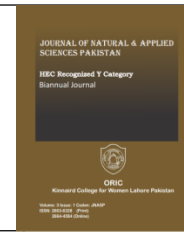
Contents list available http://www.kinnaird.edu.pk/

Journal of Natural and Applied Sciences Pakistan

Journal homepage: http://jnasp.kinnaird.edu.pk/



OCCURRENCE AND REMOVAL OF PHARMACEUTICALS AND PERSONAL CARE PRODUCTS (PPCPS) FROM DRINKING WATER SOURCES

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Article Info

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Keywords
Pharmaceuticals & Personal Care Products (PPCPs), Drinking Water Treatment Plants (DWTPs), Wastewater Treatment Plants (WWTPs), Membrane Bioreactors, Conventional Activated Sludge Treatment (CAS), Advanced Oxidation Process (AOP), Photo Catalysis

Abstract

Recently there has been an increasing awareness on occurrence of emerging pollutants in the aquatic ecosystem. Among these pharmaceuticals and personal care products (PPCPs) are of great concern as they are bioactive in nature which means they don’t evaporate or solubilize easily at normal pressures or temperatures so can easily enter into environment. Pharmaceuticals and personal care products are characterized according to their ability to persist in the ecosystem and their adsorption. They can enter in the aquatic ecosystem through various anthropogenic activities such as breeding of livestock, sewage discharge, bio-solids, landfill leachate, hospital wastewater and industrial waste. Studies have shown that PPCPs can cause damage to nervous system, reproductive disorders, cancer, increase masculinization and feminization in fish population, immune system disruption and retarded maturity in fish. Various technologies are used for the removal of PPCPs from water sources such as sand filtration, membrane filtration, adsorption, membrane bioreactors, ozonation, photo catalysis and advanced oxidation process. The performance and cost of different technologies vary according to the nature of PCPPs. This paper provides an overview of PPCPs occurrence and treatment technologies and is based on the studies in the last ten years.

1. Introduction

Pharmaceuticals are over the counter drugs that are used for the treatment or prevention of animal or human diseases. Personal care products (PCPs) are items that are applied or consumed by humans for their personal hygiene, health or for cosmetics reason. Personal care products and pharmaceuticals can range from antibiotics, contraceptives, lipid regulators to active ingredients in dyes, shampoos, soaps, detergents etc (Lapworth *et al.,* 2012) .Over the last few decades, there has been an increasing awareness on occurrence of emerging contaminants in aquatic ecosystem and among these PPCPs are of great concern. PPCPs have been recognized as emerging contaminants in aqueous environment because they have low volatility, high polarity and can infuse with the effluents of municipal waste water treatment plants. PPCPs can be classified into steroids (estrogen, progesterone, androgens, veterinary hormones etc.), personal care products (disinfectants, fragrances, UV protectors, cosmetics etc.) and drugs (antibiotics, analgesics, anti-inflammatory, anti-depressants etc.) (Ebele *et al.,* 2017)

Pharmaceuticals and personal care products are bioactive in nature and can enter into water or soil easily. PPCPs can enter into the aquatic environment through various anthropogenic activities such as breeding of livestock, sewage discharge, bio solids and landfill leachate. Continuous and long term exposure to certain PPCPs can cause detrimental effects on humans and ecosystem. Studies have shown that PPCPs can cause damage to nervous system, reproductive disorders, cancer, increase masculinization and feminization in fish population, immune system disruption and retarded maturity in fish Very less information is available in terms of their behavior, fate and toxicity because of which most of PPCPs are unregulated and only few are monitored. Moreover, wastewater treatment system does not treat pharmaceuticals as pollutants. PPCPs can be classified into steroids (estrogen, progesterone, androgens, veterinary hormones etc.), personal care products (disinfectants, fragrances, UV protectors, cosmetics etc.) and drugs (antibiotics, analgesics, anti-inflammatory, anti-depressants etc.) (Yang *et al.,* 2011)

This paper principally outlines classification of PPCPs, their characteristics, properties, sources and toxicological effects with special focus on technologies used for removal of PPCPs from drinking water and wastewater sources.

2. Sources

Most of the PPCPs are man-made except few of them such as caffeine which is produced by about 60 plants. They can enter in aquatic ecosystem through various anthropogenic activities such as breeding of livestock, sewage discharge, bio solids and landfill leachate. One of the main sources of PPCPs is hospital wastewater and industrial waste. They are also found in swimming pools through fill water and through different anthropogenic activities like sweat, urine, body surfaces and swim wear. They can also enter into the ecosystem through animal and human feces and by use of sewage sludge for amendment of soil and its fertilization (Suppes *et al.,* 2017).

3. Characteristics of PPCPs

PPCPs are characterized according to their ability to persist in the ecosystem and their adsorption. All these characteristics are briefly described below.

3.1 Persistence

Pharmaceutical and personal care products cannot be treated with conventional wastewater treatment processes that are why most of them remain persistent in the environment. Since these are not being treated there is high evidence of them returning to humans through food or water. Some studies state that some PPCPs have a restricted lifetime in the ecosystem and are not necessarily persistent in the environment but even after the process of biodegradation and sorption they are repeatedly used and released in the ecosystem so they are classified as “pseudo-persistent” (Verlicchi *et al.,* 2012). Pharmaceuticals can become persistent in the environment because of their complex nature and active ingredients used in their products. For instance, Loffer *et al.* have categorized persistence of pharmaceuticals in low, medium and high categories according to their dissipation time in sediment or water samples. The results showed that ibuprofen and paracetamol had low persistence, iopromide and ivermectin had moderate persistence whereas carbamazepine and clofibric acid had high persistence. Hence, carbamazepine and clofibric acid can persist in the environment for longer period and can bio accumulate through food chain (Richmond *et al.*, 2017). Personal care products like UV filters are also pseudo-persistent in environment. UV filters are used in many cosmetics and sunscreens. They can enter directly into the aquatic environment through various human activities like bathing and swimming. Benzophenone-type UV filters is lipophilic in nature and can persist in the environment by biomagnifying and bio accumulating through the food chain (Doretto *et al.,* 2014).

3.2 Adsorption

The fate of personal care products and pharmaceuticals in underground ecosystem may be influenced by adsorption as it affects their movement, uptake by plants and bioavailability. Chemicals which have low sorption can move deep into soil and can enter into groundwater whereas those chemicals which have strong sorption are less mobile in soil. Physiochemical parameters of PPCPs play an significant role in the adsorption of them in soil. These parameters include their molecular structure, solubility in water and hydrophobicity (Zhang *et al.,* 2014). In 2013, Yu et al. carried out a study in which they reported that carbamazepine was poorly adsorbed by soil whereas triclosan was readily adsorbed. This is due to their differences in chemical structure. Organic matter in soil also impacts the adsorption of PPCPs in soil. A study was carried out on four different Brazilian soils to study the sorption of sulfaquinoxaline, sulfadimethoxine and sulfamethazine. The results indicated that these sulfonamides showed stronger sorption in clay soils than sandy soils because of their lipophilicity (Goncalves *et al.*, 2013). Environmental conditions also play an important role in influencing adsorption of pharmaceuticals and personal care products in underground environment. Low pH positively impacts sorption of veterinary pharmaceuticals sulfonamides because at low pH they mostly exist as cations and attract negatively charged mineral surface (Arias, 2019).Many researchers have studied the adsorption of dyes using agricultural by-products. F. Deniz *et al*. carried out a research in which they studied the adsorption of methylene blue dye onto peanut hull. The results showed that peanut hulls have good adsorption capacity for the removal of methylene blue dye (Berendonk *et al.*, 2015).

4. Physiochemical Properties

4.1 pH

PPCPs can be basic or acidic in nature. Example of some basic pharmaceuticals include paroxetine, bisoprolol etc. and examples of some acidic pharmaceutical includes diclofenac, bezafibrate, etc. Pharmaceuticals can also exist in neutral form at pH below pKa. Personal care products are usually neutral having pH close to 7 but the products used for cleansing like shampoo or detergents are alkaline in nature having pH 9-10 (Becker & Stefanakis., 2017).

4.2 Solubility

Majority of PPCPs are soluble in water. They can readily dissolve in aqueous form and can persist there for long time because they don't vanish at normal pressures or temperatures (Becker & Stefanakis, 2017).

4.3 Volatility

PPCPs are either non-volatile or semi-volatile. Due to their characteristic they can get distributed in the environment either through food chain dispersal or aqueous environment (Becker & Stefanakis., 2017).

5. Toxicity of PPCPs

PPCPs can have detrimental effects on humans, animals and non-targeted organisms. When PPCPs like antibiotics, anti-inflammatories and anti-depressants enters into the aquatic environment they form unknown mixtures and can become highly toxic. Excessive use of antibiotics in animals and human medicines can cause resistance in bacteria. They also don't eliminate from wastewater treatment plants. Active compounds named as antipyrine is found in pharmaceuticals which can easily be detected in aquatic organisms have a potential to deteriorate organs when exposed over for long-term. PPCPs also affect the growth of duckweed and algae. Studies have shown that PPCPs can cause damage to nervous system, reproductive disorders, cancer, increase masculinization and feminization in fish population, immune system disruption and retarded maturity in fish (Ohoro *et al.,* 2019). They can also cause disruption of endocrine system. There are no known effects on human health when there is low-level exposure form drinking water. According to a study ibuprofen have a degradation product in it known as 4-acetylbenzonic acid which inhibits the growth of micro-green algae. PPCPs can bio accumulate and bio magnify in the aquatic food web causing more effects on the aquatic organisms. PPCPs can also delay the metamorphosis in frogs and can also alter their behavior and reproduction (Sui *et al.,* 2015). Parabens usually do not irritate normal human skin. Irritation has been reported when paraben medication is applied to broken or damaged skin. Octinoxate in UV filter have detrimental effects on the growing cells of marine bacteria. Organic UV filters used in sunscreens can cause photo allergic contact dermatitis and various allergic reactions on human skin. Octyl-triazone UV filter has been reported to cause allergic contact dermatitis in children (Bu *et al.,* 2013).

6. Environmental Matrices of PCPPs

6.1 Wastewater, Sludge, Sewage

Sewage treatment plants are one the most common sources of PCPPs in the environment. During STPs, the toxicity of PCPPs is not removed completely as alteration of PCPPs occurs on the basic of its physio-chemical properties. There are uncertainties about PCPPs of becoming completely or partially modified metabolites and sometimes remained unaffected during the sewage treatment process (Luo *et al.,* 2011). Antibodies are the major group of pharmaceuticals that are found at high concentration in wastewater supply, contaminating the groundwater source and ultimately polluting drinking water, putting the environment at risk. In recent years, much attention has been given to the issues rising from the antibiotics presence in groundwater. According to national reconnaissance carried out by U.S regarding the Pharmaceuticals and other organic pollutants in water bodies ,it had been reported that antibiotics were found in 47 groundwater sites with detection frequency exceeding more than 30%.DEET is another important PCPPs used in insect repellents, that enters into drinking water supply through sewage treatment plants and septic tanks .Del Rosario et al. detected PCPPs in groundwater and in wastewater treatment systems in coastal area of North California with concentration ranged from 540 to 1010 ng/L. There are many another PCPPs commonly found in the ground water and sewage water which includes caffeine, lipid regulators, carbamazepine, anti-inflammatories, analgesic, sunscreen agents (Peng *et al.,* 2011).

6.2 Surface Water and Sediments

PCPPs enter into the surface water bodies mainly through untreated wastewater effluents. They are found at a highest concentration in rivers and their level depends mainly on the water dilution level, which is due to the rainfall. Numerous concentrations are found in surface water bodies depending upon variety of parameters such as geographical area, meteorological conditions, and efficiency rate of wastewater treatment plant (Peng *et al.,* 2011). It was reported that about twenty-three sulfonamides were found, at least once, in the surface waters of eastern China, with concentration lower than 1 g/L, expect for the sulfamethoxazole with concentration ranging from ND to 940 ng/L found in the Haihe river basin (Arpin-Pont *et al.,* 2016) and sulfamethazine found in Pearl river (40-1390 ng/L) (Ebele *et al.,* 2017). There were number of studies conducted on the PCPPs contamination in freshwater bodies since the past 20 years, but now day's researchers are focusing more on the marine environment. PCPPs were found in the seawaters of North Europe (UK, Germany. Norway, Ireland Netherlands), Southern Europe (Spain, Italy, Greece), North America, Asia (China, India, Singapore, Taiwan). One of the most abundantly found PP compounds were antibiotics with trimethoprim, erythromycin, sulfamethoxazole, caffeine, antiflammatories with ibuprofen and analgesics with acetaminophen. Reported concentrations of PCPPs were large in seawater from limit of quantification (few ng/L) to 230,000ng/L. Among PCPs (Personal care Products), musk's, sunscreens, and disinfectants were detected at sites mainly influenced by anthropogenic activities such as harbors, or estuaries (Karnjanapiboonwong *et al.,* 2011).

Numerous PCPPs have the ability to accumulate in the sediments which serves as important sink and major source of PCPPs in the aquatic environment. They are found in the sediments of river, lakes and creeks at high concentration, e.g. triclocarban were found a high concentration up to 822ng/g in the freshwater sediments in Minnesota, UK (Ma *et al.,* 2018). There are some important processes through which solubility of PCPPs in sediments can be reduced such as adsorption process helps in making the PCPPs less toxic .There are number of good anti-microbial media such as triclosan, that adsorbs these contaminates by trapping them in the pores of sediments. Adsorption process is mainly influenced by pH level. Aqueous photolysis is another effective method for removal of tetracycline compounds found in the sediments, which can improve by increasing the pH level. Majority of the PCPPs are found in the surface water sediments (mainly rivers), at much lower concentration than the sludge samples (Ma *et al.,* 2018).

6.3 Drinking Water and Soil

Main Route of PCPPs into soil is through application of fertilizers such as livestock waste, wastewater effluents and domestic supply of water .Veterinary antibiotics were found in the soil of organic vegetable farmland that was fertilized using natural manure from Tianjin up to concentration 2683 ng/g .Variety of Pharmaceuticals, like ibuprofen ,diclofenac etc., can be found in soil, that shows inadequate adsorption under anaerobic conditions .Once the PCPPs enters into soil, it can easily leach downwards ,as it is influenced by its physio-chemical properties such as pKa values, soil properties ,salinity of irrigated water (Bu *et al.,* 2013; Ma *et al.,* 2018). Lin Ma *et al.,* reported the presence of 9 PCPPs in vadose zone of soil having 16 m depth, irrigated using different water resources (Ebele *et al.,* 2017).

In USA, there are number of communities that use wastewater effluents for the tertiary treatment of the lands. It is considered one of the oldest methods for the surface irrigation. There are number of PCPPs found in wastewater effluents that sorb to soil once they interact with soil particles. They can be transported to other aquatic environments, through runoffs, as groundwater supply and subsurface transport, threatening the drinking water resources. There are number of reports detected the presence of PCPPs, such as ibuprofen, estrone, antibiotics, and chlofibric acid, in groundwater and drinking water resources (Arpin-Pont *et al.*, 2016).

6.4 Biota

Globally, numerous studies reported deleterious effects of PCPPs on the aquatic and terrestrial organisms, mainly affecting their reproduction rates. This cause bioaccumulation of estrogenic contaminates in fish tissues, causing vitellogenin and finally contributes towards feminization of wild fishes in the rivers. In a Spanish study, it was revealed that pharmaceuticals residues were present in the meat products of pork, lamb, chicken, salmon, sea bass, available at the local markets, threatening the health of local people. Bioaccumulation of PCPPs occurs in the marine mammals as they form the top of food chain. Among PCPPs, human pharmaceuticals were detected in bull shark of Caloosahatchee River where wastewater is the major source of contamination. Major compounds detected in bull sharks were fluoxetine, paroxetine, venlafaxine and citalopram at concentration from 0.10-6.25.ng/g. Studies from Pakistan reported drastic decline in the population of vultures partially due their exposure with diclofenac treated livestock. These toxic compounds had deleterious effect on the kidneys of vultures and were found at concentration ranging from 0.051 up to 0.643 mg/g in the kidneys of 25 vultures. Steroid estrogens have been reported from Dianchi Lake in china, in different wild fishes such as carp, silvery minnow at concentration up to 11.3 ng/g (Ma *et al.,* 2018). Among PCPs, two important UV filters (EHMC and OCT) were detected in marine mussels; Mytilus edulis and Mytilus galloprovincialis at concentration up to 7112 ng/g along the Mediterranean coast and up to 14,000 ng/g in Korea around Kohyongsaong bay (Arpin-Pont *et al.,* 2016).

7. Technologies for PCPPs Removal from Drinking and Wastewater Resources

Different technologies are employed for the efficient removal of microorganisms and organic contamination from drinking water and wastewater resources. These technologies help to meet the drinking water standards, which ensure safe drinking water. Mechanical, Biological and advanced processes are commonly used for its effective removal from water resources. Despite all of these treatments, it was found that some of the PCPPs are not removed completely, as compare to municipal wastewater treatment plant; there is less knowledge about PCPPs behavior in drinking water resources. One of its reason maybe lack of systematic monitoring at the municipal sites or lack of proper analytical sensitivity for detection of PCPPs in drinking water ,which is present at a concentration of sub –ng/L. Different studies demonstrated the presence of

PCPPs (at least 25), in more than one drinking water supply, among which beta-blocker is found constantly at a high concentration above the limit of quantification in drinking water, followed by carbamazepine and salicylic ,with concentration exceeding 30% of the drinking water samples. Studies from France, Spain, china, U.S revealed maximum concentration of some of the important PCPPs in drinking water samples for instance, paracetamol (45 ng/L), meprobamate (42 ng/L), butyl paraben (28 ng/L) etc. Wastewater samples show higher concentration than drinking water samples. None of the drinking or wastewater treatment processes specifically removes PCPPs from water, as physicochemical characteristics of individual PCPPs differs from one another (Wang & Wang., 2016).

7.1 Mechanical Processes

7.1.1 Filtration Process

Filtration is widely used as mechanical process in water treatment plants, through which large and undesirable contaminates, are removed by physical barrier or through absorption into the biological film present inside the filter medium. Sand filtration and Membrane filtration are employed in the filtration process of PCPPs in drinking and wastewater supply (Wang & Wang., 2016).

7.1.2 Sand Filtration

Sand filtration is a common treatment for the secondary wastewater effluents. It has the ability to remove some portion of dissolved PCPPs having retained solids in it, but its removal efficiency is much lower than advanced treatment methods .The removal efficiency of different PCPPs depends mainly on the hydrophobicity of PCPPs, which acts a major factor in governing its ability to adhere to the colloidal particles, and also affects the filterability. Oulton *et al*., concluded that hydrophobic compounds gave the highest removal efficiencies and easily separates from water to sludge phase. Its efficiency makes them higher log K_{ow} compounds and speed up the degradation process during the conventional activated sludge treatment along with adequate hydraulic and solid retention times (Wang & Wang., 2016). Adsorption and biodegradation are two possible mechanisms responsible for PPCPs removal during sand filtration. Sandwich slow sand filtration with 20 cm of GAC gave the best PCPPs removal efficiency at 98.2% at the 10cm/h rate (Yang *et al.,* 2017).

7.1.3 Adsorption

Granular activated carbon (GAC) and powder activated (PAC) are widely used adsorbents in drinking water for the removal of microorganisms and other micro organic contaminates. Recent researches have supported the use of these adsorbents for effective removal of PCPPs from water. In activated carbon adsorption process, the partitioning co-efficient for the octanol water forms strong correlation with the PCPP removal. Some other characteristics e.g. pore volume distribution, pH, and surface area also influence the removal rate of PCPPs from water. GAC has >90% ability for the removal of PCPPs as compared to PAC. Stackelberg *et al*. conducted a study in which GAC removed 53% of tested PCPPs in conventional WTP, as compared to 32% and 15% removal efficiency by disinfectants and sedimentation processes. Another study conducted by Hernandez *et al*, demonstrated removal efficiencies for tonalide and nonylphenol from 50% -90%. Contact time affects the removal efficiency; as short contact time decreases removal rate and longer contact time results in better removal of PCPPs. Activated carbon adsorption has greater potential for the removal of antibiotics than coagulation flocculation process. GAC filtration is one of the advanced treatment method used in drinking water treatment plant, which improved PCPPs removal efficiency about 2% to 46% compared to conventional treatments (Carolin *et al.,* 2020) (Wang *et al.,* 2014).

7.2 Biological Processes

In current situation the emerging problem of micro pollutants such as pharmaceuticals and personal care products (PCPPs) has been increasing day by day at global level. These PCPPs can cause negative impacts on aquatic ecosystems and human health. Some researchers have analyzed that there are certain PPCPs which are present in trace concentrations, ranging from a few ng/L to several μg/L. But their trace concentrations also cause adverse impacts on the environment. Currently many biological processes are used both at small scale and large scale water treatment plants to improve the quality of water. Mostly wastewater treatment plants (WWTPs) use Activated Sludge Process to remove organic matter and nutrients without considering PCPPs. But through this process all contaminants are not removed completely.

During last 2 decades, another biological process has been introduced, the membrane bioreactor (MBR) process for removal of PPCPs and other conventional pollutants in water. According to a study the MBR PCPPs removal efficiency process was 15–42% higher than in the conventional activated sludge (CAS) process. Tran *et al.* (2016), the recent study demonstrated the removal efficiencies of both CAS and MBR processes; (62% in MBR, 42% in CAS). Biological processes such as biodegradation, reverse osmosis, sorption to sludge, volatilization and photo degradation all are under the category of biological processes for the removal of contaminants in water (Wang *et al.,* 2014; Park *et al.,* 2017).

7.2.1 Membrane Bioreactors

From wastewater and drinking water the combination of biological and membrane treatments is used for the removal of pharmaceuticals. This combination of biological and membrane treatments considered as membrane bioreactors. It is considered as one of the phases changing methods. It is conventional treatment method.

7.2.2 Membranes' Classification

On the basis of size of material, bioreactors membranes are classified. There are two types of membranes in bioreactor; low-pressure-driven membrane and high-pressure-driven membrane. Ultrafiltration and microfiltration membranes are considered as category of low-pressure membranes, on the other hand nanofiltration and reverse osmosis membranes come under the category of high-pressure membranes. These membrane technologies are divided into four main classes, depending upon their molecular weight; ultrafiltration (UF), nanofiltration (NF), microfiltration (MF), reverse osmosis (RO). Among these membrane technologies, NF and RO are the most effective alternatives for removal of PCPPs from wastewater. UF and MF performance is relatively poor because the size of membrane is larger than the PPCPs molecules (Yang *et al.,* 2017). Watkinson *et al.,* used NF and RO technologies for removing some of the PCPPs in the drinking water treatment. It was reported that around 60% of the diclofenac and naproxen were eliminated, whereas some concentration of carbamazepine was removed. Diclofenac and naproxen were blocked by the negatively charged membrane, while carbamazepine was not blocked. The average retention efficiency of NF for neutral pollutants is approximately 82% and 97% for ionic pollutants, whereas reverse osmosis has higher retention efficiency which can achieves 85% to 99% . The pressure-driven membrane processes, NF and RO, shows higher efficiency rate than other membrane technologies. In integrated membrane system, Membrane bioreactor (MBR) combines with nanofiltration and reverse osmosis can achieve higher removal rates exceeding 95% of most of PCPPs (Wang *et al.,* 2014). Membrane bioreactors consist of adsorption, biodegradation and membrane separation techniques. All these processes make the effluents to generate a very low quantity of total suspended solids, pathogenic microorganisms, turbidity and biological oxygen demand from contaminated water. Excluding the membrane modules, the performances of membrane bioreactors are almost equal to the conventional activated sludge (CAS) systems. Through membrane bioreactor 80 % PCPPs are removed from wastewater. This has ability to operate under high feed load and manage high sludge concentration. (Wang *et al.,* 2014).

7.2.3 Conventional Activated Sludge (CAS) Treatment

Mostly treatment plants at large scale are using conventional activated sludge reactors in this modern era. Conventional Activated Sludge treatment is one of the cheapest technologies to remove and degrade all types of contaminants in water. For the efficient removal of PCPPs and other organic matter from waste water CAS reactors are operated at Hydraulic Retention Time (HRT) of 4 to 14 h. Through this treatment PCPPs are detected even in low amount present in water. If very micro PCPPs are not completely removed by activated sludge process, then at least they can be adsorbed in biological sludge. The removal efficiency of PCPPs from water depends on their physio-chemical properties, temperature, pH, Sludge

Retention Time (SRT), redox conditions and Hydraulic Retention Time (HRT). During shorter HRTs the removal rate is lower. SRTs determines the actually residence time of microorganisms in mean value. It has been observed that during the working at high SRTs and high critical values of this parameter of about 10 days the removal efficiencies of PCPPs have high values (Park *et al.,* 2017).

7.3 Advanced Technologies for the Removal of PCPPs from Drinking and Wastewater Resources

The removal of PCPPs from drinking and wastewater is complex. In previous years, their removal from water through conventional treatment was not satisfying the quality of water. Advanced technologies photo catalysis, ozonation, advanced oxidation process, ultrasound assisted extension and liquid chromatography has emerged for the removal of PCPPs from water.

7.3.1 Ozonation Process

The post-treatment in addition to UV treatment uses ozone at wastewater treatment plant (WWTP). Ozone has ability to remove PPCPs efficiently. According to a study reported by Lee et al. (2012), who had used ozone treatment designed specifically to remove PPCPs. They demonstrated that the PCPPs using ozone and bio filtration, reached 50% with 4 mg/L O_3 and near to complete removal > 99% of PCPPs with 8mg/L Ozonation is actually the dark oxidation method which is commonly used for removal of such emergent pollutants. Several studies have explained that two strong oxidants O_3 and HO^- cause the transformation of PCPPs and other organic compounds (Park *et al.,* 2017) (Esplugas *et al.,* 2007)

7.3.2 Advanced Oxidation Process (AOP)

Chemical oxidation process called as advanced oxidation process. During AOP hydroxyl ions (OH-) are generated, these hydroxyl ions are the strongest oxidants have ability to oxidize and mineralize the PCPPs and every organic matter into inorganic ions and CO_2 which are further removed by filtration and volatilization processes. At industrial level for waste water treatment the most common technique is Fenton process. This process utilizes iron salts and hydrogen peroxides. Fenton process is used when products are acidic such as pharmaceuticals and personal care products (Yu *et al.,* 2013).

7.3.3 Photo Catalysis

One of advanced technologies is photo catalysis that is efficient for 95% removal of PCPPs from wastewater and drinking water even PCPPs are present in trace amount. UV/ H_2O_2 and titanium dioxide photolysis are the types of process which involve oxidation by using light from UV lamps or solar radiations. The process of photolysis is efficient because this technique destroys PCPPs in water. By using TiO_2 photo catalysis more than 98% removal are obtained. H_2O_2 concentration for this purpose is used from 0.1 to 1mol/L (Sharifan *et al.,* 2016).

8. Conclusion

In recent years, pharmaceutical and personal care products have become one of the emerging pollutants in environment. They are known for high persistency and great solubility level in drinking and wastewater supply. It is important to have knowledge about the occurrence, sources and fate of PCPPs in drinking and wastewater treatment plants, as they persist in trace concentration ranging from nano gram to micro gram per liter. To ensure safe drinking water, it is important to eliminate PCPPs from water supply sources by using different technologies. Mechanical, biological and advance technologies are used for its effective removal, but despites all of these treatment methods, many studies found that PCPPs are unable to eliminate completely. The main reason is due to less knowledge about PCPPs behavior in drinking water resources. There may be lack of systematic monitoring at the municipal sites or lack of proper analytical sensitivity for detection of PCPPs in drinking water, which is present at a concentration of sub –ng/. Recently, among some advanced technologies, such as ozonation and photo catalysis processes are found much more effective than other technologies employed for its removal. The performance and cost of different technologies vary according to the nature of PCPPs. Therefore, it is important to evaluate the PCPPs effects on the performance of treatment, stability of processes in treatment plants. There should be better understanding about the occurrence, behavior, toxicity and appropriate technologies for PCPPs removal that will eventually help to ensure safe drinking water.

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Table 1: Summary of Treatment Technologies for the Removal of PPCPs from Drinking Water with Their Advantages and Limitations

Sr. No.	Technologies	Procedure	Advantages	Limitations
Mechanical Treatment				
1.	**Sand Filtration**	Constructed beds of sand or other suitable granular material usually two to three feet deep. As the drinking water containing PCPPs percolates slowly through the filter media, natural physical, biological, and chemical processes combine to provide treatment.	• Relatively simple process • Low operation and maintenance requirements	• Low removal efficiency • A problem with sand filters can be freezing.
2.	**Membrane Filtration**	Pressure driven process in which the membrane acts as a selective barrier to restrict the passage of residual PCPPs, and allowing relatively clear water to pass through Makes drinking water free from PCPPs. Pressure-driven membrane filtration includes: • Microfiltration (MF) • Ultrafiltration, (UF) • Nano filtration, (NF) • Reverse Osmosis (RO)	• Significant removal efficiency (especially NF and RO) • Less solid waste produced • Less chemical consumption • Less energy consumption	• High Initial and running cost • Low flow rates • Prone to membrane fouling
3.	**Adsorption** **1. GAC** **2. PAC**	Surface phenomenon with common mechanism for organic and inorganic pollutants removal. Effective advanced treatment process includes both granular and powdered form of activated carbon.	**GAC** • Widely used in drinking water treatment than PAC **PAC** • Less expensive • Finer particle size than GAC	**GAC** • Clogging Problem • High operating cost **PAC** • Labor intensive • Less efficient
Biological Treatment				
1.	**Membrane Bioreactor**	Adsorption, Biodegradation and membrane separation applied to remove PCPPs of all size.	• 80% PCPPs removal • Ability to operate under high feed load • High rate of degradation • Easily manages sludge concentration	• Membrane Pollution • High Cost • Stress on sludge in external MBR
2.	**Conventional Activated Sludge**	Reactors operated at (HRT), then for complete removal of pollutants from water are absorbed in biological sludge	• Cheapest procedure • High removal efficiency of PCPPs • Micro-sized pollutant can be removed	• During short HRTs removal rate is very low • High operational cost
Advanced Treatment				
1.	**Ozonation**	Dark Oxidation Process Two strong oxidants O^3 and HO^- used to transform PCPPs	• Removal Efficiency >99%, using high ozone concentration • Ozone has oxidizing properties • Applied at ambient temperature and pressure	• High energy required • High operational Cost • High Maintenance cost
2.	**Advanced Oxidation Process (AOP)**	Strong oxidants hydroxyl ions generate, which oxidizes and mineralize PCPPs in water Followed by filtration and volatilization	• Fast Treatment • Catalyst can be reused and regenerated repeatedly	• High capital and operating cost • Optimum pH conditions are typically acidic
3.	**Photocatalysis**	UV/H_2O_2 and TiO_2 photolysis oxidizes PCPPs in water even in trace amount	• Solar energy can be used at slow reaction rate • Catalysts can be used repeatedly • Removal efficiency >98%	• TiO_2 used in Photocatalysis is non-toxic and inexpensive • Lamp Performance deteriorates at high temperature