrates, and fishes	• It decreases the amount of platelets and leukocytes in the blood and increases the risk of fatal distress • It majorly affects children's neural development • Its high concentration can cause migraines headaches, neuropathic pain, and psychiatric disorders	Rezka et al. [34] Joyce A & Mattson Kimford J et al.
Antiseptics and disinfectants	Chlorhexidine Anti-bacterial dyes Metal peroxides Metal permanganates Halogenated phenol derivatives	Humans, Humans, veterinary (pets) Humans, veterinary (cattle, dogs) Humans, veterinary Humans, veterinary	• It effects the softness of water which lead to stone problems • Heavy metals such as mercury can cause serious physical and mental disorders in various organisms [35] • It reduces the oxygen level in water which somehow affects aquatic life [36]	• Its intake is harmful and causes stomach ache • Long-term intake can cause various disorders mentally and physically • Mercury in drinking water can cause disorders in next generations	Williams and White [37]

leachate from landfills, mines, quarries, wastewater treatment plants (WWTPs), and so on ([69, 40, 44, 70, 63, 71]. The large quantity of various pollutants relies upon the accessibility of their root sites, such as excess wastewater coming from pharma industries, medical clinics, dispensaries, and hospitals [8, 72–75].

Due to their widening uses in humans and animals, PhACs are emerging pollutants in the environment [76]. Oral narcotics and drugs travel through the human body ending up with concentrations in the bloodstream ranging from ng/L (e.g., carbamazepine) to μg/L (e.g., acesulfame). Therefore, PhACs remain inevitable as they are an integral part of contemporary civilization [15, 72, 77]. PhACs concentration in different water matrices covers few orders of magnitude: in industrial untreated water, it was found below ng/L; in raw wastewater, often measured in thousands μg/L; while in drinking water, usually in the ng/L range or its fraction [78–93]. The Global Water Research Coalition (a non-profit organization founded in 2002 that serves as the collaborative mechanism for water research) has rated various PhACs, such as carbamazepine, diclofenac, sulfamethoxazole, gemfibrozil, atenolol, erythromycin, ibuprofen, bezafibrate, and naproxen, as being of primary concern to PhACs in the hydrological cycle [40]. An enormous number of veterinary PhACs like anti-parasitic drugs, antibiotics, antifungal drugs, hormones, anti-inflammatory drugs, anesthetics, sedatives, and so forth set foot in the water resources worldwide and make a deep impact on non-target organisms including fish and plants [94]. PhACs can impact water quality by exceeding, persisting beyond predicted no effect concentration (PNEC—concentration limit below which no adverse effect will occur during long- or short-term exposure), and significantly affecting the availability of drinking water, environmental health, and the efficiency and EC removal cost of WWTPs [40, 64, 77, 95–97]. In surface water and the marine ecosystem, the involvement of human or veterinary PhACs is prolific [92, 98–104]. However, only based on specific compounds has the danger of drinkable water with PhACs been measured and there is a keen need to evaluate the long-term toxicity of these compounds [52, 105].

Owing to the growing use of PhACs in everyday life, PhACs are being pollutants to the environment due to which health and ecological risks increased [76]. Increasing PhACs in water bodies may have a significant impact on organisms and agriculture yield. Often, it is also possible for certain bacteria to build a resistant antimicrobial-antibiotic coating all over their cell, which can cause detrimental effects on the human body and other creature; for example, β-lactam anti-infection agents can cause harmful effects on green algae [106–108]. Less concentration of multiple PhACs mixtures on water biota can result in acute and long-term damage, behavioral changes, tissue aggregation, reproductive damage, and cell proliferation reduction [12]. Hazardous impacts on non-targeting species such as marine environments comprising freshwater algae, zooplankton, and phytoplankton are increasing with the application of vast quantities of antibiotics for humans and animals [109–113]. Such chemicals induce hermaphroditism in marine organisms, which can contribute to effects on freshwater organisms (amphibians and fish), animals, and humans. It also increases possibilities for human testicular and breast cancers [114, 115].

2 Origin and classification of groundwater contaminants

The major burden has been applied to groundwater infrastructure because of rising pollution and depletion of surface water supply [116]. If we consider how ECs are produced and their source or origin and embrace the prevention methods, pollutants that have adverse effects on humans and the environment may be minimized. They include toxins, PhACs, synthetic chemicals, PCPs, aromatic, nicotine, and many more that have a major impact on the ecosystem and human health [117, 118]. The origin of water contaminants can be traced to their occurrence on earth, the conversion of natural materials, and their synthesis [119].

Contaminants can be classified based on the following:

(1) Occurring process:

(a) Naturally occurring contaminants:

Natural contaminants are produced due to long-term contamination of natural compounds by microorganisms and such contaminants may be poisonous or can lead to chronic diseases [54]. Substances like natural antibiotics and hormones may have a significant impact on ecosystems [119–121].

(b) Man-made or anthropogenic contaminants:

Anthropogenic contaminants have a large variety of compounds as their production and discharge in water, land, and atmosphere is more. This can further be classified into PCPs, natural and synthetic hormone and steroids, pesticides, dietary supplements, wood additives, cleaning products, surfactants, antiseptics, fire retardants, pollutants, NO_3, NH_4Cl, dissolved organic carbon, SO_4, aromatic, and halogenated hydrocarbons [54, 121].

(2) Sources:

(a) By the release path:

It includes contaminants originating from discharge sources, transport sources, injection wells (pathogens NO_3, NH_4, Cl, brine disposal, drainage), septic tanks, cesspools, wastewater, and its by-products (e.g., spray irrigation, sludge). Leachate from garbage dumps, septic systems, and sewage pipes and water management for irrigated agriculture are minor antibiotic sources [114, 122, 123].

(b) By origin:

It comprises contaminants from domestic and agricultural sources, landfills, hazardous and non-hazardous liquid waste (e.g., brine, sludge), mining waste tailings, material stockpiles (coal, salt, etc.), illegal dumps, spills, leaks, radioactive disposal sites, graveyards, mobile containers, etc.

(iii) By chemical form:

Contaminants based on their properties and chemical type occurring from various sources such as hydrocarbons and pesticides are categorized.

(iv) By point of location:

Contaminants in this category are classified based on their presence above or below ground surface (containing contaminants from injection wells). An important cause of ECs in groundwater appears to be the penetration of contaminated wastewater to the subsurface or below ground level [124–126].

(e) By character:

Contaminants can be classified by their character based on point, diffuse, and line sources. Point sources and diffuse sources are the main sources of water contaminants. Significant examples include pipeline oil leaks, hazardous waste, sewage treatment plants, and mixed storm-water sewage overflows, mining of energy, and underground septic tanks [61]. In groundwater contaminated by sewage effluent, caffeine and nicotine were commonly identified [117]. Diffuse contamination has non-identifiable origins where pollutants come from poorly described, diffuse origins with large regional scales and pollutants are not directly absorbed into the water but from those that eventually land there, such as fertilizers, chemicals, and agricultural waste that are eventually washed into the soil making their way through groundwater and into the watercourse [61].

3 Occurrence and classification of PhACs-based emerging contaminants

The increase of PhACs as EC in the ecosystem is due to their expanding applications in human medication and livestock (Meng [76]). PhACs are primarily found in discharged wastewater from pharmaceutical industries, dispensaries, and hospitals [8, 72–75]. PhACs migrate through the sewage system until they reach WWTPs and reach water supplies where a wide number of such substances and their derivatives have been identified [11, 97, 127–130]. A lot of oral narcotics and medicines migrate into the human body, resulting in bloodstream amounts varying from ng/L (e.g., carbamazepine) to mg/L (e.g., acesulfame). Therefore, since they are an indispensable part of contemporary balanced civilization, pharmaceutical pollutants remain unavoidable [72, 77, 131]. In fish ranches, PhACs are used as antibiotic for fishes to prevent them from epidemic infections; such antibiotics are good for short-term periods but in the long term, they pollute surface water and groundwater and eventually disturb the ecosystem [97, 132, 133]. Agricultural lands and landfills are major reasons for leaching of PPCPs containing biosolids into groundwater of local regions [134, 135]. Figure 1 illustrates various potential routes by which compounds from PPCPs reach water.

[136] carried out an evaluation of water quality interims for the existence of some selected PPCPs and artificial sweeteners (ASWs) in the groundwater of the Ganga River basin. The focus of the study was to assess ECs (such as PPCPs and ASWs) and to evaluate human health and ecological risk. For examination purposes, they collected 9 samples of groundwater and surface water from various regions within 5 km of the Ganga River basin. After examining, they found 13 PPCPs in groundwater ranging from 34 to 293 ng/L such as atenolol, ibuprofen, DEFT, ketoprofen, triclocarban, sulfamethoxazole, and caffeine (highest 743 ng/L); similarly, they found 3 artificial sweeteners such as saccharine, sucralose, and cyclamate in groundwater ranging from 0.2 to 102 ng/L and 0.5 to 25 ng/L, respectively. Concentrations from 4.8 μg/L to 12.8 mg/L of all detected PPCPs have been found in people with risk quotient (RQ) ranging from 1.5×10^{-7} to 0.0021.

[137] conducted research to deliver the initial and detailed evidence upon the existence of 17 main PPCPs in the groundwater of Singapore. The main purpose of their study was to establish the adequacy of PPCPs as unique molecular markers for the pollution of untreated liquid waste in water resources. For analysis, they have chosen different sites to collect samples from groundwater. After chemical and statistical analyses, they have found 9 PPCPs in groundwater ranging from < 0.3 to 16,249 ng/L where < specifies underneath method quantification limit. Analytical findings for wastewater revealed that only 5 PPCPs (acetaminophen, salicylic acid, carbamazepine, diethyltoluamide, caffeine) were reported in large concentrations among the 17 target PPCPs analyzed. Concentrations were higher for the 3 PPCPs (acetaminophen, salicylic acid, carbamazepine) compared to the rest of the PPCPs and it was concluded that only those 3 compounds can be utilized as appropriate molecular markers of unprocessed sewage in aquifers, springs, wells, oceans, rivers, and so forth.

[138] convey information of about 24 PhACs from distinct sources like rivers, ponds, and groundwater wells from Nairobi and Kisumu City, Kenya. From a groundwater perspective, they have collected water samples from three shallow wells which are near populated cities. The concentrations that resolute in the shallow wells are relatively lesser than those found in the river and wastewater, which is

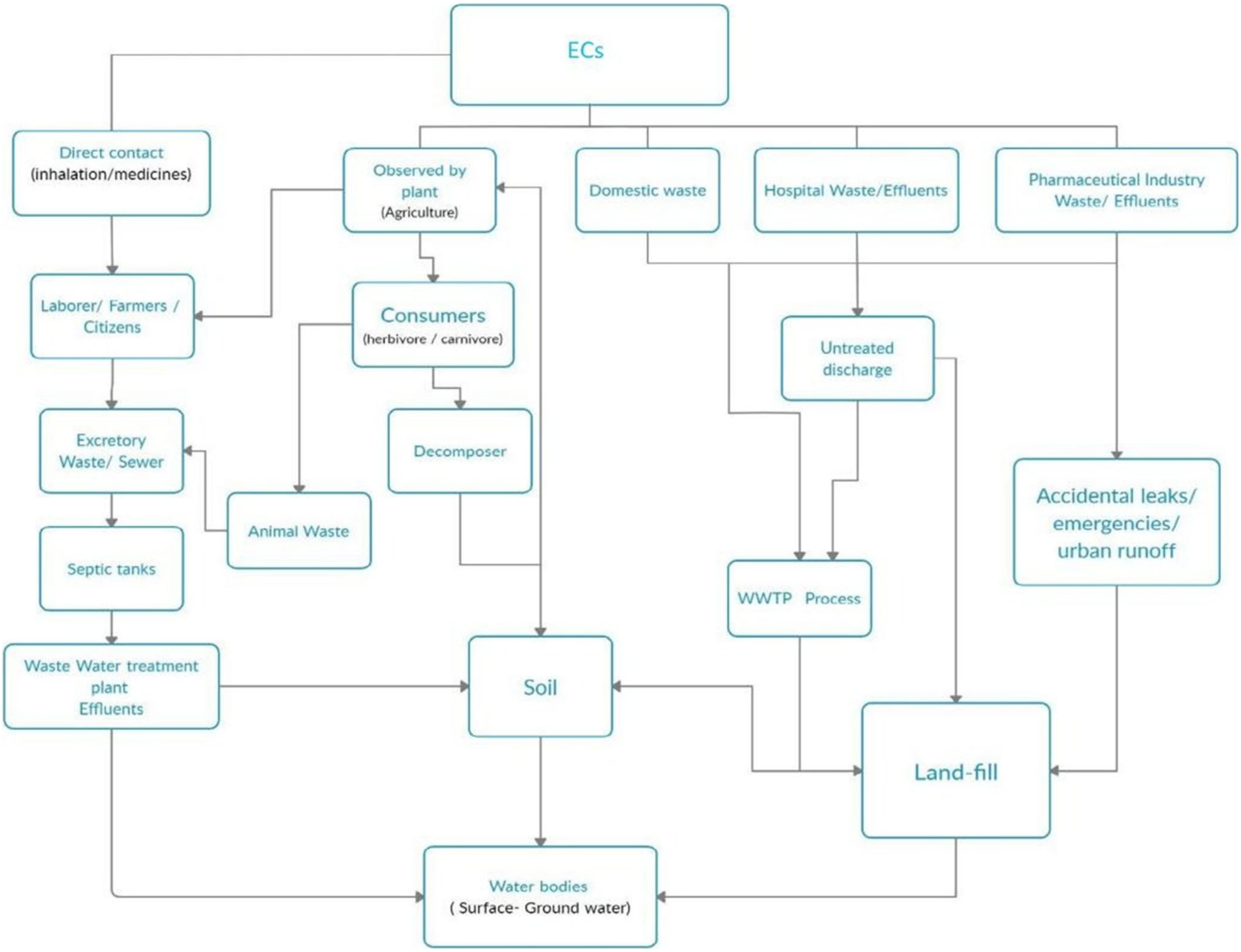


Fig. 1 Flowchart showcasing pathways of contaminants to water bodies

similar to their low detection frequency. Numerous values are in the range of 5–50 ng/L, which is alike from other literature. In groundwater, there are antibiotics and psychiatric drugs that have been detected, where concentration ranges from 18 to 40 ng/L [139]. In their study, concentrations of about 1.2–1.6 mg/L are measured from nevirapine from the first two shallow wells and were relatively higher than the third well because nevirapine is a densely populated shanty town where groundwater is lacking in these shallow wells. Protection and located near latrines and septic tanks make them much more susceptible to contamination. Such areas are responsible for emerging organic pollutants in groundwater. This requires further investigation as most of the shallow wells are sources of drinking water and such contaminants have impacts on human health. Their literature was the first literature in which occurrence of antiretrovirals in groundwater is reported in Kenya which explains their forthcoming conditions of groundwater. In overview, compounds like antiretrovirals zidovudine and nevirapine, and the antibiotics metronidazole, trimethoprim, and sulfamethoxazole are detected frequently with high concentration values up to 160 mg/L.

[139] analyzed the California Groundwater Ambient Monitoring and Assessment Program Priority Basin Project of 2004–2010. It had 14 PhACs from 1231 sites (groundwater samples) in California. In the collected groundwater sample, 2.3% of contaminants were detected as PhACs. The concentration of half of the PhACs was found to be higher than the detection limits of other articles in that region. With a detection frequency of 1.5–2%, carbamazepine was the most frequently encountered drug. Carbamazepine is not reduced greatly and has little to no sorption in water-sediment systems, as per laboratory and field research. The involvement of modern water and the presence of other anthropogenic compounds were found to be directly correlated with the presence of PhACs. The presence of modern water and the presence of other anthropogenic compounds were expected to be fully related. At least some modern water could be found in

groundwater samples with tritium concentration greater than 0.2 TU (water recharged since 1952).

Godfrey et al. 2007 [140] investigated the presence and persistence of 22 target PhACs in two shallow coarse-grained aquifers in Western Montana. After percolation via 2.0-m-thick powder, sulfamethoxazole, nicotine, and carbamazepine were found in groundwater. Groundwater tests at Frenchtown High School revealed carbamazepine concentrations of 60–210 ng/L, sulfamethoxazole concentrations of 10–450 ng/L, and nicotine concentrations of 50 ng/L. Pharmaceutical concentrations in Missoula City and metropolitan area site samples were less than 25 ng/L. Local monthly use is related to the presence of PhACs in aquifers. Under a variety of geochemical conditions, some PhACs are found in groundwater, according to their research. The presence of measurable compounds in aquifers means that sewage wastewater infiltrating into shallow groundwater may affect. Human health assessment studies will be required after additional studies are carried out to characterize groundwater to avoid the possibility of the water containing traces of PhACs.

Paiga et al. 2016 [141] conducted research in five Portuguese cemeteries with the aim of testing and determining PhACs in groundwater. In total, 33 PhACs were selected for the analysis from 3 therapeutic classes that were tested in groundwater samples, including non-steroidal anti-inflammatory/analgesics, psychiatric, and antibiotic medications, as well as some of their primary metabolites. Two groundwater samples were gathered from each cemetery. The PhACs used in the tested samples included acetaminophen, carbamazepine, sertraline, ibuprofen, nimesulide, ketoprofen, fluoxetine, and salicylic acid. Antibiotics were not detected in any of the samples that were tested. In the remaining PhACs, fluoxetine was included in eight of the ten samples tested, acetaminophen in four, sertraline in three, and nimesulide in one. Fluoxetine, carbamazepine, and salicylic acid were the only PhACs that had a detection level greater than 10% and concentrations greater than the MDL (method detection limit—the lowest concentration of a drug that can be determined with 99% certainty that the analyte concentration is greater than zero), except for nimesulide. Salicylic acid (33.7–71.0 ng/L) and carbamazepine (20.0–22.3 ng/L) have the highest concentration.

[142, 143] collected samples in the Rhône-Alpes region of southeast France. From March to April 2007, January, September, and October 2008, using standard sampling site protocols, they collected 70 groundwater samples in amber glass bottles. In Serbia, the concentration range between 78 and 610 ng/L of acetaminophen was detected in only 15% of groundwater samples. Regarding PhACs, the frequency of groundwater testing and the increase in the average level are relatively small and less polluted compared with other groundwaters. Several of the PhACs were not detected in groundwater. This is the case with metronidazole, ibuprofen, ofloxacin, bezafibrate, and pravastatin. The PhACs are most commonly detected in groundwaters, and the highest medium concentration was carbamazepine—PhACs most related to groundwater infiltration—and the highest concentration that was detected in groundwaters is 900 ng/L. The second PhAC observed was sulfamethoxazole, which has the highest frequency and average concentration in groundwater. Sulfamethoxazole accounts for about 70% and 53.9 ng/L concentration in the groundwater samples. Through analysis of PhACs, the research was initially resting on the quantity and nature of the substance, while the source of groundwater was determined by the number of samplings.

[144] looked at emerging pollutants including PhACs and industrial compounds in Taiwanese groundwater and linked their existence to potential pollution sources. The presence, climatic distribution patterns, and attenuation mechanism of PPCPs in riverside groundwater parts of Beijing's Bei Yun River were examined by Lei Yang et al. in 2017. Yen-Ching Lin's study uses spatiotemporal data to assess 50 PhACs and per-fluorinated molecules in groundwater as well as investigates the relationship between emerging pollutant concentration in groundwater and surface waters, with 20 groundwater wells in the sedimentary basin and plains of Hsinchu and Taipei, while Lei Yang examined 15 PPCPs in riverside groundwater and neighboring rivers at 5 riverside regions of the Bei Yun River and two different riverside areas in Beijing as comparisons. Both the studies have 10 PhACs in common for analysis: diclofenac, gemfibrozil, bezafibrate, clofibric acid, nalidixic acid, trimethoprim, propranolol, metoprolol, caffeine, carbamazepine. In Taiwan, after per-fluorinated compounds, caffeine (ranging from 1.2 to 930.7 ng/L and is one of the psychostimulant PhACs) and carbamazepine (ranging from 0.4 to 37.9 ng/L) were the most frequently detected compounds in the groundwater. Caffeine and bezafibrate were the most prevalent compounds in riverside groundwater in China's Bei Yun River, with an average concentration of 125.0 ng/L, respectively, with metoprolol being responsible for groundwater attenuation.

Rosario et al. 2014 [142] conduct an analysis in the coastal plain of NC, USA, to find PPCPs in groundwater below onsite wastewater treatment systems. [145] performed a thorough study into the phenomenon of 9 PPCPs in collecting groundwater and reclaimed water in China. Water samples were taken from 12 cities in 11 Chinese provinces (12 reclaimed and groundwater samples), whereas the groundwater samples in North Carolina were taken from aquifers in the coastal plain. The only common PPCP in both was caffeine which was detected only in the coastal plain of North Carolina and not from 12 selected cities of China. As median PPCP concentrations across all 4 onsite wastewater treatment systems together, N,N-diethyl-meta-toluamide (1.01 μg/L) and ibuprofen (3.46 μg/L) were the most observed compounds in groundwater, followed by caffeine (0.36 μg/L) and homosalate (0.29

μg/L). The overall concentration of PPCPs in groundwater samples from China varies from not detected to 60.1 ng/L, with ketoprofen (4.0 ng/L), mefenamic acid (1.1 ng/L), nalidixic acid (2.7 ng/L), and sulfide (60.1 ng/L) being the only PPCPs found in groundwater.

[146] studied PhACs from non-steroidal anti-inflammatory/analgesics, antibiotics, and psychiatric drugs in cemetery areas and collected samples of the groundwater, whereas Banzhaf et al. 2012 [147] investigated the applicability of selected PhACs as anthropogenic of groundwater indicators for the interaction and field site in Grand Duchy of Luxembourg, Europe. Five cemeteries were observed in Portugal and 2 samples were collected in each cemetery from two separate places. On the other hand, the second study focused on 4 sampling campaigns in June, August, October, and November 2010 that included 35 groundwater samples in total from the Grand Duchy. Ibuprofen, carbamazepine, and sulfamethoxazole changed into the PhACs achieved within the analyzed samples areas. The highest concentration obtained was 20.0–22.3 ng/L for carbamazepine from the cemetery region and the concentrations detected were up to 600 ng^{-1} from the Grand Duchy site, whereas sulfamethazine of only up to 19 ng/L and carbamazepine concentrations as much as 100 ng/L in groundwater near a riverbank. A combination with all internal standards became organized and 5 of the combination turned into delivered to the requirements and the extracts acquiring a final concentration of 75 μg/L for ibuprofen-d3, 10 μg/L for carbamazepine-d10, and 50 μg/L sulfamethoxazole-d4, respectively. The PhACs ibuprofen and carbamazepine had been prescribed to be present in all samples with 100% of discernment frequency.

[148] collected water samples from 37 rivers in the winter of 2004–2005; surveys were carried out within the Tamagawa estuary, Japan. Yang et al. 2017 [101] investigated the prevalence, seasonal spatial distribution characteristics, and attenuation procedure of 15 PPCPs in riverside sections of the Bei Yun River of Beijing, China. They accumulated 15 groundwater samples from the Tokyo metropolitan region. Groundwater samples were gathered from thirty-four20-m-deep monitoring wells of the seven riverside sections by a sampling equipment in May 2014 and December 2015. Thirteen PPCPs are found such as crotamiton, ibuprofen, naproxen, triclosan, propyphenazone, carbamazepine, diethyltoluamide, ethenzamide, ketoprofen, fenoprofen, mefenamic acid, thymol, and caffeine, whereas in the riverside section, 7 representative PPCPs were found such as caffeine, carbamazepine, metoprolol, N,N-diethyl-meta-toluamide, diclofenac, bezafibrate, and gemfibrozil. In most of the groundwater sample from Tokyo, they detected PPCPs like carbamazepine, ketoprofen, and ibuprofen (5 out of 14 samples), caffeine (4/14), and diethyltoluamide (3/14), whereas caffeine and bezafibrate, respectively, were the most abundant compounds in the riverside groundwater, with median concentrations of 3020.0 and 125.0 ng/L. In 3 surveys in the Tamagawa estuary, crotamiton, carbamazepine, and mefenamic acid behaved conservatively throughout seasons within a salinity range of 0.4–29%.

4 Health and ecological risk assessment of pharmaceutical contaminants

PhACs are EC in the environment due to their increasing use in daily life, which significantly expands the environmental evaluation of human and veterinary drugs, particularly in water, resulting in increased health and environmental risks [76, 149]. The increase in the number of pharmacological compounds in the atmosphere and their potential adverse effects on biological processes are a global problem that will cause greater difficulties for countries with high population growth rates. The incorporation of pharmacological agents into species and ecosystems presents a challenge to genetic diversity, diversity of ecosystems, and diversity of biomass [10, 150]. The existence of human or veterinary pharmaceutics is prolific in seawater and the marine surroundings [79, 92, 99, 100, 102–104, 151]. By increasing, persisting above acceptable thresholds, and substantially influencing the supply of drinking water and environmental health [152], PhACs can influence water quality [40, 64, 77, 95–97]. Massive amounts of veterinary PhACs, such as anti-parasitic medicines, antibiotics, antifungal medicines, hormones, anti-inflammatory drugs, anesthetics, and sedatives, have set foot in the atmosphere and can have a profound effect on non-target animals, including fish and plants [94]. Hermaphroditism-causing chemicals in aquatic living organisms may contribute to the impact on animals and humans, and can generate chances for testicular and human breast tumors (Liu et al. 2011; [115, 153]). The accumulation of PhACs in plants, regardless of any adverse effects, leads to growth degradation and chlorophyll content loss [154, 155]. For both human health and the environment, continuous release and sustained exposure to either of these pollutants can pose a risk [156]. The chronic toxicity prompted by these PhACs can therefore not be overlooked and more precise studies are required to evaluate its side effects on human, aquatic, and animal health through comprehensive surveillance and toxicological studies [11, 12, 157].

Bartelt-Hunt et al. 2010 [91] conducted an experiment and describe it in their journal paper; the experiment was to determine seventeen veterinary PhACs and thirteen hormones in groundwater. Samples were collected from groundwater flow of four different sites, two of them are swine facilities and other two are beef facilities, and site selection was based on previous indication of contamination due to nitrogen sources and wastewater. Contamination from the sites was analyzed by different methods for different compounds. The journal paper describes about contamination of these compounds in various months including October and December; from the experiment, it was found that concentrations of monensin, sulfathiazole, and erythromycin were higher in the October sampling in comparison with sampling in December ranging from approximately 980 to 12,900 ng/L. Almost every PhACs found in this experiment was veterinary as sites were cattle facilities. Contamination of groundwater near such cattle facilities was higher than other rural regions and drinking this contaminated water for a long time can lead to various chronic diseases.

[158] evaluated the uptake of antibiotics by vegetable (carrot and lettuce) and human risk to antibiotics due to contaminated water used in irrigation. For evaluation purposes, they have collected some vegetable samples which they planted and some from a native farmer in Ghana. They found amoxicillin and tricyclene as the main contamination compounds in vegetables such as carrot and lettuce [159]. The concentrations of antibiotics in carrot (27 ± 9.3 ng/g) were slightly higher than those in lettuce (20.3 ± 9.4 ng/g). As the detected concentration is less, those plants are safe to consume and there is no occurrence of antibiotic-resistant bacteria. But other studies of antibiotics in sewage water and irrigation water determine that there were some possibilities of occurrence of antibiotic-resistant bacteria in vegetable plant and soil. They concluded that as the concentration of antibiotics in vegetable is acceptable, human health risk is low yet.

Sarva et al. 2019 [160] carried out an evaluation of the occurrence of PhACs impurity in drinking water and their possible human risk in Putrajaya. For this purpose, they have collected 80 samples of potable water from the residential area of Putrajaya. After examining samples, they found 9 residues up to 0.38 ng/L such as amoxicillin, caffeine (highest 0.38 ng/L), chloramphenicol, ciprofloxacin, dexamethasone, diclofenac (0.14 ng/L), nitrofurazone, sulfamethoxazole, and triclosan. The hazardous quotient (HQ) values were found out for the groups of all ages (ranging 8.76×10^{-7} to 3.0×10^{-3}). They reported that ECs have the ability to create problems with the endocrine and biological function of hormones and cause infertility problem in humans [161]. An HQ value less than 1 indicates the possible human risk is considerably low yet though it might increase in a short time as emergence of PhACs is more.

[162] have shown the pathways of PhACs from the effluent of irrigation to groundwater. A 14-month research was conducted to analyze the fate and concentration of PPCPs in around 13 groundwater wells at Penn State. Sulfamethoxazole and caffeine were detected frequently with a concentration of about 40% and 32% of the groundwater samples and other contaminants such as naproxen (19%), ampicillin, ofloxacin, acetaminophen, and trimethoprim were found in less than 15%. Detection of such PPCPs in groundwater clearly indicates the contribution of wastewater in contaminating groundwater in the past few years. The flow of such contaminated groundwater will affect the groundwater of the other nearby regions where spray irrigation is not commonly used. However, the concentration in the groundwater was less than the effluent of WWTPs. It can be determined that in the travel of wastewater from effluents of spray irrigation to groundwater, some of the contaminants were absorbed by soil which eventually affects the agriculture and the crops that are grown on it. [163] Moreover, such contaminants in groundwater are a serious threat for drinking water as this can cause chronic diseases and the purification of such contaminated groundwater will lead to more effort and energy in making this water drinkable.

Mutiyar et al. 2009 [164] from the Department of Civil Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India, analyzed the environmental and ecological effects related to PhACs as a new class of ECs in the water environment. The main goal was to recognize the risks to the environment posed by PhACs because they have been ignored and it is a sensitive issue. The pharmaceutical industrial effluent was sampled from Patancheru Pharmaceutical Industrial Cluster, Hyderabad (India), and was diluted to 1000 times before exposing to fishes [165]. The results showed that PPCP residues in the Indian environment are at dangerous levels. Analgesic drug residues (such as diclofenac, ibuprofen, ketoprofen) were associated with a decrease in the Indian vulture's population [166]. In several rivers of Switzerland, about 50% decrease in fish was observed and associated with increased organic micro-pollutant concentrations in rivers [167], while an increase in the growth of cyanobacterial species and duckweed by ibuprofen exposure is reported [105]. Most studies report acute toxicity for short-term exposures, while aquatic species are exposed over their entire life cycle and real exposure is much longer than the period of exposures used in the experiments [89]. Considering the concern over increased incidence of harmful impacts and possible increased incidence of other disorders of the male reproductive system, urgent efforts must be taken to obtain accurate data regarding the possible existence of a syndrome of which sperm count, testicular cancer, and other reproductive disorders are symptoms. Future research on PPCPs in India needs to address the issue.

Lisa et al. 2013 [168] reviewed the health effects of four compounds from multiple treatment ranges in groundwater. A review of the literature was conducted, as well as a risk assessment of the chemicals in question. Based on the concentrations detected, the USEPA methodology for deducing atmospheric water quality criteria for human health safety was used to estimate the water. According to the available evidence, there are no significant risks to humans because the concentrations of PhACs detected (less than 1 μg/L) were well below the derived acceptable limits, and detection limits are expected to decrease over time. Only clofibric acid was found in the groundwater of the four PhACs. It has been proposed that adverse effects and the possibility for idiosyncratic reactions be checked too, to compensate for a specific purpose in regions of complexity. A sole analysis in Germany showed that groundwater had greater clofibric acid quantities than surface water, which defied the pattern. This occurred as a result of direct groundwater contamination from sewage tanks or various ground sources. The research focused on the danger to humans rather than the ecological consequences of polluted groundwater due to a lack of data and methodology.

[169] reviewed and analyzed the occurrence of PPCPs in China's aquatic climate. The purpose was to check the pollution levels of PPCPs associated with China's densely populated megacities with high density. The purpose of screening the level ecological risk assessment was to assess the potential natural risks of PPCP to marine species. It has a clear leadership role in selected PPCPs in surface waters to mirror the general level of risks in China. The 6 types PPCPs were macrolide anti-infection agents, anti-inflammatory drugs, and anti-microbial sulfonamides. It can be estimated that with the development of China's economy and the improvement of clinical considerations, the trend of PPCP emissions and pollution will appear, which will bring more risks to human welfare and ecology. However, it shows adverse health results in marine species. A best management practice should be tried during the season of PPCP existence in the climate which involves production, transportation, use, and garbage removal of PPCP in surface and groundwater. Lately, in China, by the beginning of 2013, the Ministry of Environmental Protection starts 12 five-year plans to control and predict the environmental risks of synthetic substances alongside PhACs as one of the major contaminants of the environment.

[170] evaluated a study to estimate risk against different aquatic species and human health risk due to antibiotics in groundwater. Similarly, Zhen [145] carried out a study to assess the risk of PhACs and PPCPs in reclaimed and receiving groundwater in China. For the calculation of RQ and HQ, highest investigated concentrations of PhACs were used. They have shown that detected PhACs have acute biological activity even at insignificant concentration and may impose toxic impacts on human and maritime life. Even ng/L range concentration exposure may lead to miss function of the body. Measured RQs and HQs for the different age groups are found less than 1 ranging from 1.5×10^{-5} to 6.1×10^{-2} which indicates no potential human and ecotoxicological or environmental risk, however, as groundwater is a crucial source of drinking water, increasing contaminant and RQ level may be a concern in native decades.

[171] carried out evaluations for possible adverse effect on human health through environmental exposures via potable water and fish intake for 44 active pharmaceutical ingredients at trace amounts (ng/L) in chosen GlaxoSmithKline-marketed products in surface waterways in Europe and North America. Similarly, [172] performed a study to provide a step-wise implementation of the system for quantitative pharmaceutical risk assessment, involving a Monte Carlo uncertainty evaluation for meprobamate, carbamazepine, and phenytoin in kids and adults through unintentional exposure to river water and fish consumption and direct intake of finished drinking water during outdoor activities. Characterization of risk from environmental exposures for human health was carried out by measuring the ratio of 90th percentile PECs to the PNECs in the study of [171], and the findings revealed that ratios of all the 44 active pharmaceutical ingredients were < 1, ranging from 7×10^{-2} to 6×10^{-11}, implying no major risk to human health due to environmental exposure from ingestion of drinking water and fish, whereas [172], access hazards to humans related to exposures of non-therapeutic PhACs doses from water utilizing HQ and ADI-equivalent drinking water levels ($DWEL_{ADI}$) for all 3 PhACs; the analysis indicates that mean HQ was between 1×10^{-10} and 3×10^{-5} and 99th percentile HQ values were less than 1×10^{-4} along with concentrations less than respective $DWEL_{ADI}$, signifying no permissible risks to human health due to exposure to PhACs.

[173] screened seventeen different PhACs and their transition products in Dutch waters and assessed their human health risks. Vanessa [174] initiated a surveillance system to examine the presence and status of thirty-one PhACs in the Empresa Portuguesa das Aguas Livres water supply system of Portugal, as well as the possibility of negative health impacts on consumers. Two samples were analyzed as a drinking water source from groundwater that is influenced by river bank filtrate and surface water from the overall samples gathered in Dutch waters. The samples from the Netherlands came from a screening program that looked at the prevalence and toxicological importance of substances of trafficking in (drinking water) supplies. The water supply system depends on 20 groundwater sources, which supply nearly 10% of the total amount of drinking water generated, and 250 samples of raw water including groundwater and potable water were obtained for the study. The estimation of RQs was used to characterize human health risks in the study of [174]. Ten PhACs out of 31 were found in groundwater samples, with varying concentrations from 0.005 to 12 ng/L. The only common compound found in groundwater samples from both studies was carbamazepine. The majority of PhACs found in Dutch waters came from surface waters, with PhACs being almost nonexistent in groundwater. According to the findings of the screening campaign, no negative health effects of the compounds tested are reported in drinking water sources of the Netherlands. Similarly, no PhACs with $RQ > 0.1$ were observed in any water supply system groundwater sample, meaning that the PhACs found in the water samples tested do not pose a health risk to consumers.

[136] have evaluated human health and ecological risk linked with PPCPs and ASWs in drinking water (mostly

groundwater) near the Ganga River basin as a second major goal and Tiziana [175] have carried out a study to provide the 1st estimation of environmental risk of propranolol in groundwater of Europe. Age-dependent RQ was calculated for each PPCP found in groundwater. RQ values of caffeine, sulfamethoxazole, and triclosan were found greater than 1 for algae. Overall, there is no substantial human health and ecological risk found of PPCPs in groundwater. Most of the PhACs' RQ level indicated as less than 1. They absorbed a moderate risk of some PPCPs for aquatic organisms such as algae and *Daphnia magna*. A potential risk due to propranolol in European groundwater is null. However, increasing contaminant rates show the possibility of human health and ecological risk in the near future that requires a potential mitigation strategy.

5 Comparison of worldwide PhACs in groundwater

Increasing PhACs ingredient as a contaminant in groundwater is a global concern. To trace the exact concentration of PhACs in the global groundwater scale is still elusive. In many countries, researchers have examined water samples from 5–50 m below the earth's surface and well. Some common PhACs that were found in the ground and drinking water worldwide are carbamazepine, sulfamethoxazole, acetaminophen, sertraline, atenolol, ibuprofen, caffeine, salicylic acid, ciprofloxacin, N,N-diethyl-meta-toluamide, and diclofenac [176]. Comprehensive data relating to the concentration of PhACs on the global scale has been given in various studies. There are more than 70 countries in which at least one pharmaceutical substance was reported in the literature at a concentration exceeding the detection limit of the analytical method employed. Mainly analyzed PhACs are the therapeutic group of the antibiotic, analgesic, and estrogens. In the Asia-Pacific region, mostly antibiotics; in Africa, estrogens; and in Eastern Europe and Western Europe, various ranges of PhACs were found [177, 178].

The globally detected pharmaceutical groups with their percentage ratio are shown in Fig. 2. This data is generated by reviewing other studies and it is based on comparison and average proportion.

Many researchers have included data related to the concentration of PhACs in various studies like [177, 179]; Qian [180–182]; and [183, 184]. According to studies, the highest concentration is detected at nearly 12,000 ng/L which is of ibuprofen and primidone (Fig. 3). Other pharmaceutical contaminants like clofibric acid, N,N-diethyl-meta-toluamide, ketoprofen, and phenazone are detected in the range of 2500–7500 ng/L. Lincomycin, sulfamethazine, salicylic acid, diclofenac, sulfamethoxazole, triclosan, and lopamidol are detected in lower range of 300–2500 ng/L.

This map chart is made by comparing different studies such as [117, 146, 177, 180–182, 185]; Ngoc Han Tran et al. 2013; Laurel A. [186]; Lei [144, 183, 187]; and [81] (Fig. 4).

6 Challenges and future scope

As the population grows, pharmaceutical pollution of water sources increases and the problems associated with the management of such pollutants increase. Some of the major challenges are mentioned as follows: (1) issues for surveillance systems which include challenges related to chemical detection, inspection methods, evolving pollutant properties and behaviors, and multi-compartment river scale monitoring; (2) challenges relating to the modelling of instruments and the fate of emerging contaminants that include issues concerning the determination and fate of pollutant sources; (3) challenges in the risk management of pollutants which require different methods used for risk assessment; and lastly (4) water quality management and policy issues which include multiple PhACs usage policies, their treatment parameters,

Fig. 2 Percentage of pharmaceutical group detected globally

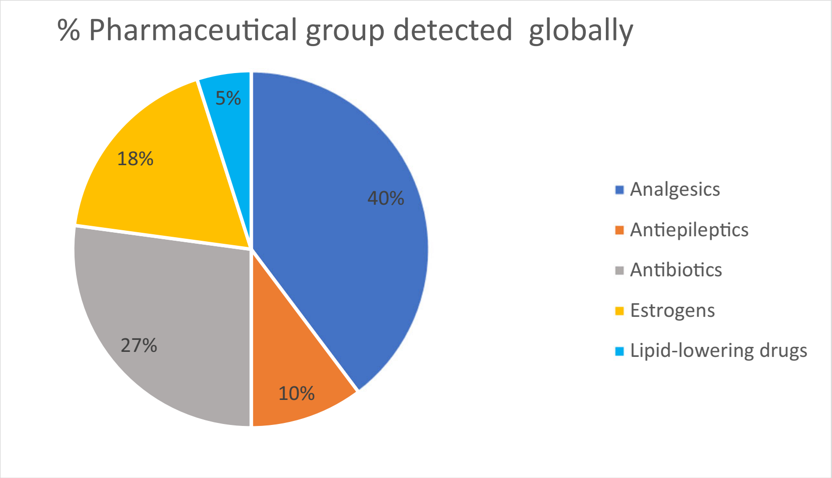
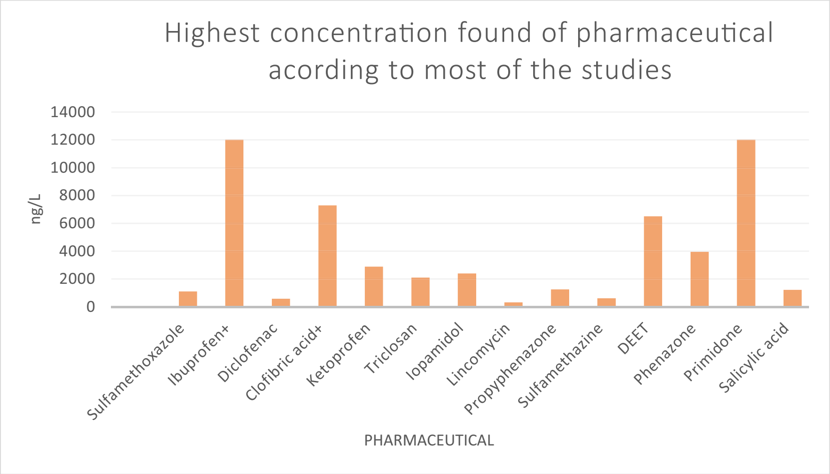


Fig. 3 Highest concentration (in ng/L) of some PhACs in groundwater from various areas of the world



industrial effluent restriction, and comparatively strict rules and regulations for such offenses.

According to WHO, to address challenges such as tracing contaminants or determining pharmaceutical pollution level, index of how much environment and people are attached to it (here PhACs), and determining what impact could be on human health and the environment as a result of polluted water intake, new tools and techniques should be made, since in the current situation, it is seen that very less amount of data is available due to adequacy of treatment techniques including electrochemical oxidation process, photo-Fenton process, membrane filtration, nanofiltration, photocatalysis, adsorption process, and various other chemical and biological treatments [188–190]. The design of a conventional water treatment plant is not much efficient to eliminate all PhACs. However, it possesses the ability to remove active pharmaceutical ingredients to a certain range. Conventional methods measure only a priority of selected ECs. PhACs are developed to interact with target molecules or certain parts of human bodies at small concentrations. Many PhACs tend to affect the environment and living bodies at an extremely low concentration so for their identification, new analytic methods are needed and for the time being, a revolution in pharma industries new type of drugs are being developed whose fate, occurrence, and human intervention are still unaware (Violette [191, 192]). Drugs used for animal and human consumption are not taken in their

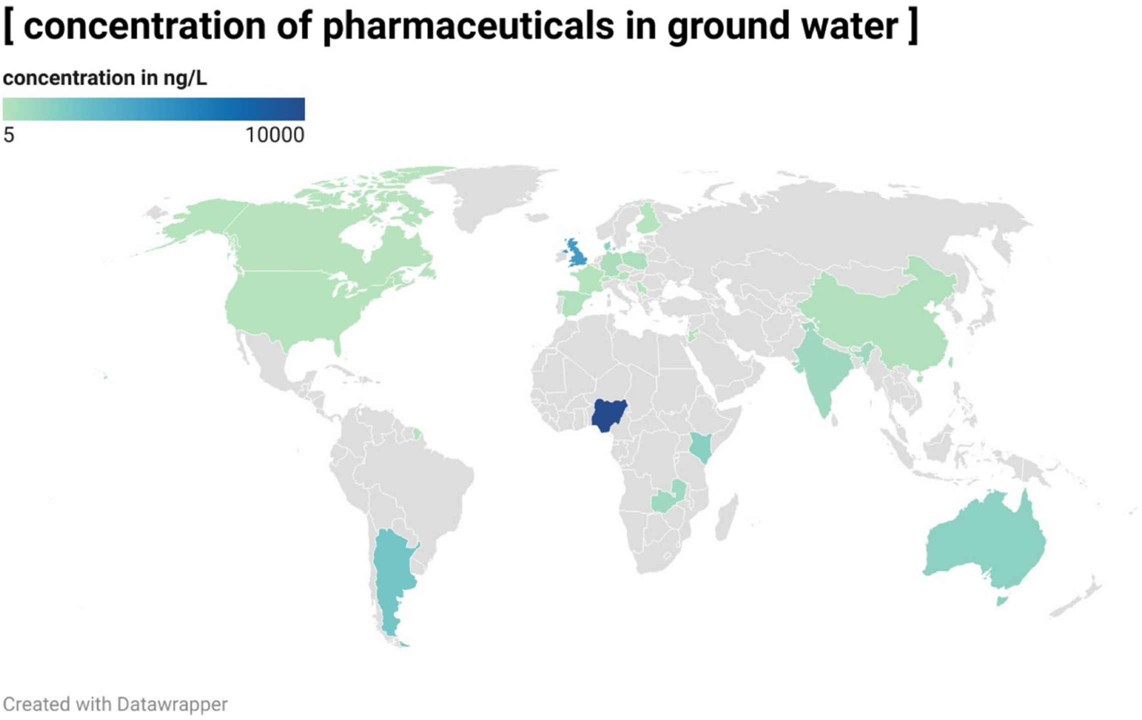


Fig. 4 Maximum concentration (in ng/L) of PhACs on a global scale

entirety, but the majority of drugs ingested are excreted in urine or feces [193]. With this, the industry cannot fully control the movement of PhACs. Properties and environmental behavior of many PPCPs and other contaminants are still not known, for example, ENM-engineered nanomaterials. Due to contact with other substances in the atmosphere including humid acids, cations, and anions or dissolution, ENM may modify in an environment that enhances difficulty in tracing and managing its fate [194, 195]. The developed modelling framework for the fate of pollutants is less efficient. By the time, increase in contaminants results in complexity to assess the risk. Previously, assessment of risk is done by comparing natural concentration in the environment but it is not much efficient as the exposure is expected from different paths and it is difficult to deal with PNEC data for a single species [191], so new analytical techniques are needed for determination of risk on humans and the environment, and relatively there is a need of implementation of new rules, regulation, and other policies to commercialize the use and to control the emission of ECs in the environment. To track very low concentrations of PhACs, highly sensitive and selective analysis methods are needed such as liquid chromatography, solid-phase extraction, and mass spectrometry [196].

From a future perspective, population growth is a major concern as it leads to a higher consumption rate of PhACs which causes an increase in chances of PhACs in water, consequently increasing various adverse effects on the environment and organisms such as chronic diseases and other diseases [197]. Under the current treatment process, removal of every single EC is not efficient, so the development of advanced analytical techniques is needed to quantify the contaminants. In our complex environment, many new ECs are arising and are not reported or detected from current analytical techniques so new efficient removal strategies should be made to detect such ECs. For removal of ECs, more efficient combinations of treatment methods should be applied. Materials like biochar, graphene, and activated carbon from various sources are used in current analytical techniques but they face recycling and recovery problems which further leads to economic problems in the removal of such compounds [198]. New materials such as polymers and nanomaterials with increased stability and adsorption capacity such as carbon spheres, carbon nanotubes, and various other nanoporous materials can be used as filter media by taking all of this into account.

Polymers experience disadvantages such as low efficient surface area, while high efficiency can be obtained in the removal of ECs using nanofilters, but this advantage is at the expense of a reduced life cycle [199]. Studies have shown that there is an increasing need to improve existing materials such as polymer nanomaterials for large-scale water purification. WWTPs should use new treatment methods for treating water having PhACs as contaminants and treatment should have good efficiency along with less cost. Nanomaterials, activated carbon, and numerous other nanoporous polymers have a very promising future in research and can help fix all our current issues, such as efficiency, recovery rate, and several others. There is truly little knowledge of the toxic effects of ECs and, since they act in a natural environment that cannot be observed in laboratories, new protocols are now required to measure certain effects on multiple species with sufficient endpoints. In the future, the estimation of the fate, sources, and behavior of ECs in the ecosystem should be focused on the risks to humans and the environment, and screening should be based on models and framework.

7 Conclusion

Groundwater quality is supremely important for people's health. Groundwater is an important natural resource and occupies an eminent position in the environment. Water-related disease is still one of the major health concerns in the world. It causes local and global diseases through the spread of infectious diseases and chemical hazards. In most parts of the country, the quality of groundwater is acceptable and reasonable for drinking, agricultural, or mechanical purposes. The chemical substances, PPCPs, are covered by contaminants of emerging concerns in surface and groundwaters. The contaminant of groundwater can be classified based on synthesis and source. Groundwater poisoning occurs when synthetic pollutants meet groundwater and lead it to get unfortunate and unsuitable for human utilization. This paper reviews more than 50 studies from the literature (2000–2020) that provide accurate and analytical information on PhACs and their composition in water bodies. In total, 28 reviews focused on the occurrence and classification of PhACs as ECs in water bodies. And 24 reviews focused on the assessment of health and ecological risk due to PhACs as ECs. Individual EC parameters occur usually at different concentrations. Regarding the ecological risk caused by the presence of target compounds on the surface and groundwaters [200], it can also be estimated by calculating RQs and it can also be estimated based on the maximum measured concentration of PhACs in wastewater. The expansion of the measurement range of pharmacological compounds in the air and its potential inverted impact on natural measurement are worldwide problems, which will pose more prominent challenges to countries with high population growth rates. For human health and the environment, both continual release and supported exposure to these pollutants may pose risks. Hundreds of different chemical substances have not been monitored, and many of their health consequences have yet to be determined. Therefore, their risk assessment has become more important, leading to better treatment techniques of contaminated water thereby reducing environmental and health concerns.

Acknowledgements The authors are grateful to the Department of Chemical Engineering, School of Technology, Pandit Deendayal Energy University, for the permission to publish this research.

Author contribution All the authors make a substantial contribution to this manuscript. YV, VP, PP, MG, CG, KM, and MS participated in drafting the manuscript. YV, VP, PP, MG, CG, KM, and MS wrote the main manuscript. All the authors discussed the results and implication on the manuscript at all stages.

Availability of data and material All relevant data and material are presented in the main paper.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

Abbreviations ECs, emerging contaminants; PhACs, pharmaceutical contaminants; PPCPs, pharmaceuticals and personal care products; PCPs, personal care products; EDCs, endocrine-disrupting compounds; ASWs, artificial sweeteners; WWTPs, wastewater treatment plants; DWTPs, drinking water treatment plants; RQ, risk quotient; HQ, hazardous quotient; MDL, method detection limit; PECs, predicted environmental concentrations; PNECs, predicted no effect concentration

References

1. Jakeman AJ, Barreteau O, Hunt RJ, Rinaudo JD, Ross A (2016). Integrated groundwater management: concepts, approaches and challenges. Integr Groundw Manag Concepts, Approaches Challenges. Published online 1-762. https://doi.org/10.1007/978-3-319-23576-9
2. K. Fent, A.A. Weston, D. Caminada, Ecotoxicology of human pharmaceuticals. Aquat. Toxicol. **76**(2), 122–159 (2006). https://doi.org/10.1016/j.aquatox.2005.09.009
3. National Groundwater Association. (2013) Facts about global groundwater usage. (2):7-8. http://www.ngwa.org/Fundamentals/use/Documents/global-groundwater-use-fact-sheet.pdf. accessed 28 Nov 2020
4. V. Geissen, H. Mol, E. Klumpp, et al., Emerging pollutants in the environment: a challenge for water resource management. Int Soil Water Conserv Res. **3**(1), 57–65 (2015). https://doi.org/10.1016/j.iswcr.2015.03.002
5. David W. Clark and David W. Briar What is ground water? Open-File Report 93–643. https://doi.org/10.3133/ofr93643
6. M.J. Benotti, B.J. Brownawell, Microbial degradation of pharmaceuticals in estuarine and coastal seawater. Environ. Pollut. **157**(3), 994–1002 (2009). https://doi.org/10.1016/j.envpol.2008.10.009
7. M. Giordano, Global groundwater? Issues and solutions. Annu. Rev. Environ. Resour. **34**, 153–178 (2009). https://doi.org/10.1146/annurev.environ.030308.100251
8. M.B. Tahir, H. Kiran, T. Iqbal. The detoxification of heavy metals from aqueous environment using nano-photocatalysis approach: a review. Environmental Science and Pollution Research **26**, 10515–10528 (2019)
9. A. Togola, H. Budzinski, Multi-residue analysis of pharmaceutical compounds in aqueous samples. J. Chromatogr. A **1177**(1), 150–158 (2008). https://doi.org/10.1016/j.chroma.2007.10.105
10. Néstor M.C., Mariana C. Impact of Pharmaceutical Waste on Biodiversity. In: Gómez-Oliván L. (eds) Ecopharmacovigilance. The Handbook of Environmental Chemistry, vol 66. Springer, Cham (2017). https://doi.org/10.1007/698_2017_151
11. M. la Farré, S. Pérez, L. Kantiani, D. Barceló, Fate and toxicity of emerging pollutants, their metabolites and transformation products in the aquatic environment. TrAC - Trends Anal Chem. **27**(11), 991–1007 (2008). https://doi.org/10.1016/j.trac.2008.09.010
12. A. Pal, K.Y.H. Gin, A.Y.C. Lin, M. Reinhard, Impacts of emerging organic contaminants on freshwater resources: review of recent occurrences, sources, fate and effects. Sci. Total Environ. **408**(24), 6062–6069 (2010). https://doi.org/10.1016/j.scitotenv.2010.09.026
13. S.K. Sharma, R. Sanghi, Wastewater reuse and management. Wastewater Reuse Manag. Published online 1-500 (2013). https://doi.org/10.1007/978-94-007-4942-9
14. T. Yin, H. Chen, M. Reinhard, X. Yi, Y. He, K.Y. Gin, Perfluoroalkyl and polyfluoroalkyl substances removal in a fullscale tropical constructed wetland system treating landfill leachate. Water Res. **125**, 418–426 (2017). https://doi.org/10.1016/j.watres.2017.08.071
15. B.A. Wilson, V.H. Smith, F. Denoyelles, C.K. Larive, Effects of three pharmaceutical and personal care products on natural freshwater algal assemblages. Environ. Sci. Technol. **37**(9), 1713–1719 (2003). https://doi.org/10.1021/es0259741
16. P. Rezka, W. Balcerzak, Z. Naukowe, et al., The occurrence of non-steroidal anti-inflammatory drugs in wastewater and water environment and methods of their removal – selected issues. Arch Waste Manag Environ Prot. **7**(2), 6–11 (2013)
17. C.B. Patneedi, P.K. Durga, Impact of pharmaceutical wastes on human life and environment. Rasayan J. Chem. **8**(1), 67–70 (2015)
18. J. Wu, J. Yue, R. Hu, Z. Yang, L. Zhang, Use of caffeine and human pharmaceutical compounds to identify sewage contamination. World Acad. Sci. Eng. Technol. **44**, 438–442 (2008)
19. B. Halling-Sørensen, Algal toxicity of antibacterial agents used in intensive farming. Chemosphere. **40**(7), 731–739 (2000). https://doi.org/10.1016/S0045-6535(99)00445-2
20. S.S.D. Foster, P.J. Chilton, Groundwater: the processes and global significance of aquifer degradation. Philos. Trans. R.Soc, B, Biol, Sci. **358**(1440), 1957–1972 (2003). https://doi.org/10.1098/rstb.2003.1380
21. M. Xu, H. Huang, N. Li, F. Li, D. Wang, Q. Luo, Occurrence and ecological risk of pharmaceuticals and personal care products (PPCPs) and pesticides in typical surface watersheds, China. Ecotoxicol. Environ. Saf. **175**(October 2018), 289–298 (2019). https://doi.org/10.1016/j.ecoenv.2019.01.131
22. D.G.J. Larsson, Antibiotics in the environment. Ups. J. Med. Sci. **119**(2), 108–112 (2014). https://doi.org/10.3109/03009734.2014.896438
23. A. Hossaina, S. Nakamichia, M. Habibullah-Al-Mamuna, K. Tania, S. Masunagac, H. Matsuda, Environ. Res. **165**, 258–266 (2018)
24. I. Hantoro, A.J. Löhr, F.G.A.J. Van Belleghem, B. Widianarko, A.M.J. Ragas, Microplastics in coastal areas and seafood: implications for food safety. Food Addit Contam - Part A Chem Anal Control Expo Risk Assess. **36**(5), 674–711 (2019). https://doi.org/10.1080/19440049.2019.1585581
25. Q. Zhang, P. Xu, H. Qian, Groundwater quality assessment using improved Water Quality Index (WQI) and Human Health Risk (HHR) evaluation in a semi-arid region of Northwest China. Expo Health. **12**(3), 487–500 (2020). https://doi.org/10.1007/s12403-020-00345-w
26. C.S.H. Tan, K.D. Go, X. Bisteau, et al., Thermal proximity coaggregation for system-wide profiling of protein complex

dynamics in cells. Science (80-)**359**(6380), 1170–1177 (2018). https://doi.org/10.1126/science.aan0346

27. K. Kümmerer, The presence of pharmaceuticals in the environment due to human use - present knowledge and future challenges. J. Environ. Manag. **90**(8), 2354–2366 (2009a). https://doi.org/10.1016/j.jenvman.2009.01.023
28. C. Ding, J. He. Effect of antibiotics in the environment on microbial populations. Appl Microbiol Biotechnol 87, 925–941 (2010). https://doi.org/10.1007/s00253-010-2649-5
29. X. Peng, Y. Yu, C. Tang, J. Tan, Q. Huang, Z. Wang, Occurrence of steroid estrogens, endocrine-disrupting phenols, and acid pharmaceutical residues in urban riverine water of the Pearl River Delta. South China. Sci. Total. Environ. **397**(1-3), 158–166 (2008). https://doi.org/10.1016/j.scitotenv.2008.02.059
30. P.K. Bishop, B.D. Misstear, M. White, N.J. Harding, Impacts of sewers on groundwater quality. Water. Environ. J. **12**(3), 216–223 (1998). https://doi.org/10.1111/j.1747-6593.1998.tb00176.x
31. L. Minguez, J. Pedelucq, E. Farcy, C. Ballandonne, H. Budzinski, M.P. Halm-Lemeille, Toxicities of 48 pharmaceuticals and their freshwater and marine environmental assessment in northwestern France. Environ. Sci. Pollut. Res. **23**(6), 4992–5001 (2016). https://doi.org/10.1007/s11356-014-3662-5
32. L. Ahrens, H. Gashaw, M. Sjöholm, et al., Poly- and perfluoroalkylated substances (PFASs) in water, sediment and fish muscle tissue from Lake Tana, Ethiopia and implications for human exposure. Chemosphere. **165**, 352–357 (2016a). https://doi.org/10.1016/j.chemosphere.2016.09.007
33. P.K. Jjemba, Excretion and ecotoxicity of pharmaceutical and personal care products in the environment. Ecotoxicol. Environ. Saf. **63**(1), 113–130 (2006). https://doi.org/10.1016/j.ecoenv.2004.11.011
34. R. Akhbarizadeh, S. Dobaradaran, T.C. Schmidt, I. Nabipour, J. Spitz, Worldwide bottled water occurrence of emerging contaminants: a review of the recent scientific literature. J. Hazard. Mater. **392**(February), 122271 (2020). https://doi.org/10.1016/j.jhazmat.2020.122271
35. H. Arfaeinia, I. Nabipour, A. Ostovar, et al., Assessment of sediment quality based on acid-volatile sulfide and simultaneously extracted metals in heavily industrialized area of Asaluyeh, Persian Gulf: concentrations, spatial distributions, and sediment bioavailability/toxicity. Environ. Sci. Pollut. Res. **23**(10), 9871–9890 (2016). https://doi.org/10.1007/s11356-016-6189-0
36. J. Wilkinson, P.S. Hooda, J. Barker, S. Barton, J. Swinden, Occurrence, fate and transformation of emerging contaminants in water: an overarching review of the field. Environ. Pollut. **231**, 954–970 (2017b). https://doi.org/10.1016/j.envpol.2017.08.032
37. J.O. Williams, S.P. White, Impact of disinfectants on antimicrobial potentials of some microorganisms impact of disinfectants on antimicrobial potentials of some microorganisms. J Pharm Biol Sci. **11**(6), 104–107 (2016). https://doi.org/10.9790/3008-110606104107
38. S. Fattorini, B. Fiasca, T. Di Lorenzo, M. Di Cicco, D.M.P. Galassi, A new protocol for assessing the conservation priority of groundwater-dependent ecosystems. Aquat. Conserv. Mar. Freshwat. Ecosyst. **30**(8), 1483–1504 (2020). https://doi.org/10.1002/aqc.3411
39. R. Akhbarizadeh, F. Moore, B. Keshavarzi, Investigating microplastics bioaccumulation and biomagnification in seafood from the Persian Gulf: a threat to human health? Food Addit Contam - Part A Chem Anal Control Expo Risk Assess. **36**(11), 1696–1708 (2019). https://doi.org/10.1080/19440049.2019.1649473
40. A. Gogoi, P. Mazumder, V.K. Tyagi, G.G. Tushara Chaminda, A.K. An, M. Kumar, Occurrence and fate of emerging contaminants in water environment: a review. Groundw. Sustain. Dev. **6**(December 2017), 169–180 (2018). https://doi.org/10.1016/j.gsd.2017.12.009
41. M.C.V.M. Starling, C.C. Amorim, M.M.D. Leão, Occurrence, control and fate of contaminants of emerging concern in environmental compartments in Brazil. J. Hazard. Mater.. Published online **372**, 17–36 (2019). https://doi.org/10.1016/j.jhazmat.2018.04.043
42. K.L. Del Rosario, S. Mitra, C.P. Humphrey, M.A. O'Driscoll, Detection of pharmaceuticals and other personal care products in groundwater beneath and adjacent to onsite wastewater treatment systems in a coastal plain shallow aquifer. Sci. Total Environ. **487**, 216–223 (2014)
43. P. Bottoni, S. Caroli, A.B. Caracciolo, Pharmaceuticals as priority water contaminants. Toxicol. Environ. Chem. **92**(3), 549–565 (2010). https://doi.org/10.1080/02772241003614320
44. K.A. Ahrens, B.A. Haley, L.M. Rossen, P.C. Lloyd, Y. Aoki, Housing assistance and blood lead levels: children in the United States, 2005-2012. Am. J. Public Health **106**(11), 2049–2056 (2016b). https://doi.org/10.2105/AJPH.2016.303432
45. B. Soulet, A. Tauxe, J. Tarradellas, Analysis of acidic drugs in Swiss wastewaters. Int. J. Environ. Anal. Chem. **82**(10), 659–667 (2002). https://doi.org/10.1080/0306731021000075384
46. O.A.H. Jones, N. Voulvoulis, J.N. Lester, Human pharmaceuticals in wastewater treatment processes. Crit. Rev. Environ. Sci. Technol. **35**(4), 401–427 (2005). https://doi.org/10.1080/10643380590956966
47. W. Petersen, 2016 exploring the occurrence and distribution of contaminants of emerging concern through unmanned sampling from ships of opportunity in the North Sea. J Mar Syst **162**, 47–56 (2016). https://doi.org/10.1016/j.jmarsys.2016.03.004
48. I.Y. López-Pacheco, A. Silva-Núñez, C. Salinas-Salazar, et al., Anthropogenic contaminants of high concern: existence in water resources and their adverse effects. Sci. Total Environ. **690**, 1068–1088 (2019a). https://doi.org/10.1016/j.scitotenv.2019.07.052
49. J.O. Tijani, O.O. Fatoba, O.O. Babajide, L.F. Petrik, Pharmaceuticals, endocrine disruptors, personal care products, nanomaterials and perfluorinated pollutants: a review. Environ. Chem. Lett. **14**(1), 27–49 (2016). https://doi.org/10.1007/s10311-015-0537-z
50. J.E. Drewes, P. Fox, M. Jekel, Occurrence of iodinated X-ray contrast media in domestic effluents and their fate during indirect potable reuse. J Environ Sci Heal - Part A Toxic/Hazardous Subst Environ Eng. **36**(9), 1633–1645 (2001). https://doi.org/10.1081/ESE-100106248
51. M. Ahmadi, R. Akhbarizadeh, N.J. Haghighifard, G. Barzegar, S. Jorfi, Geochemical determination and pollution assessment of heavy metals in agricultural soils of south western of Iran 05 Environmental Sciences 0503 Soil Sciences. J. Environ. Health Sci. Eng. **17**(2), 657–669 (2019). https://doi.org/10.1007/s40201-019-00379-6
52. K.O. K'oreje, M. Okoth, H. Van Langenhove, K. Demeestere, Occurrence and treatment of contaminants of emerging concern in the African aquatic environment: literature review and a look ahead. J. Environ. Manag. **254**(February 2019), 109752 (2020). https://doi.org/10.1016/j.jenvman.2019.109752
53. E. Archer, B. Petrie, B. Kasprzyk-Hordern, G.M. Wolfaardt, The fate of pharmaceuticals and personal care products (PPCPs), endocrine disrupting contaminants (EDCs), metabolites and illicit drugs in a WWTW and environmental waters. Chemosphere. **174**, 437–446 (2017). https://doi.org/10.1016/j.chemosphere.2017.01.101
54. A. Helenkár, Á. Sebk, G. Záray, I. Molnár-Perl, A. Vasanits-Zsigrai, The role of the acquisition methods in the analysis of the non-steroidal anti-inflammatory drugs in Danube River by gas chromatography-mass spectrometry. Talanta. **82**(2), 600–607 (2010). https://doi.org/10.1016/j.talanta.2010.05.014

55. J. Li, Y. Wang, X. Xie, C. Su, Hierarchical cluster analysis of arsenic and fluoride enrichments in groundwater from the Datong Basin, Northern China. J. Geochem. Explor. **118**, 77–89 (2012). https://doi.org/10.1016/j.gexplo.2012.05.002
56. A. Nikolaou, S. Meric, D. Fatta, Occurrence patterns of pharmaceuticals in water and wastewater environments. Anal. Bioanal. Chem. **387**(4), 1225–1234 (2007). https://doi.org/10.1007/s00216-006-1035-8
57. J. Li, Y. Wang, X. Xie, C. Su, Hierarchical cluster analysis of arsenic and fluoride enrichments in groundwater from the Datong Basin, Northern China. J. Geochem. Explor. **118**, 77–89 (2012). https://doi.org/10.1016/j.gexplo.2012.05.002
58. S. Dobaradaran, T.C. Schmidt, I. Nabipour, et al., Cigarette butts abundance and association of mercury and lead along the Persian Gulf beach: an initial investigation. Environ. Sci. Pollut. Res. **25**(6), 5465–5473 (2018b). https://doi.org/10.1007/s11356-017-0676-9
59. D. Ghernaout, N. Elboughdiri, Water reuse: emerging contaminants elimination—progress and trends. OALib. **06**(12), 1–9 (2019a). https://doi.org/10.4236/oalib.1105981
60. M. Boy-Roura, B.T. Nolan, A. Menico, J. Mas-Pla, Regression model for aquifer vulnerability assessment of nitrate pollution in the Osona region (NE Spain). J. Hydrol. **505**, 150–162 (2013)
61. A.L. Baker, J.M. Warner, Burkholderia pseudomallei is frequently detected in groundwater that discharges to major watercourses in northern Australia. Folia Microbiol. **61**, 301–305 (2016). https://doi.org/10.1007/s12223-015-0438-3
62. H. Bouwman, C. Bezuidenhout, S. Horn, T. Vogt, L. Bothma, E. Gerber, D. van Aswegen, K. Blom, D. Fouché, J. Potgieter, M. Spies, L. van der Merwe, R. Muller, R. Pieters, M. Muller, S. Cilliers, F. Wafawanaka, T. Erasmus, P. Bester, et al., Quantification, fate and hazard assessment of hiv-arvs in water resources. Report to the Water Research Commission **2**, 1–124 (2020)
63. T. Di Lorenzo, G.C. Hose, D.M.P. Galassi, Assessment of different contaminants in freshwater: origin, fate and ecological impact. Water **12**(6), 1810 (2020). https://doi.org/10.3390/w12061810
64. S. Corsolini, G. Sarà, The trophic transfer of persistent pollutants (HCB, DDTs, PCBs) within polar marine food webs. Chemosphere. **177**, 189–199 (2017). https://doi.org/10.1016/j.chemosphere.2017.02.116
65. A.J. Ebele, M. Abou-Elwafa Abdallah, S. Harrad, Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. Emerg. Contam. **3**(1), 1–16 (2017). https://doi.org/10.1016/j.emcon.2016.12.004
66. K.O. K'oreje, L. Vergeynst, D. Ombaka, et al., Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu City. Kenya. Chemosphere. **149**, 238–244 (2016). https://doi.org/10.1016/j.chemosphere.2016.01.095
67. Ahmad AA et al. (2017) Book. 2019;(December 2017).
68. M. Abtahi, A. Mohseni-Bandpei, A. Koolivand, et al., Defluoridation of synthetic and natural waters by polyaluminum chloride-chitosan(PACl-Ch) composite coagulant. Water Sci. Technol. Water Supply **18**(1), 259–269 (2018). https://doi.org/10.2166/ws.2017.085
69. Z. Visanji, S.M.K. Sadr, M.B. Johns, D. Savic, F.A. Memon, Optimising wastewater treatment solutions for the removal of contaminants of emerging concern: a case study for application in India. J. Hydroinf. **22**(1), 93–110 (2020). https://doi.org/10.2166/hydro.2019.031
70. K. Balakrishna, A. Rath, Y. Praveenkumarreddy, K.S. Guruge, B. Subedi, A review of the occurrence of pharmaceuticals and personal care products in Indian water bodies. Ecotoxicol. Environ. Saf. **137**, 113–120 (2017). https://doi.org/10.1016/j.ecoenv.2016.11.014
71. S. Dobaradaran, T.C. Schmidt, N. Lorenzo-Parodi, et al., Polycyclic aromatic hydrocarbons (PAHs) leachates from cigarette butts into water. Environ. Pollut. **259**, 113916 (2020b). https://doi.org/10.1016/j.envpol.2020.113916
72. U. Eriksson, A. Kärrman, A. Rotander, B. Mikkelsen, M. Dam, Perfluoroalkyl substances (PFASs) in food and water from Faroe Islands. Environ. Sci. Pollut. Res. **20**(11), 7940–7948 (2013). https://doi.org/10.1007/s11356-013-1700-3
73. X. Yang, R.C. Flowers, H.S. Weinberg, P.C. Singer, Occurrence and removal of pharmaceuticals and personal care products (PPCPs) in an advanced wastewater reclamation plant. Water Res. **45**(16), 5218–5228 (2011). https://doi.org/10.1016/j.watres.2011.07.026
74. W.C. Li, Occurrence, sources, and fate of pharmaceuticals in aquatic environment and soil. Environ. Pollut. **187**, 193–201 (2014). https://doi.org/10.1016/j.envpol.2014.01.015
75. P. Verlicchi, A. Galletti, M. Petrovic, D. Barceló, M. Al Aukidy, E. Zambello, Removal of selected pharmaceuticals from domestic wastewater in an activated sludge system followed by a horizontal subsurface flow bed — analysis of their respective contributions. Sci Total Environ., ISSN: 0048-9697 **454**, 411–425 (2013). https://doi.org/10.1016/j.scitotenv.2013.03.044
76. M. Lei, L. Zhang, J. Lei, et al., Overview of emerging contaminants and associated human health effects. Biomed. Res. Int. **2015**, 404796 (2015). https://doi.org/10.1155/2015/404796
77. G. Lofrano, G. Libralato, S. Meric, et al., Occurrence and potential risks of emerging contaminants in water. Elsevier Inc. (2020). https://doi.org/10.1016/b978-0-12-818334-2.00001-8
78. S. Weigel, U. Berger, E. Jensen, R. Kallenborn, H. Thoresen, H. Hühnerfuss, Determination of selected pharmaceuticals and caffeine in sewage and seawater from Tromsø/Norway with emphasis on ibuprofen and its metabolites. Chemosphere. **56**(6), 583–592 (2004). https://doi.org/10.1016/j.chemosphere.2004.04.015
79. J.L. Wilkinson, P.S. Hooda, J. Swinden, J. Barker, S. Barton, Spatial distribution of organic contaminants in three rivers of Southern England bound to suspended particulate material and dissolved in water. Sci. Total Environ **593-594**, 487–497 (2017a). https://doi.org/10.1016/j.scitotenv.2017.03.167
80. N.H. Tran, J. Li, J. Hu, S.L. Ong, Occurrence and suitability of pharmaceuticals and personal care products as molecular markers for raw wastewater contamination in surface water and groundwater. Environ. Sci. Pollut. Res. **21**(6), 4727–4740 (2014). https://doi.org/10.1007/s11356-013-2428-9
81. J.K. Sial, S. Mahmood, Groundwater contamination from agrochemicals in irrigated environment: field trials. Groundw Updat. **3**(5), 129–134 (2000). https://doi.org/10.1007/978-4-431-68442-8_22
82. R. Rahman, A.J. Plater, P.J. Nolan, B. Mauz, P.G. Appleby, Potential health risks from radioactive contamination of saltmarshes in NW England. J. Environ. Radioact. **119**, 55–62 (2013). https://doi.org/10.1016/j.jenvrad.2011.11.011
83. B.L.L. Tan, D.W. Hawker, J.F. Müller, F.D.L. Leusch, L.A. Tremblay, H.F. Chapman, Modelling of the fate of selected endocrine disruptors in a municipal wastewater treatment plant in South East Queensland, Australia. Chemosphere. **69**(4), 644–654 (2007). https://doi.org/10.1016/j.chemosphere.2007.02.057
84. N. Lindqvist, T. Tuhkanen, L. Kronberg, Occurrence of acidic pharmaceuticals in raw and treated sewages and in receiving waters. Water Res. **39**(11), 2219–2228 (2005). https://doi.org/10.1016/j.watres.2005.04.003
85. J. Lienert, M. Koller, J. Konrad, C.S. McArdell, N. Schuwirth, Multiple-criteria decision analysis reveals high stakeholder preference to remove pharmaceuticals from hospital wastewater. Environ. Sci. Technol. **45**(9), 3848–3857 (2011). https://doi.org/10.1021/es1031294

86. M. Kajta, J. Rzemieniec, E. Litwa, et al., The key involvement of estrogen receptor β and G-protein-coupled receptor 30 in the neuroprotective action of daidzein. Neuroscience. **238**, 345–360 (2013). https://doi.org/10.1016/j.neuroscience.2013.02.005

87. D.B. Huggett, J.C. Cook, J.F. Ericson, R.T. Williams, A theoretical model for utilizing mammalian pharmacology and safety data to prioritize potential impacts of human pharmaceuticals to fish. Hum. Ecol. Risk. Assess. **9**(7), 1789–1799 (2003). https://doi.org/10.1080/714044797

88. I.B. Gomes, L.C. Simões, M. Simões, The effects of emerging environmental contaminants on Stenotrophomonas maltophilia isolated from drinking water in planktonic and sessile states. Sci. Total Environ. **643**, 1348–1356 (2018). https://doi.org/10.1016/j.scitotenv.2018.06.263

89. D. Fatta-Kassinos, S. Meric, A. Nikolaou, Pharmaceutical residues in environmental waters and wastewater: current state of knowledge and future research. Anal. Bioanal. Chem. **399**(1), 251–275 (2011). https://doi.org/10.1007/s00216-010-4300-9

90. S.S.D. Foster, P.J. Chilton, Downstream of downtown: urban wastewater as groundwater recharge. Hydrogeol. J. **12**(1), 115–120 (2004). https://doi.org/10.1007/s10040-003-0296-y

91. S. Bartelt-Hunt, D.D. Snow, P.T. Damon, D. Miesbach, Occurrence of steroid hormones and antibiotics in shallow groundwater impacted by livestock waste control facilities. J. Contam. Hydrol. **123**(3–4), 94–103 (2011)

92. A.J. Barbera, V.D. McConnell, The impact of environmental regulations on industry productivity: direct and indirect effects. J. Environ. Econ. Manag. **18**(1), 50–65 (1990). https://doi.org/10.1016/0095-0696(90)90051-Y

93. E. Mohle, S. Horvath, W. Merz, J.W. Metzger, Determination of hardly degradable organic compounds in wastewater—identification of drugs. Vom Wasser **92**, 207–223

94. H. Bártíková, L. Skálová, L. Stuchlíková, I. Vokřál, T. Vaněk, R. Podlipná, Xenobiotic-metabolizing enzymes in plants and their role in uptake and biotransformation of veterinary drugs in the environment. Drug Metab. Rev. **47**(3), 374–387 (2015 Aug). https://doi.org/10.3109/03602532.2015.1076437

95. Y. Luo, W. Guo, H.H. Ngo, L.D. Nghiem, F.I. Hai, J.J. Zhang, S. Liang, X.C. Wang, A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Sci. Total Environ. 473, 619–641 (2013). ISSN: 0048-9697, https://doi.org/10.1016/j.scitotenv.2013.12.065

96. S. Esplugas, D.M. Bila, L. Gustavo, T. Krausec, M. Dezottic, Ozonation and advanced oxidation technologies to remove endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) in water effluents. J Hazard Mater. **149**(3), 631–642 (2007)

97. J. Rivera-Utrilla, M. Sánchez-Polo, M.Á. Ferro-García, G. Prados-Joya, R. Ocampo-Pérez, Pharmaceuticals as emerging contaminants and their removal from water. A review. Chemosphere **93**(7), 1268–1287 (2013). https://doi.org/10.1016/j.chemosphere.2013.07.059

98. C. Sonnenschein, A.M. Soto, An updated review of environmental estrogen and androgen mimics and antagonists. J. Steroid Biochem. Mol. Biol. **65**(1-6), 143–150 (1998). https://doi.org/10.1016/S0960-0760(98)00027-2

99. C. Ding, J. He, Effect of antibiotics in the environment on microbial populations. Appl. Microbiol. Biotechnol. **87**(3), 925–941 (2010). https://doi.org/10.1007/s00253-010-2649-5

100. S. Sauvé, M. Desrosiers, A review of what is an emerging contaminant. Chemistry Central Journal **8**, 15 (2014). https://doi.org/10.1186/1752-153X-8-15

101. L. Yang, J.-T. He, S.-H. Su, Y.-F. Cui, D.-L. Huang, G.-C. Wang, Occurrence, distribution, and attenuation of pharmaceuticals and personal care products in the riverside groundwater of the Beiyun River of Beijing, China. Environ. Sci. Pollut. Res. **24**(18), 15838–15851 (2017)

102. M.A.M. Mahmoud, A. Kärrman, S. Oono, K.H. Harada, A. Koizumi, Polyfluorinated telomers in precipitation and surface water in an urban area of Japan. Chemosphere. **74**(3), 467–472 (2009). https://doi.org/10.1016/j.chemosphere.2008.08.029

103. L. Jiang, X. Hu, T. Xu, H. Zhang, D. Sheng, D. Yin, Prevalence of antibiotic resistance genes and their relationship with antibiotics in the Huangpu River and the drinking water sources, Shanghai, China. Sci. Total Environ. **458-460**, 267–272 (2013). https://doi.org/10.1016/j.scitotenv.2013.04.038

104. L.M. Boström, B. Olof, Influence of pH-dependent aquatic toxicity of ionizable pharmaceuticals on risk assessments over environmental pH ranges. Water Res., ISSN: 0043-1354 **72**, 154–161 (2014). https://doi.org/10.1016/j.watres.2014.08.040

105. F. Pomati, A.G. Netting, D. Calamari, B.A. Nelian, Effects of erythromycin, tetracycline and ibuprofen on the growth of Synechocystis sp. and Lemna minor. Aquat. Toxicol. **67**(4), 387–396 (2004). https://doi.org/10.1016/j.aquatox.2004.02.001

106. K. Kümmerer, Antibiotics in the aquatic environment - a review - Part I. Chemosphere. **75**(4), 417–434 (2009b). https://doi.org/10.1016/j.chemosphere.2008.11.086

107. R.A. Mathew, S. Kanmani, A review on emerging contaminants in Indian waters and their treatment technologies. Nat. Environ. Pollut. Technol. **19**(2), 549–562 (2020). https://doi.org/10.46488/NEPT.2020.V19I02.010

108. J.L. Martinez, Environmental pollution by antibiotics and by antibiotic resistance determinants. Environ. Pollut. **157**(11), 2893–2902 (2009). https://doi.org/10.1016/j.envpol.2009.05.051

109. V. Homem, L. Santos, Degradation and removal methods of antibiotics from aqueous matrices - a review. J. Environ. Manag. **92**(10), 2304–2347 (2011). https://doi.org/10.1016/j.jenvman.2011.05.023

110. X.S. Miao, B.G. Koenig, C.D. Metcalfe, Analysis of acidic drugs in the effluents of sewage treatment plants using liquid chromatography-electrospray ionization tandem mass spectrometry. J. Chromatogr. A **952**(1-2), 139–147 (2002). https://doi.org/10.1016/S0021-9673(02)00088-2

111. N.J. Velez-Ruiz, K.J. Meador, Neurodevelopmental effects of fetal antiepileptic drug exposure. Drug Saf. **38**(3), 271–278 (2015). https://doi.org/10.1007/s40264-015-0269-9

112. S. Kim, D.S. Aga, Potential ecological and human health impacts of antibiotics and antibiotic-resistant bacteria from wastewater treatment plants. J Toxicol Environ Heal - Part B Crit Rev. **10**(8), 559–573 (2007). https://doi.org/10.1080/15287390600975137

113. P. Kovalakova, L. Cizmas, T.J. McDonald, B. Marsalek, M. Feng, V.K. Sharma, Occurrence and toxicity of antibiotics in the aquatic environment: a review. Chemosphere. **251**, 126351 (2020). https://doi.org/10.1016/j.chemosphere.2020.126351

114. R. López-Serna, A. Jurado, E. Vázquez-Suñé, J. Carrera, M. Petrović, D. Barceló, Occurrence of 95 pharmaceuticals and transformation products in urban groundwaters underlying the metropolis of Barcelona, Spain. Environ Pollut. **174**, 305–315 (2013). https://doi.org/10.1016/j.envpol.2012.11.022

115. G. Prasannamedha, P.S. Kumar, A review on contamination and removal of sulfamethoxazole from aqueous solution using cleaner techniques: Present and future perspective. J. Clean. Prod. **250**, 119553 (2020). https://doi.org/10.1016/j.jclepro.2019.119553

116. D. Chapman, Groundwater pollution - developments in water science. Water Qual Assessments - A Guid to Use Biota, Sediments Water Environ Monit - Second Ed Ed **5**(21), 273 (1996) http://www.who.int/water_sanitation_health/resourcesquality/wqachapter9.pdf. accessed 17 October 2020

117. M. Stuart, D. Lapworth, Smart Sensors for Real-Time Water Quality Monitoring. **4**, 259–284 (2013). https://doi.org/10.1007/978-3-642-37006-9
118. N. Nakada, K. Kiri, H. Shinohara, et al., Evaluation of pharmaceuticals and personal care products as water-soluble molecular markers of sewage. Environ. Sci. Technol. **42**(17), 6347–6353 (2008). https://doi.org/10.1021/es7030856
119. Bonavigo M. De Salve, M. Zucchetti, D. Annunziata, Radioactivity release and dust production during the cutting of the primary circuit of a nuclear power plant: the case of E. Fermi NPP, Prog. Nucl. Energy. **52**(4), 59–366 (2010). https://doi.org/10.1016/j.pnucene.2009.07.009
120. F. Baquero, J.L. Martínez, R. Cantón, Antibiotics and antibiotic resistance in water environments. Curr. Opin. Biotechnol. **19**(3), 260–265 (2008). https://doi.org/10.1016/j.copbio.2008.05.006
121. S. Dobaradaran, T.C. Schmidt, I. Nabipour, et al., Characterization of plastic debris and association of metals with microplastics in coastline sediment along the Persian Gulf. Waste Manag. **78**, 649–658 (2018a). https://doi.org/10.1016/j.wasman.2018.06.037
122. J.L. Liu, M.H. Wong, Pharmaceuticals and personal care products (PPCPs): a review on environmental contamination in China. Environ. Int. **59**, 208–224 (2013). https://doi.org/10.1016/j.envint.2013.06.012
123. N.S. Rao, Nitrate pollution and its distribution in the groundwater of Srikakulam district, Andhra Pradesh. India. Environ Geol. **51**(4), 631–645 (2006). https://doi.org/10.1007/s00254-006-0358-2
124. G.E. Cordy, N.L. Duran, H. Bouwer, R.C. Rice, E.T. Furlong, S.D. Zaugg, M.T. Meyer, L.B. Barber, D.W. Kolpin, Do pharmaceuticals, pathogens, and other organic waste water compounds persist when waste water is used for recharge? **24**(2), 58–69 (2004). https://doi.org/10.1111/j.1745-592.2004.tb00713.x
125. M. Silvia Díaz-Cruz, D. Barceló, Trace organic chemicals contamination in groundwater recharge. **72**(3), 0–342 (2008). https://doi.org/10.1016/j.chemosphere.2008.02.031
126. G. Massmann, J. Greskowiak, U. Dünnbier, S. Zuehlke, A. Knappe, A. Pekdeger, The impact of variable temperatures on the redox conditions and the behavior of pharmaceutical residues during artificial recharge. **328**(1–2), 0–156 (2006). https://doi.org/10.1016/j.jhydrol.2005.12.009
127. B. Kasprzyk-Hordern, R.M. Dinsdale, A.J. Guwy, The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK. Water Res. **42**(13), 3498–3518 (2008). https://doi.org/10.1016/j.watres.2008.04.026
128. J.K. Böhlke, Groundwater recharge and agricultural contamination. Hydrogeol. J. **10**(1), 153–179 (2002). https://doi.org/10.1007/s10040-001-0183-3
129. J.L. Shuster, A comparison of valproate with carbamazepine for the treatment of complex partial seizures and secondarily generalized tonic clonic seizures in adults. Psychosomatics. **34**(5), 464 (1993). https://doi.org/10.1056/nejm199209103271104
130. K.V. Thomas, M.J. Hilton, The occurrence of selected human pharmaceutical compounds in UK estuaries. Mar. Pollut. Bull. **49**(5-6), 436–444 (2004). https://doi.org/10.1016/j.marpolbul.2004.02.028
131. S.H. Campbell, P.R. Williamson, B.D. Hall, Microplastics in the gastrointestinal tracts of fish and the water from an urban prairie creek. FACETS **2**, 395–409 (2017). https://doi.org/10.1139/facets-2017-0008
132. D.N.R. de Sousa, S. Insa, A.A. Mozeto, M. Petrovic, T.F. Chaves, P.S. Fadini, Equilibrium and kinetic studies of the adsorption of antibiotics from aqueous solutions onto powdered zeolites. Chemosphere. **205**, 137–146 (2018). https://doi.org/10.1016/j.chemosphere.2018.04.085
133. T.A. Ternes, Occurrence of drugs in German sewage treatment plants and rivers. Water Res. **32**(11), 3245–3260 (1998). https://doi.org/10.1016/S0043-1354(98)00099-2
134. A.B.A. Boxall, M.A. Rudd, B.W. Brooks, D.J. Caldwell, K. Choi, S. Hickmann, E. Innes, K. Ostapyk, J.P. Staveley, T. Verslycke, G.T. Ankley, K.F. Beazley, S.E. Belanger, J.P. Berninger, P. Carriquiriborde, A. Coors, P.C. DeLeo, S.D. Dyer, J.F. Ericson, et al., Pharmaceuticals and personal care products in the environment: what are the big questions? Environ. Health Perspect. **120**(9), 1221–1229 (2012). https://doi.org/10.1289/ehp.1104477
135. B.F. da Silva, A. Jelic, R. López-Serna, A.A. Mozeto, M. Petrovic, D. Barceló, Occurrence and distribution of pharmaceuticals in surface water, suspended solids and sediments of the Ebro river basin, Spain. Chemosphere. **85**(8), 1331–1339 (2011). https://doi.org/10.1016/j.chemosphere.2011.07.051
136. T. Rasheed, M. Bilal, F. Nabeel, M. Adeel, H.M.N. Iqbal, Environmentally-related contaminants of high concern: potential sources and analytical modalities for detection, quantification, and treatment. Environ. Int. **122**(November 2018), 52–66 (2019). https://doi.org/10.1016/j.envint.2018.11.038
137. Y. Chen, G. Yu, Q. Cao, H. Zhang, Q. Lin, Y. Hong, Occurrence and environmental implications of pharmaceuticals in Chinese municipal sewage sludge. Chemosphere. **93**(9), 1765–1772 (2013). https://doi.org/10.1016/j.chemosphere.2013.06.007
138. J. Sanchís, L. Kantiani, M. Llorca, et al., Determination of glyphosate in groundwater samples using an ultrasensitive immunoassay and confirmation by on-line solid-phase extraction followed by liquid chromatography coupled to tandem mass spectrometry. Anal. Bioanal. Chem. **402**(7), 2335–2345 (2012). https://doi.org/10.1007/s00216-011-5541-y
139. M.S. Fram, K. Belitz, Occurrence and concentrations of pharmaceutical compounds in groundwater used for public drinking-water supply in California. **409**(18), 3409–3417 (2011). https://doi.org/10.1016/j.scitotenv.2011.05.053
140. E. Godfrey, W.W. Woessner, M.J. Benotti, Pharmaceuticals in on-site sewage effluent and ground water, Western Montana. **45**(3), 263–271 (2007). https://doi.org/10.1111/j.1745-6584.2006.00288.x
141. P. Paíga, L.H.M.L.M. Santos, S. Ramos, S. Jorge, J.G. Silva, C. Delerue-Matos, Presence of pharmaceuticals in the Lis river (Portugal): sources, fate and seasonal variation. Sci. Total Environ. **573**, 164–177 (2016). https://doi.org/10.1016/j.scitotenv.2016.08.0
142. S. Kar, K. Roy, Risk assessment for ecotoxicity of pharmaceuticals an emerging issue. Expert Opin. Drug Saf. **11**(2), 235–274 (2012). https://doi.org/10.1517/14740338.2012.644272
143. E. Vulliet, C. Cren-Olivé, Screening of pharmaceuticals and hormones at the regional scale, in surface and groundwaters intended to human consumption. Environ. Pollut. **159**(10), 2929–2934 (2011). https://doi.org/10.1016/j.envpol.2011.04.033
144. Y.C. Lin, W.W.P. Lai, T.H. Hsin, L. AYC, Occurrence of pharmaceuticals, hormones, and perfluorinated compounds in groundwater in Taiwan. Environ. Monit. Assess. **187**(5), 256 (2015). https://doi.org/10.1007/s10661-015-4497-3
145. P.E. Stackelberg, E.T. Furlong, M.T. Meyer, S.D. Zaugg, A.K. Henderson, D.B. Reissman, Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water-treatment plant. Sci. Total Environ. **329**(1-3), 99–113 (2004). https://doi.org/10.1016/j.scitotenv.2004.03.015
146. P. Paíga, C. Delerue-Matos, Determination of pharmaceuticals in groundwater collected in five cemeteries' areas (Portugal). Sci. Total Environ. **569-570**, 16–22 (2016). https://doi.org/10.1016/j.scitotenv.2016.06.090
147. S. Banzhaf, K. Nödler, T. Licha, A. Krein, T. Scheytt, Redox-sensitivity and mobility of selected pharmaceutical compounds

in a low flow column experiment. Sci. Total Environ. **438**, 113–121 (2012)

148. A.C. Collier, Pharmaceutical contaminants in potable water: potential concerns for pregnant women and children. Ecohealth. **4**(2), 164–171 (2007). https://doi.org/10.1007/s10393-007-0105-5
149. R.J. Phillips, E.J. Kieffer, T.L. Powley, Loss of glia and neurons in the myenteric plexus of the aged Fischer 344 rat. Anat. Embryol (Berl)**209**(1), 19–30 (2004). https://doi.org/10.1007/s00429-004-0426-x
150. A. Kumar, I. Xagoraraki, Human health risk assessment of pharmaceuticals in water: an uncertainty analysis for meprobamate, carbamazepine, and phenytoin. Regul. Toxicol. Pharmacol. **57**(2-3), 146–156 (2010). https://doi.org/10.1016/j.yrtph.2010.02.002
151. M. Kumar, S. Jaiswal, K.K. Sodhi, et al., Antibiotics bioremediation: perspectives on its ecotoxicity and resistance. Environ. Int. **124**(October 2018), 448–461 (2019). https://doi.org/10.1016/j.envint.2018.12.065
152. EFSA Panel on Contaminants in the Food Chain (CONTAM), Presence of microplastics and nanoplastics in food, with particular focus on seafood. EFSA J. **14**(6), e04501 (2016). https://doi.org/10.2903/j.efsa.2016.4501
153. I.Y. López-Pacheco, C. Salinas-Salazar, A. Silva-Núñez, et al., Removal and biotransformation of 4-nonylphenol by Arthrospira maxima and Chlorella vulgaris consortium. Environ. Res. **179**, 108848 (2019b). https://doi.org/10.1016/j.envres.2019.108848
154. L.J. Carter, M. Williams, C. Böttcher, R.S. Kookana, Uptake of pharmaceuticals influences plant development and affects nutrient and hormone homeostases. Environ. Sci. Technol. **49**(20), 12509–12518 (2015). https://doi.org/10.1021/acs.est.5b03468
155. L. Migliore, G. Brambilla, P. Casoria, C. Civitareale, S. Cozzolino, L. Gaudio, Effects of sulphadimethoxine contamination on barley (Hordeum distichum L., Poaceae, Liliopsida). Agric. Ecosyst. Environ. **60**, 121–128 (1996)
156. S.M. Zainab, M. Junaid, N. Xu, R.N. Malik, Antibiotics and antibiotic resistant genes (ARGs) in groundwater: a global review on dissemination, sources, interactions, environmental and human health risks. Water Res. **187**, 116455 (2020). https://doi.org/10.1016/j.watres.2020.116455
157. F.J. Peng, C.G. Pan, M. Zhang, et al., Occurrence and ecological risk assessment of emerging organic chemicals in urban rivers: Guangzhou as a case study in China. Sci. Total Environ. **589**, 46–55 (2017). https://doi.org/10.1016/j.scitotenv.2017.02.200
158. M.H. Wu, C.J. Que, G. Xu, et al., Occurrence, fate and interrelation of selected antibiotics in sewage treatment plants and their receiving surface water. Ecotoxicol. Environ. Saf. **132**, 132–139 (2016). https://doi.org/10.1016/j.ecoenv.2016.06.006
159. D. Azanu, C. Mortey, G. Darko, J.J. Weisser, B. Styrishave, R.C. Abaidoo, Uptake of antibiotics from irrigation water by plants. Chemosphere. **157**, 107–114 (2016). https://doi.org/10.1016/j.chemosphere.2016.05.035
160. M.P. Sarva, Z.M.R. Maizatul, A.M.R. Fauzan, Y.W. Sze, Z.A. Ahmad, Occurrence and potential human health risk of pharmaceutical residues in drinking water from Putrajaya (Malaysia). Ecotoxicology and Environment Saftey **180**, 549–556 (2019)
161. D. Ghernaout, N. Elboughdiri, Water reuse: emerging contaminants elimination—progress and trends. OALib. **06**(12), 1–9 (2019b). https://doi.org/10.4236/oalib.1105981
162. F.A. Kibuye, H.E. Gall, K.R. Elkin, et al., Fate of pharmaceuticals in a spray-irrigation system: from wastewater to groundwater. Sci. Total Environ. **654**, 197–208 (2019). https://doi.org/10.1016/j.scitotenv.2018.10.442
163. M.B. Leite, R.O. Xavier, P.T.S. Oliveira, F.K.G. Silva, D.M. Silva Matos, Groundwater depth as a constraint on the woody cover in a Neotropical Savanna. Plant Soil. **426**(1-2), 1–15 (2018). https://doi.org/10.1007/s11104-018-3599-4
164. P.K. Mutiyar, A.K. Mittal, A. Pekdeger, Identification and monitoring of pesticides in a well field in Delhi, India. Chemical, Biological and Environmental Engineering. 188–191 (2009). https://doi.org/10.1142/9789814295048_0039
165. V. Roos, L. Gunnarsson, J. Fick, D.G.J. Larsson, C. Ruden, Prioritising pharmaceuticals for environmental risk assessment: towards adequate and feasible first-tier selection. Sci. Total Environ. **421-422**, 102–110 (2012)
166. J.L. Oaks, M. Gilbert, M.Z. Virani, R.T. Watson, C.U. Meteyer, B.A. Rideout, et al., Diclofenac residues as the cause of vulture population decline in Pakistan. Nature **427**(6975), 630–633 (2004)
167. P. Burkhardt-Holm, A. Peter, H. Segner, Decline of fish catch in Switzerland. Aquat. Sci. **64**(1), 36–54 (2002)
168. L.J. Schulman, E.V. Sargent, B.D. Naumann, E.C. Faria, D.G. Dolan, J.P. Wargo, A human health risk assessment of pharmaceuticals in the aquatic environment. Human and Ecological Risk Assessment: An International Journal **8**(4), 657–680 (2002). https://doi.org/10.1080/20028091057141
169. Q. Bu, B. Wang, J. Huang, S. Deng, G. Yu, Pharmaceuticals and personal care products in the aquatic environment in China: a review. J. Hazard. Mater. **262**, 189–211 (2013). https://doi.org/10.1016/j.jhazmat.2013.08.040
170. L.F.V. Francisco, B. do Amaral Crispim, J.C.V. Spósito, et al., Metals and emerging contaminants in groundwater and human health risk assessment. Environ. Sci. Pollut. Res. **26**(24), 24581–24594 (2019). https://doi.org/10.1007/s11356-019-05662-5
171. X.I.N. Ie, X.I.W. Ang, J.U.C. Hen, V.L.Z. Itko, T.A.N. Aichen, Response of the freshwater alga Chlorella vulgaris to trichloroisocyanuric acid and ciprofloxacin - Nie - 2009. Enviro. Toxicol Chem. Wiley OnlineLibrary **27**(1), 168–173 (2008)
172. V.L. Cunningham, S.P. Binks, M.J. Olson, Human health risk assessment from the presence of human pharmaceuticals in the aquatic environment. Regul. Toxicol. Pharmacol. **53**(1), 39–45 (2009). https://doi.org/10.1016/j.yrtph.2008.10.006
173. C.M. de Jongh, P.J.F. Kooij, P. de Voogt, T.L. ter Laak, Screening and human health risk assessment of pharmaceuticals and their transformation products in Dutch surface waters and drinking water. Sci. Total. Environ. **427-428**, 70–77 (2012). https://doi.org/10.1016/j.scitotenv.2012.04.010
174. J.P.R. Sorensen, D.J. Lapworth, D.C.W. Nkhuwa, et al., Emerging contaminants in urban groundwater sources in Africa. Water Res. **72**, 51–63 (2015). https://doi.org/10.1016/j.watres.2014.08.002
175. T. Di Lorenzo, M. Di Cicco, D. Di Censo, et al., Environmental risk assessment of propranolol in the groundwater bodies of Europe. Environ. Pollut. **255**, 113189 (2019). https://doi.org/10.1016/j.envpol.2019.113189
176. N.H. Tran, M. Reinhard, E. Khan, et al., Emerging contaminants in wastewater, stormwater runoff, and surface water: application as chemical markers for diffuse sources. Sci. Total Environ. **676**, 252–267 (2019). https://doi.org/10.1016/j.scitotenv.2019.04.160
177. T. Aus der Beek, F.A. Weber, A. Bergmann, et al., Pharmaceuticals in the environment-global occurrences and perspectives. Environ. Toxicol. Chem. **35**(4), 823–835 (2016). https://doi.org/10.1002/etc.3339
178. J.O. Straub, Aquatic environmental risk assessment for human use of the old antibiotic sulfamethoxazole in Europe. Environ. Toxicol. Chem. **35**(4), 767–779 (2016). https://doi.org/10.1002/etc.2945
179. Q. Sui, X. Cao, S. Lu, W. Zhao, Z. Qiu, G. Yu, Occurrence, sources and fate of pharmaceuticals and personal care products in the groundwater: a review. Emerg. Contam. **1**(1), 14–24 (2015). https://doi.org/10.1016/j.emcon.2015.07.001
180. G.V. de Jesus, C.M.M. Almeida, A. Rodrigues, E. Ferreira, M.J. Benoliel, V.V. Cardoso, Occurrence of pharmaceuticals in a water supply system and related human health risk assessment. Water

Res. **72**, 199–208 (2015). https://doi.org/10.1016/j.watres.2014.10.027

181. Z. Li, X. Xiang, M. Li, Y. Ma, J. Wang, X. Liu, Occurrence and risk assessment of pharmaceuticals and personal care products and endocrine disrupting chemicals in reclaimed water and receiving groundwater in China. Ecotoxicol. Environ. Saf. **119**, 74–80 (2015). https://doi.org/10.1016/j.ecoenv.2015.04.031
182. L.M. Bexfield, P.L. Toccalino, K. Belitz, W.T. Foreman, E.T. Furlong, Hormones and pharmaceuticals in groundwater used as a source of drinking water across the United States. Environ. Sci. Technol. **53**(6), 2950–2960 (2019). https://doi.org/10.1021/acs.est.8b05592
183. B.M. Sharma, J. Bečanová, M. Scheringer, et al., Health and ecological risk assessment of emerging contaminants (pharmaceuticals, personal care products, and artificial sweeteners) in surface and groundwater (drinking water) in the Ganges River Basin. India. Sci Total Environ. **646**, 1459–1467 (2019). https://doi.org/10.1016/j.scitotenv.2018.07.235
184. L.A. Kristofco, B.W. Brooks, Global scanning of antihistamines in the environment: analysis of occurrence and hazards in aquatic systems. Sci. Total Environ. **592**, 477–487 (2017). https://doi.org/10.1016/j.scitotenv.2017.03.120
185. Murdoch K (2015) Pharmaceutical pollution in the environment: issues for Australia, New Zealand and Pacific Island countries. Natl Toxics Netw (May):36. http://www.ntn.org.au/wp/wp-content/uploads/2015/05/NTN-Pharmaceutical-Pollution-in-the-Environment-2015-05.pdf. accessed 5th January 2020
186. L.A. Schaider, R.A. Rudel, J.M. Ackerman, S.C. Dunagan, J.G. Brody, Pharmaceuticals, perfluorosurfactants, and other organic wastewater compounds in public drinking water wells in a shallow sand and gravel aquifer. Sci. Total Environ. **468-469**, 384–393 (2014). https://doi.org/10.1016/j.scitotenv.2013.08.067
187. L. Tong, S. Huang, Y. Wang, H. Liu, M. Li, Occurrence of antibiotics in the aquatic environment of Jianghan Plain, central China. Sci. Total Environ. **497-498**, 180–187 (2014). https://doi.org/10.1016/j.scitotenv.2014.07.068
188. Maycock DS, Watts CD. (2011) Pharmaceuticals in drinking water. Encycl Environ Health. Published online 472-484. https://doi.org/10.1016/B978-0-444-52272-6.00457-8
189. Beere W, Mullet S, Wingstedt E, Berg Ø, Savoainen S, Lahti T. (2010)Model-based condition monitoring techniques for balance of plant analysis using tempo. 7th Int Top Meet Nucl Plant Instrumentation, Control Human-Machine Interface Technol 2010, NPIC HMIT 2010 3(2):1920-1924.
190. Groundwater P (n.d.) Protecting Groundwater for Health.
191. M.N. Fienen, B.T. Nolan, D.T. Feinstein, Evaluating the sources of water to wells: three techniques for metamodeling of a groundwater flow model. Environ. Model. Softw. **77**, 95–107 (2016). https://doi.org/10.1016/j.envsoft.2015.11.023
192. P.C. Von der Ohe, V. Dulio, J. Slobodnik, E. De Deckere, R. Kühne, R.-U. Ebert, et al., A new risk assessment approach for the prioritization of 500 classical and emerging organic microcontaminants as potential river basin specific pollutants under the European water framework directive. Sci. Total Environ. **409**(11), 2064–2077 (2011)
193. Mittal PKM and Atul K. Pharmaceuticals and personal care products (PPCPs) residues in water environment of India: a neglected but sensitive issue Pravin K Mutiyar and Atul K Mittal Department of Civil Engineering Indian Institute of Technology Delhi, Hauz Khas , New Delhi 1. 2013;110016
194. D. Kasel, S.A. Brandford, J. Simunek, M. Heggen, H. Vereecken, E. Klumpp, Transport and retention of multi-walled carbon nanotubes in saturated porous media: effects of input concentration and grain size. Water Res. **47**(2), 933–944 (2013)
195. Y. Liang, S.A. Bradford, H. Vereecken, E. Klumpp, Sensitivity of the transport and retention of stabilized silver nanoparticles to physicochemical factors. Water Res. **47**(7), 2572–2582 (2013)
196. T. Azuma, H. Ishiuchi, T. Inoyama, Y. Teranishi, M. Yamaoka, T. Sato, Y. Mino, Occurrence and fate of selected anticancer, antimicrobial, and psychotropic pharmaceuticals in an urban river in a subcatchment of the Yodo River basin. Japan Environmental Science and Pollution Research **22**(23), 18676–18686 (2015)
197. M. Abtahi, S. Dobaradaran, M. Torabbeigi, et al., Health risk of phthalates in water environment: occurrence in water resources, bottled water, and tap water, and burden of disease from exposure through drinking water in tehran. Iran. Environ Res. **173**(January), 469–479 (2019). https://doi.org/10.1016/j.envres.2019.03.071
198. R. Kumar, P. Kumar, Wastewater stabilisation ponds: removal of emerging contaminants. J Sustain Dev Energy, Water Environ Syst **8**(2), 344–359 (2020). https://doi.org/10.13044/j.sdewes.d7.0291
199. A.J. Swallow, An introduction to radiation chemistry. Int. J. Radiat. Biol. **30**(4), 399–399 (1976). https://doi.org/10.1080/09553007614551181
200. X. Lin, J. Xu, A.A. Keller, et al., Occurrence and risk assessment of emerging contaminants in a water reclamation and ecological reuse project. Sci. Total Environ. **744**, 140977 (2020). https://doi.org/10.1016/j.scitotenv.2020.140977