Peer-Reviewed/ISSN: 2663-1040 AJ Life Sci. 2022, 5 (1): 56-71 Review Article

Abasyn Journal of Life Sciences

Open Access

DOI: 10.34091/AJLS.5.1.6

A Review on Pharmaceutical Waste Pollution in Water: Extent, Management and Removal Strategies

Umair Riaz[1*], Laila Shahzad[2], Ambreen Aslam[3], Muhammad Akram Qazi[4], Muhammad Nasim[5], Wajiha Anum[6], Rehmat Ullah[7], Madiha Mobeen Khan[8], Ilyas Ahmad[9]

[1]*Department of Soil & Environmental Sciences, MNS-University of Agriculture Multan, Pakistan*
[2]*Sustainable Development Study Center, Government College University, Lahore, Pakistan*
[3]*Department of Environmental Sciences, University of Lahore, Pakistan*
[4]*Rapid Soil Fertility Research Institute, Lahore, Punjab, Pakistan*
[5]*Soil and Water Testing Laboratory for Research, Agriculture Department, Government of Punjab, Bahawalpur, Pakistan*
[6]*Regional Agricultural Research Institute, Bahawalpur, Pakistan*
[7]*Soil and Water Testing Laboratory for Research, Agriculture Department, Government of Punjab, Dera Ghazi Khan, Pakistan*
[8]*Entomology Section, Regional Agricultural Research Institute, Bahawalpur, Pakistan*
[9]*Pesticide Quality Control Laboratory, Multan, Agriculture Department, Government of Punjab, Pakistan*

Abstract

Pharmaceutical waste and presence of hazardous pollutants in them is a growing concern due to their fate, origin, higher rate of utilization and varying nature of active ingredients resulting in water contamination. However, there is few research on the graving nature of the problem. Cascading impacts on human and ecosystems can be expected from contaminated groundwater and other aquatic channels. While, various technologies used and studied for the removal/reduction/sedimentation of pharmaceutical pollutants. At the initial stages, level of toxicity should check with respect to flora, fauna, environment, and human health. Furthermore, the production of by-products from pharmaceutical pollutants should also be checked and regulated. These by-products can be much more toxic, than the original contaminants and can exert significant toxic effects. It was concluded that there should be ongoing efforts to reduce the cost associated with pharmaceutical waste and their pollutants removal processes to ensure sustainability in the environment and human being.

Keywords nanoparticles, oxidation, pharmaceutical pollution, radiation, sustainable environment, toxicity

Article Info:
Received:
February 10, 2022
Received Revised:
September 10, 2022
Accepted:
September 11, 2022
Available online:
September 17, 2022

***Corresponding author:**
umairbwp3@gmail.com,
umair.riaz@mnsuam.edu.pk

1. INTRODUCTION

The presence of pharmaceutical based pollutants has been widely studied in the aquatic environment ranging from drinking water to river, sea, or wastewater streams. The use of pharmaceuticals was reported

Published by Abasyn University

thousands of years back from different civilizations like Muslims, Chinese Hindu, Greek. The early use was usually extracted from natural products like herbs, vines, plants, their roots, or fungi[1]. Although with more advancement in medical sciences and related research, chemical-based pharmaceuticals were produced. As an outcome of this, pharmaceuticals-based pollutants were first reported in wastewater in 1976[2]. Yet last two decades proved to be more significant when it comes to analysing persistence of pharmaceutical waste in aquatic environment [3, 4].

The usage of pharmaceuticals has been increasing from the last few decades. Pharmaceutical products save millions of lives every year in the past due to lack of cure. Pharmaceutical products are blessing in disguise. Although it has emerged as a new class of contaminant for the environment. The product used in manufacturing of pharmaceutical products and other by-products produced have acute to chronic effects on environment. The waste produced from pharmaceutical products enters into the soil, water that ultimately contaminates the environment, pharmaceutical waste is spreading rapidly over the biosphere, the pristine areas of the globe like Antarctica; Polar Regions are also polluted with the pharmaceutical waste. Although the persistence capacity of the pharmaceuticals is not high but continuous, addition would lead to harmful and prolonged impact on the environment[5, 6].

Water pollution is a growing environmental problem, and its major contribution is related to the discharge of many chemical compounds and their resistance and persistence in aquatic environment. Pharmaceutical pollution is also referred to drug pollution[7] which may have serious consequences on the aquatic biota. On the other hand, the growing use of pharmaceuticals worldwide generated highest revenue of 1462 billion US dollars by 2021[8]. A variety of pharmaceuticals are available in market which includes many antibiotics, hormone replacements, antiseptics, antidepressants, analgesics, antipyretics, statins, and many more[3, 9]. There are many bioactive compounds in these pharmaceuticals which may have natural origin, or either derived from process of genetic engineering otherwise can be solely chemically manufactured[10]. Such enormous use of medications results in releasing many active pharmaceuticals ingredients (APIs) in the environment. The removal of these APIs in aquatic environment depends upon several factors, light & oxygen availability, pH, temperature, physiochemical properties and microbial communities[11]. Pharmaceutical pollutants are demonstrated in the environment from last many years. First studies (1970s) reported cardiac medicines, pain relievers, and contraceptives by USA in their wastewater[12, 13]. After this, most in-depth study was carried out by USGS (United States Geological Survey) reported almost 50 pharmaceutical based pollutants across thirty states in one hundred thirty-nine streams[14]. Lately studies were conducted in United Kingdom reporting almost twelve such compounds and their metabolites[15]. The resolution of the multi-criteria problem allowed the most efficient WWTPs in the removal of each PhAC to be classified, indicating that the criterion of technology was not overly important. However, some criteria were more relevant than others[16].

Persistence of pharmaceuticals in aquatic environment is also subject of interest because of growing use of these chemical compounds. Persistence is described as an inherent property of chemicals based on guided lab tests[11]. The United Nations Environmental Program (UNEP) arrays chemical persistence of a chemical as 60 days half-life. Pharmaceuticals are considered as pseudo-persistent as these are frequently detected in aquatic environments through high residual concentrations. Other viewpoint is due to their regular emission from sewerage treatments plants which in comparison is higher than their removal rates from environment. To explain this, there are three well researched pharmaceuticals considering their half-lives, diclofenac, carbamazepine, and ibuprofen. There is striking difference in their lab and field tests. Diclofenac has short half-life than 60 days, whereas ibuprofen has varied range from 19-413 days of half-life because of environmental conditions. Similarly, half-life for carbamazepine vary from 3.5 to 233 days. The contradictory results in varying half-lives were attributed to APIs[17, 18, 19]. There are many general sources of pharmaceuticals in environment which can be described broadly as raw and treated effluents of industries, hospital waste, run off from agricultural fields which were given sewage sludge or industrial waste, and excretions from human and livestock[20]. To date, based on scientific literature there are almost twenty-five pharmaceutical pollutants detected from drinking water or wastewater which need to be removed for health and safety of human and other animals. It has also been revealed that aquatic environments and effluents of sewage treatment plants contains bacteria along with antibiotics like tetracycline (TC) and sulfamethoxazole (SMX), thus affirming that bacteria are resistant to the mentioned antibiotics[21]. Furthermore, these bacteria can spread and proliferate into the environment and become source of disease for humans. The treated wastewater when applied to the plants can also cause detrimental effects to the plants like a stress response was induced in tomato plant by production of Reactive oxygen species (ROS), shock proteins, osmoregulation as well as causes expressions on defence genes[22]. Many countries still do not have any monitoring programs for the pharmaceutical's pollutants. There is dire need of research on active pharmaceutical ingredients and their metabolites to know their elimination method for aquatic bodies. Effective monitoring system is required for industrial influents, effluents, and waste disposal for developed and developing countries. This review article will illustrate the range of pharmaceutical wastes and their presence in water.

1.1 Chemistry and outlook of pharmaceuticals

Most commonly found chemicals in beginning of pharmaceuticals industry were caffeine, oestrogens, theophylline and tetracycline. There is still no proper legislation about the scrutiny of dumping of chemical waste. Scientists are still trying to find ways to decompose this waste because pharmaceutical products have potential to cause harmful impact on human beings as well as on environment. Millions of people use medicines on daily basis, thousands of companies are producing pharmaceuticals on daily basis and the waste ultimately generated in the form of human waste or from pharmaceutical industries enter into the soil, or water and its fate is ultimately entering into environment. The continuous addition of pharmaceuticals is called as ''a complex pharmaceutical pool''[5].

When pharmaceutical residue enters into soil the plants grown from this soil are also polluted and contaminated. There is various type of methods are used to remove pharmaceutical products waste from the environment which includes oxidation, photolysis, UV-degradation, and reverse osmosis. The treatment plants installed to clean the residual waste of pharmaceuticals or for treatment of the water treat less than 10% of the waste residue. The need of the hour is to study this type of waste from the broader spectrum including all its chemistry, remediation impacts and prospects from health point of view. The chemical composition of the pharmaceutical products is different from the chemical structures of the other products. Most of these products have lipophilic composition and some are water soluble due to which some accumulate in the environment, persist in environment and nature and remain active biologically and causing continuous impact on the environment[6].

The composition of the pharmaceutical products is so complex like there are bacteria that are unable to decompose or degrade these chemical products. The estimation shows by the end of 2020 pharmaceutical products reached to 4.5 trillion doses. The pharmaceutical products usage by the end of 2020 increased to 500 billion doses in the Middle East countries. There are various factors contribute in the usage of pharmaceutical products like socioeconomic conditions. The most common use of the pharmaceutical products is due to psychological issues, seasonal changes like use of such type of products is more common in the winters. In winter the spell of respiratory diseases increases due to which the use of pharmaceutical products also increases. The more shocking effect about pharmaceutical product is their use in animal husbandry. In animal husbandry, the use of pharmaceutical is more alarming than the human use because in fertilizers the use of pharmaceuticals, for the growth, biotechnology, culturing, due to which the waste produced from it directly enters into the water or become waste. More often the human waste is being treated but animal waste is directly dump into the water or become sludge. If we studied about the different classes or categories of the most commonly used pharmaceuticals, it is painkiller. The painkiller is mostly used on a wide scale in Asia. We can determine the use and ecological foot print of the pharmaceutical products continent wise. There are generally six factors that are used to determine the ecological footprint of the pharmaceutical waste. In developing countries although the exposure to such type of waste is wider but treatment scenario or capacity is below average. Therefore, it is a need of hour to treat such type of waste or dump it properly so that we can prevent it entering into the environment or pollute the environment[5,6].

1.2 Classification of pharmaceuticals pollutants in water

The umbrella of classification covers wide range of medications and the grouping is varying from countries to countries based on research and development. Many studies across UK, Europe and USA have reported the level of active pharmaceuticals ingredients detected in their drinking water or river bodies. Few studies have only detected levels in drinking water; however, most studies have reported pollutants in river channels. The monitoring of these bioactive molecules and metabolites have not been studied properly neither have not been reported more frequently as compare to their use and disposal into aquatic environments. Most studies have identified APIs in the effluents or influents of wastewater treatment plants. The below table is an effort to categorize the pharmaceutical based pollutants into certain groups considering the treatment for which it is used. The table is derived from the online studies, from WHO reports and other authentic data. There are no studies from developing countries on the graving issue yet [5; references of cited literature are given in table-1].

Table 1. Classification of identified pharmaceuticals in different parts of world (reported from drinking water or river water)

Pharmaceuticals detected	APIs	References	Environmental effects (Reported in different studies)
Analgesic	Ibuprofen	23	The most common effect of pharmaceutical products from their manufacturing chain to end of life is on water which is when ultimately consumed by aquatic creatures or by human beings it causes catastrophic and deleterious effects on all type of life forms. The complex chemical structures of the chemicals used in medicines production takes hundreds of years to decompose. But we human beings without any notice producing such waste on large scale and rather than proper treatment we are directly dumping into the aquatic environment.
Antibiotics	Amoxycillin Erythromycin Erythromycin Metronidazole	24 25	
Anti-depressants	Venlaflaxin, Moclobemid	26	
Anti-diabetic	Metformin	27	
Anti-inflammatory	Diclofenac	28	
Beta Blocker	Atenolol, Metoprolol	20 29	
Cardiac	Bisoprolol, Furosemide, Valsartan Trimetazidine	29 22	
Contraceptives	Levonorgestrel	27	
Gastric	Ranitidine		
Anxiolytic	Diazepam	24	
Hormone Replacement	Progesteron		
Antihistamine	Loratadine Ranitidine	30	
Lipid Regulator	Bezafibrate, Clofibric acid	20 27	
Non-steroidal anti-inflammatory drugs	Aspirin, Ibuprofen	31	
Seizures	Carbamazepine	20 32	

1.3 Pharmaceutical's pollutants cycle in water (cycle/sketch)

There is no clear pathway to describe how these pharmaceuticals travel through the environment, once prepared by certain industries or manufacturing units these chemicals enter a life cycle. Utilized by human and other animals, the pharmaceuticals pollutants may be excreted into wastewater treatment. From there, these pollutants have a fate to release in surface water, reaches groundwater or entering river/streams. Such transformations give a reach to drinking water. It can be said that these pollutants become part of food chains and food web on land or in water. The fate of pharmaceutical pollutants' is modified from few studies found in literature[32, 33]. The cycle of pharmaceutical waste entry in aquatic environment shows in Fig. 1.

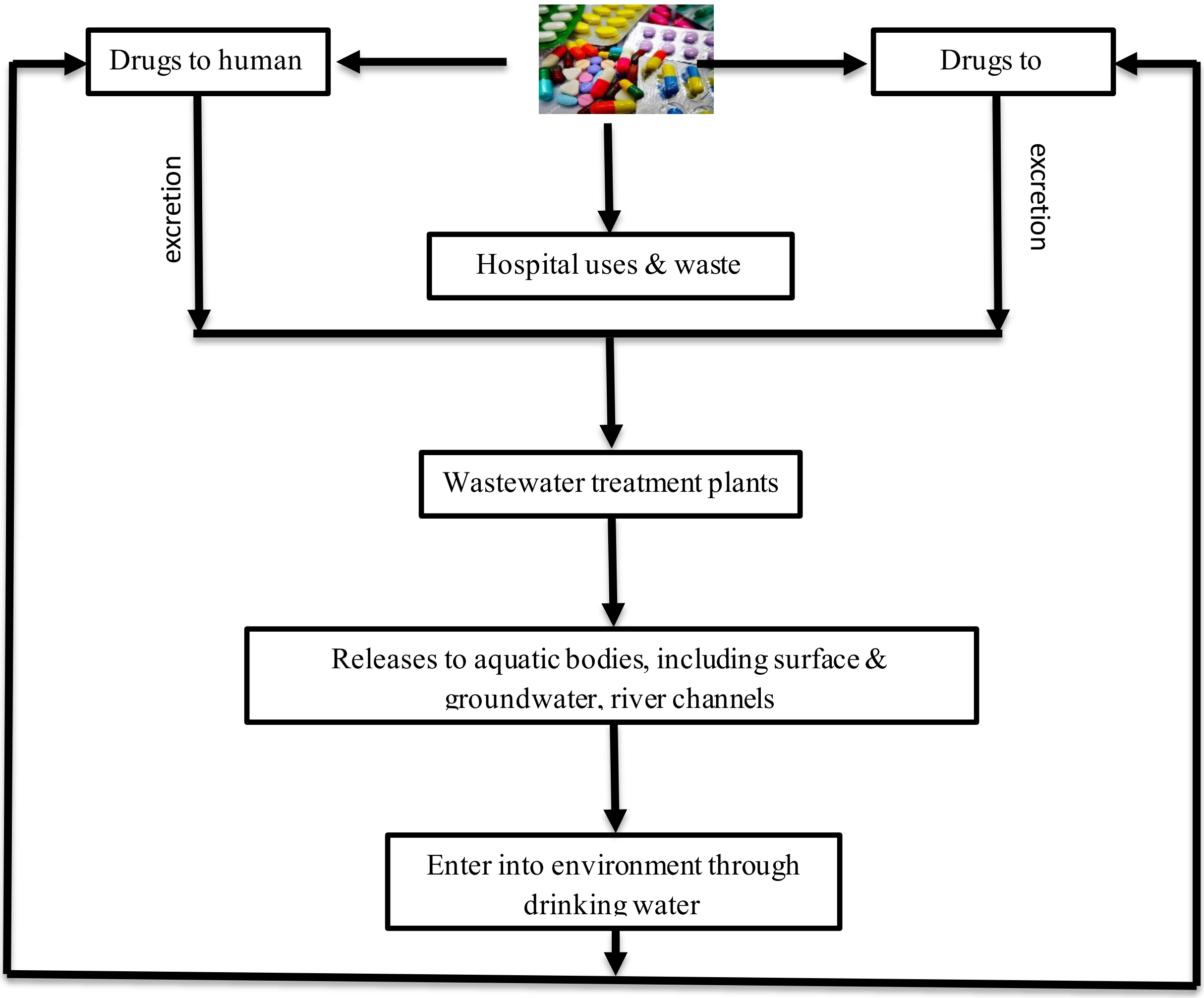

Fig. 1. The flowchart indicates how pharmaceuticals pollutants enter aquatic environment

2. TECHNOLOGIES FOR REMOVAL OF PHARMACEUTICAL POLLUTANTS FROM WATER

Engineering applications, and scientific research-based approaches are focused to find most sustainable, and economical solutions for the treatment of pharmaceutical pollutants in the wastewater, and other water sources. This wastewater can be treated by using various physical, chemical, and biological techniques. These techniques are essentially helpful to remove dangerous pharmaceutical pollutants from wastewater, and thus the potential impacts of pharmaceutical pollutants on human health, aquatic life, and environment can be significantly reduced.

2.1. Coagulation

Coagulation is the addition of specific chemical agents to the wastewater containing pharmaceutical compounds and is followed by dispersion by the rapidly mixing. In this way, stable pollutants are converted to precipitable, and unstable matters. The mechanism behind this process is quite complex, but is very important for squeezing, and removing water bound hydrophilic colloids. The characteristics of flocculants are greatly important as they are directly related to coagulation effects. This process can significantly remove pharmaceutical pollutants from wastewater, by enhancing their biodegradability[33].

2.2. Sedimentation

Sedimentation is another significant method and it causes separation of pollutants under the specific gravity. Both coagulation, and sedimentation have various advantages such as use of efficient and mature technologies, and easier operations. But these techniques are not much useful for the removal of dissolved organic matter and dissolved organic pharmaceutical pollutants[33].

2.3. Electro Oxidation

Electro-oxidation is most used technique for remediation of wastewater and is also known as anodic oxidation when there is no treatment of chloride solutions. This procedure causes removal of pharmaceutical pollutants by their oxidation in electrolytic cell. There is requirement of high cell voltage to ensure oxidation of water and pharmaceutical pollutants along with maintenance of anode activity. Now this process is not considered sustainable due to its high operational cost, and electrode fouling due to deposition of materials[34].

2.4. Flotation

Floatation technique is essentially helpful for the removal of suspended solids of pharmaceutical contaminants in the secondary effluents. In this process, tiny bubbles are produced by the injection of air to the wastewater, that in turn make the floating flocks having less density than the density of wastewater. Later, floating segments on the surface of wastewater can be separated[35].

2.5. Activated Carbon Adsorption

Activated carbon has good adsorption capacity and offer significant advantages for the removal of pharmaceutical pollutants from wastewater. It has multilevel pore structure, specific and large surface area, stable chemical properties, and high capacity of adsorption. So, it is widely used as catalyst carrier, or as adsorbent. It is specifically a good option for the removal of toxic pollutants which are hard to handle, and discharge. It is an advanced treatment for the removal of pharmaceutical pollutants from wastewater. Activated carbon adsorption is classified into two different types: chemical adsorption, and physical adsorption. Physical adsorption is specifically reversible process and there is no selectivity for the adsorbates. When the activated carbon becomes saturated with the adsorbates, then it can be easily desorbed. Whereas, chemical adsorption only adsorbs one or many specific adsorbates. This is an irreversible process, and its desorption is very difficult. Activated carbon can also restore its adsorption properties by regeneration and offers good cyclic utilization. This method offers advanced treatment for the removal of pharmaceutical pollutants from water, as it is sustainable, and effective treatment, as it can also be recycled. However, there are some drawbacks of using this technology, as it is expensive approach, and sometimes regeneration efficiencies are also reduced due to complex operational processes[36]. A number of investigations have been carried out that revealed the usage of layered double hydroxides (LDH) and their high adsorption capacities in energy, environment and biomedicine fields[37]. But only a few investigations are carried out on the usage of LDH based adsorbents in removal of pharmaceuticals[38].

2.6. Advanced Oxidation Process

Advance oxidation processes can easily oxidize the pharmaceutical pollutants by making the free radicals. There are different types of advanced oxidation processes such as supercritical water oxidation, ozonation, electrochemical oxidation, ultrasound oxidation, photocatalytic oxidation, Fenton reagent, and wet air oxidation. This technology offers additional and potential treatment for the removal of high concentrations of pharmaceuticals. Moreover, advanced oxidation process is more efficient than other technologies and offers good removal of pharmaceutical pollutants[39].

2.7. Membrane Separation

The working of membrane separation is based on driving forces across a specific membrane, and components of pharmaceutical pollutants in water are selectively permeating through this membrane through specific permselective membrane media for separation. This is an efficient way for purification, and separation of specific concentration of targeted substances from polluted water. There are various techniques of membrane separation such as electrodialysis, reverse osmosis, ultrafiltration, and microfiltration.

Technically, use of membrane separation is a good approach, but its application is limited due to associated operational cost. Although, this technology is widely used for the application of drinking water, but its application for the removal of pharmaceutical pollutants from wastewater on commercial scale is very limited. Findings of different scientific studies have proven that membrane bioreactors are more efficient to remove pharmaceutical pollutants from water than plants[40]. In nano-composite membranes, exfoliation of LDH is another aspect which enhances the adsorption capacity of particles as well as reduces agglomeration of particles in[41]. Nitrate anions were best in their exfoliation performance. It is also stated that inter laminar anions also play its role in governing the proton conductivity of the membranes[42].

2.8. Hybrid Technologies

Hybrid technologies are modern and most effective solution for removal of pharmaceutical pollutants from water. Many pharmaceutical companies are opting for membrane bioaugmentation hybrid technologies and the use of this technique is being increased all over the globe. Wastewater is fed in these bioreactors and containers are provided with biological elements such as enzymes and bacteria for bioaugmentation. The movement of water through the membranes causes the filtration of pharmaceutical contaminants, and microorganisms. Hybrid technologies produces cleanest quality water than any other technique and also helps in the recycling of removed elements or materials from the wastewater[43].

2.9. Irradiation

Irradiation is a process of removing organic, and inorganic pharmaceutical pollutants by exposing water to specified radiation. Different kinds of radiation sources such as UV light, and gamma rays can be used for this purpose. Irradiation is especially useful for removing antibiotics, and hormones. However, the removal efficiency is dependent on various factors such as source of light, and type of contaminants. Ionizing irradiation can remove 100% pharmaceutical pollutants from wastewater and is regarded as most efficient among all kinds of irradiation technologies. However, irradiation may cause serious health concerns to human beings. Moreover, it may also cause the production of by products, so this technology should be used with utmost care[44].

3. NANOTECHNOLOGY BASED ADVANCE TREATMENTS FOR REMOVAL OF PHARMACEUTICAL CONTAMINANTS

Recent advancement in nanomaterials, and nanotechnology has offered incredible wonders for the development of novel strategies for effective degradation of pharmaceutical contaminants. The size of nanomaterials is ranging between 1-100 nm, and they have excellent physico-chemical properties, such as catalytic activities, photosensitivity, surface activities, and high surface area. The surface of nanomaterials has excellent functionalization which significantly improves their chemical, and environmental stability, uses, and catalytic affinities towards targeted group/contaminants. At present, metal oxide nanomaterials, nanofiltration membranes, nano assisted advanced oxidation processes, nano adsorbents, graphene oxide, graphene, and carbon nanotubes are widely exploited for treatment of wastewater.

3.1. Nanofiltration

Membranes for nanofiltration are being widely explored for removing pharmaceutical pollutants in wastewater, as they are highly efficient and are very easy to operate. They offer good retention of different multivalent anionic salts, in significantly low investment. Selection of these membranes is greatly dependent on nature, and size of pollutants[45]. Incorporation of nanomaterials, in these membranes for flux enhancement, and mitigation of membrane fouling has been reported as a sustainable approach by various researchers[46].

3.2. Catalytic Ozonation

There is diverse use of ozonation for the removal of organic pollutants from wastewater and drinking water. However, pharmaceutical pollutants have slow ozonation kinetics as compare to other organic pollutants[47].

But reactivity of surface sites can be improved by increasing the surface area. Mass transfer, and modified nanomaterials serves as unique and highly efficient catalysts for these ozonation reactions[47]. The integration of intrinsic properties of nanomaterials, and ozonation exerts synergistic effects to remove pharmaceutical contaminants from wastewater. Sometimes, photocatalysis is also coupled with the process of ozonation to enhance the removal efficiencies of pharmaceutical pollutants. Although, catalytic ozonation offers excellent results, but practical uses of this methods are very limited. This limitation is possibly due to lack of understanding about specific mechanisms and hinderances in precise use of nano catalysts. However, the role off this process can be employed by developing a good understanding about its working mechanisms, and potential benefits of efficient removal of pharmaceuticals can be achieved in short time. Although, ozonation is a useful process but sometimes, it may lead to the production of toxic by-products[48].

3.3. Biochar

Biochar is a carbon-based material and it offers good adsorption of pharmaceutical contaminants. Its synthetic procedure, physiochemical properties, and structure is greatly like activated carbon. Biochar produced from different biomass sources has been found to be very effective for the removal of sulphapyridine, sulfamethoxazole, chloramphenicol, sulphonamides, sulfamethazine, and oxytetracycline[49]. Modification of biochar by the incorporation of nanomaterials significantly enhances its functionality, adsorption capacity, porosity, and surface area. High pore volume, and high surface area are strongly associated with the increased adsorption of pharmaceutical pollutants.

There are materials which have porous structures and high surface areas and can improve the photo-activity of Layered Double Hydroxide (LDH). Activated carbon, biochar and graphene derived compounds have structural defective sites and are widely used in LDH. The use of biochar results in a decrease of electron hole recombination in photocatalytic process owing to its remarkable electrical conductivity, it further leads to the enhanced oxidation rate of pollutants derived from pharmaceuticals. For example, the paper sludge and wheat husks derived biochar was used as a support material for the immobilizing ZnCo-LDH[50]. The adsorption of fluoxetine (FLX), selected as a model pollutant, in an eco-friendly adsorbent, biochar, was followed by an in-situ removal of the pharmaceutical in the solid matrix by the action of sulphate radicals. Initially, an in-depth characterisation of the adsorbent and the adsorption process was carried out. The pseudo-2nd order kinetic and Freundlich isotherm described well the process, and the electrostatic attractions were revealed as the primary adsorption mechanism. Later, the removal of the FLX was studied by the sulphate radicals, in the presence of activators (Fe^{2+} and citric acid), in liquid and onto the biochar medium. It was concluded that in order to enhance the pollutant removal it is necessary the presence of both activators in liquid media. However, in in-situ removal onto biochar, it was not necessary the Fe^{2+} presence and only the addition of complexing agents was required as a result of biochar's mineral content[51].

3.4. Carbon Nanotubes

Carbon nanotubes have unique physico-chemical properties, and mechanical, and electronical structure. They have high adsorption capacity and are ideal candidates for the removal of pharmaceutical pollutants from wastewater. Finding of various scientific studies have shown excellent recovery of pefloxacin, sulfamethazine, amoxicillin, norfloxacin, ofloxacin, cipro-floxacrine, tetracycline, iopromide, and sulphonamide. Adsorption capacities of powdered activated carbon, single walled carbon nanotubes, and multiwalled carbon nanotubes are significantly efficient for the removal of pharmaceutical contaminants. So, functional activation of carbon nanotubes is promising solution to introduce functional moieties for increased surface area for adsorption of pharmaceutical pollutants[52].

3.5. Zeolites

Zeolites are specifically minerals and they consist of microporous, and crystalline hydrates of aluminosilicates. They have exceptional intrinsic properties and are widely used as adsorbent, ion exchanger, and catalysts for wastewater treatment. Nano-zeolites have 3D structural framework and they are ideal candidates for the removal of pharmaceutical pollutants from wastewater due to their physico-chemical properties, and pore size. Although, natural zeolites are less efficient for the removal of pharmaceutical pollutants but chemically synthesized, and nanomaterial incorporated zeolites are greatly effective for the removal of different kinds of pharmaceutical pollutants such as ofloxacin drugs, sulfamethoxazole, azithromycin, sulphonamide, and sulfamethoxazole[53].

3.6. Nano-photocatalysts

Photocatalysis can be described as catalysis of specified photocatalytic reactions usually taking place at any solid surface. Extent, and nature of these reactions is greatly dependent on electron structures, bulk surface, and the intensity of photons absorption[54]. Recently, there has been a rapid expansion in the use of heterogenous photocatalysis focused on the use of nanomaterials for the removal of pharmaceutical compounds from wastewater. Various nanomaterials such as $ZnSnO_3$ nanospheres, tungsten dioxide (WO_3), cerium oxide, graphite carbon nitride (g C_3N_4) have tremendous fascinations to be used as photocatalysts for the removal of pharmaceutical pollutants. Catalytic efficiencies of these nanomaterials may be reduced due to multiple factors but such as low quantum efficiencies in the visible regions, and rapid recombination of electron hole pairs[54,55]. But these problems can be greatly avoided by using excellent techniques such as functionalization of nanoparticles, and nanomaterials, controlling stoichiometry reactions, effective modulation of defected sites, development, and proper use of heterojunction materials, and doping of metal oxides [54]. Evidences for the photocatalytic applications of (C_3N_4) were reported in 2006 after observation of photocatalytic splitting of water under specific visible light irradiation[55]. This compound is regarded as efficient photocatalysts as it has excellent flexibility and polymeric nature, so it is compatible outstanding host matrix for many nanoparticles. The use of graphitic carbon nitride removes pharmaceutical pollutants by forming intimate heterojunction along with semiconductors, and thereby significantly improves photocatalytic performance. Cerium oxide along with oxygen vacancies is also an excellent photocatalyst and offers good oxidation of numerous compounds. It has significant potential of offering visible light active photocatalysis[56]. Tungsten dioxide (WO_3) also has excellent properties for photocatalytic removal of pharmaceutical pollutants as it has high stability, and non-toxic nature. However, sometimes low conduction band edge can cause rapid recombination of exciton and may even cause less and inefficient photocatalytic activities. However, this problem can be easily fixed by using great care, and by deposition and doping of metals on tungsten dioxide and by coupling it with some other semiconductor[57]. The $ZnSnO_3$ is a novel photocatalyst as it contains hollow nanospheres and offers effective photocatalytic degradation of pharmaceutical pollutants under ultraviolet light irradiation. Moreover, its photocatalytic activities can be significantly improved by its coupling with graphene oxide that will cause improved visible light absorption, and adsorption efficiencies[58]. Numerous investigations have reported the high photocatalytic efficiency of TiO_2 for the degradation of organic pollutants. Nevertheless, the catalytic activity of this commercial photocatalyst is compromised by the high agglomeration of the particles and complicated recovery process after each catalytic cycle. Mourid et al[59], supported TiO particles on ZnAl-LDH by a solid-state impregnation method. The TiO_2/ZnAl-LDH heterostructure displayed an enhanced catalytic activity in the degradation of sulfamethoxazole (SMX) under UV-A irradiation as well as an excellent recyclability.

Table 2.

Technique	Description
Coagulation	Removal by addition of specific chemical agent, and dispersion by rapid mixing[33]
Sedimentation	Separation of pollutants under specific gravitational conditions[33]
Electro oxidation	Removal of pollutants by their oxidation in electrolytic cells[34]
Floatation	Removal of suspended pharmaceutical pollutants in the form of floating segments[35]
Activated carbon adsorption	Removal of pharmaceutical pollutants by physical and chemical adsorption[36]

Advanced oxidation process	Removal of pharmaceutical pollutants by their oxidation and making free radicals[37]
Membrane separation	Removal of pharmaceutical pollutants by driving forces across a specific membrane[38]
Hybrid technologies	Removal of pharmaceutical pollutants by the combined action of various technologies[39]
Irradiation	Removal of pharmaceutical pollutants by exposing water to specified radiation[44]
Nanofiltration	Removal of pharmaceutical pollutants by the incorporation of nanomaterials in specific membranes[46]
Catalytic ozonation	Removal of pharmaceutical pollutants by direct or indirect oxidation with ozone[47]
Biochar	Removal of pharmaceutical pollutants by adsorption[48,49]
Carbon nanotubes	Removal of pharmaceutical pollutants by adsorption[52]
Zeolites	Removal of pharmaceutical pollutants by adsorption[53]
Nano-photocatalysts	Removal of pharmaceutical pollutants by photocatalytic reactions[54]

4. Health Effects Associated with Pharmaceutical Waste

According to surveys, health centre waste is one of the most perilous types of wastes because of all the pathogens and hazardous substances that can spread diseases as well as the direct or indirect effects on the staff dealing with healthcare, the sick people, the individuals who interact with the waste and the environment. Hospital wastes are divided into hazardous and non-hazardous types. The none hazardous are all those wastes that consist of domestic and municipal wastes and the hazardous ones are all those wastes that consist of contagious, pathogenic, genotoxic, chemical and pharmaceutical substances, sharps, waste containing heavy metals, pressurized containers and radioactive substances[60]. Sharp wastes like needles and knife are tremendously dangerous and have lethal effects on human health. Similarly, genotoxic, pharmaceutical, pressurized waste causes the different types of cancer, skin diseases, asthma and blood borne diseases. The hazardous intensity of medical waste is further increased when it is mixed with domestic waste[61]. About 10-25% of the total health centres' waste is hazardous. Some kinds of illnesses such as cholera, dysentery, skin infection and infectious hepatitis can spread epidemically[62] showed some of the potential micro-organisms and the infected ways in the bodies of humans. Some infection types are gastro enteric infections, respiratory infections, AIDS and viral hepatitis A, B & C[63]. The medical waste management elements include waste segregation, storage, transportation, disinfection and final disposal[64].

While clear links between cause and effect are disputed and often hard to discern, however a general perception is that medical waste comprise toxic compounds which have damaging effects on health of ecosystems components (vertebrates, invertebrates, ecosystem structure and function). However, it is quite difficult to assess their impacts owing to certain factors. For instance, there are chances that small and microorganisms are under the negative influence of pharmaceutical waste, however their impact is not fully known unless a deep and extensive research is carried out. Other gaps which veil the exact impact may include misleading and underplay of toxic substances when they are assessed at individual level and may render different results when they are assessed in aggregates[65].

Public behaviours and expectations also play a key role in use and misuse of medicines. Research has demonstrated, for example, how socially and culturally defined norms can problematize certain forms of appearance or behaviours, which then get defined in medical terms, understood through the use of a medical framework, or treated with a medical intervention. The increasing availability of methylphenidate, for example, has been said to have accelerated the acceptance of attention-deficit hyperactivity disorder (ADHD) as a medicalized description of disruptive behaviours in children[66], while the same drug has recently been re-marketed to improve cognitive performance among healthy people[67].

5. Future prospect and challenges of pharmaceutical pollutant

Over past two decades rapid development has significantly influenced personal, and community's apprehension for healthcare, and better hygiene. Emergence of pharmaceutical sector as main beneficiary of progress has witnessed greatly improved affordability, and accessibility. Although, these pharmaceutical compounds are extremely important for life saving but some endocrine disrupting chemicals, and pharmaceutical compounds have been categorized as emerging contaminants. These contaminants have ultra-low biodegradability and recalcitrant nature. So, scientists, researchers should focus to use efficient, cost-effective, and sustainable technologies to removing these pharmaceutical pollutants from aquatic sources. Portable water is a significantly important for growing global population. However, the presence of pharmaceuticals in water is creating, health and environmental concerns, and loss of biodiversity[67]. Increased diversification and levels of pharmaceuticals in water sources is accelerating various dangerous global changes such as pollution due to nutrients, habitat destruction, and increased level of carbon dioxide, leading to global warming, and climate change.

Pharmaceuticals are widely used across the world, and they are significantly important components of health care system, but their inappropriate handling, and disposal is creating serious concerns. Various studies have reported the worldwide presence of pharmaceuticals in the drinking water, ground water, surface water, sediments, and soil biota[66,67]. Detection of nature of pharmaceutical pollutants in wastewater is a major concern, and it must be studied for the efficient remediation of water sources on sustainable basis. The composition of wastewater containing pharmaceutical pollutants is very complex, as wastewater also contains high salt contents, microbial toxicities, and organic matter. So, their interaction with other kind of contaminants in water can produce even more toxic products. Although, there are many operational plants for the removal of pharmaceutical pollutants by the treatment of wastewater, but these are not specifically designed for the removal of all kinds of pharmaceutical compounds. So, the wastewater should only be discharged after proper treatment for removal of pharmaceutical compounds. Generally, wastewater, and water sources contains higher proportion of veterinary pharmaceuticals. These pharmaceuticals are directly entering to fresh water and ground water sources through leaching or surface runoff, and are causing significant problems to human beings, wildlife, microbiota, and environment. Furthermore, they are also reducing the fertility, and productivity of agricultural lands, so some serious measures should be taken to reduce the occurrence of these harmful compounds in water. The level of pharmaceutical pollutants in water will be increased with increase in the life span of population, growth of economy, intensification of aquaculture, and livestock practices, and manufacturing of new pharmaceuticals. So, modern technologies must be applied to remove the entries of pharmaceuticals to water sources[67].

There should be strong collaboration between pharmacists, agricultural researchers, soil scientists, and meteorologists to manage concentration dependent factors, identification of important environmental sinks, modification of pharmaceutical properties, concentration patterns such as seasonal, and intermittent, determination of point, and non-point sources for efficient management and handling. There should be ongoing efforts in the research and development sector for cross cutting, designing, authorization, production, consumption (professional use/self-prescription), collection, and disposing off activities, and water treatment technologies. The mitigation and remediation tasks can be greatly achieved by the strong collaboration between government, industries, intergovernmental organizations, health sector, agriculture, consumer behaviour management, utilization of solid waste, and drinking water utilities. There should be a good categorization of pharmaceuticals, based on their potential toxicity, safety, and neutral aspects. Unnecessary use of antibiotics, veterinary, and human pharmaceuticals should be reduced, and efficient regulatory activities should be implemented for safe disposal of pharmaceuticals, in the specialized dump, and disposal sites. Implementation of environmental checklist should be ensured to cut the ever-increasing levels of pharmaceuticals in water sources, and wastewater. Collection and disposal activities and program should be promoted at both national and international levels, and these sites can also be accessed by the pharmacies for future research, and developmental perspectives. There should be implementation of collective approaches for the management of pharmaceuticals in the water sources. The use of specialized scientific designing, and implementation of use oriented, and source directed approaches should be promoted by the establishment of good combination of economic, volunteer, and well-organized regulatory measures. Furthermore, there should be strategic action plans for the management and regulation of contamination risks. Effective implantation can only be made possible by using strategies financial strategies[67].

There should be proper risk assessment of specific environmental and health concerns of presence of pharmaceuticals in water, and sediments. Research programs for developing degradable, and less toxic pharmaceuticals should be supported for labelling different standards of pharmaceuticals. Pharmacists, and doctors should promote the production and use of safe, and environmentally friendly pharmaceuticals. Total consumption of pharmaceuticals should be optimized and reduced by prescribing smaller packets of specific medicines for first time use. Behavioural changes, and physical activities to promote healthier lifestyles should be prescribed. There should be awareness campaigns for proper disposal or collection of expired, and unused medicines. Moreover, new business models should also be developed instead of retailer type business. Furthermore, health sectors should have specialized focus to promote E-health, and IT based health care services. Identification of point sources and proper investigation of effects of specific pharmaceuticals should be properly studied. Studying prominent point sources such as oncology clinics, psychiatric, hospitals, and retirements homes, should more focused to develop efficient and sustainable strategies to minimize the entries of pharmaceutical pollutants in water. Treatment of wastewater needs holistic approaches to address the problem of pharmaceutical contamination. There is a dire need of to implement coherent actions at different levels to reduce the hazards of pharmaceutical contamination. Although, there are many efficient scientific technologies, but some of them have some dark sides, in terms of costs, and efforts. So, this challenge should be solved on sustainable basis, without exerting any negative influence on economy, health, and environment.

CONCLUSIONS

Pharmaceuticals are compounds prepared to treat targeted health issues, these can be natural or synthetic. These chemicals contain active ingredients which further transform and become major pollutants which persist in environment. These enter in aquatic bodies through various chains and may be very harmful in their bioactive nature. There is a dire need of research and policy call up on this growing issue due to ubiquitous nature of pharmaceuticals. Although, many techniques are being employed and some are being tested and researched for the removal of pharmaceutical pollutants from water, but removal efficiency is most important concern for all techniques. The level of toxic concentration of pharmaceutical pollutants in water should be checked and removed to minimize the damage to human beings, livestock, and environment. Moreover, the production of by-products from pharmaceutical pollutants should also be checked and regulated. These by-products can be much more toxic, than the original contaminants and can exert significant toxic effects. Furthermore, there should be ongoing efforts to reduce the cost associated with pharmaceutical removal processes to ensure sustainability

CONFLICT OF INTEREST

No conflict of interest

REFERENCES

1. Jones, A. W. (2011). Early drug discovery and the rise of pharmaceutical chemistry. Drug testing and analysis, 3(6), 337-344.
2. Garrison-Gund, C. K., & Neff, N. H. (1976). Deuterium-labeled choline: Lack of isotope effects during the synthesis and catabolism of acetylcholine in vivo. Neurochemical research, 1(6), 679-682.
3. Zou, H., MacLeod, M., & McLachlan, M. S. (2014). Evaluation of the potential of benchmarking to facilitate the measurement of chemical persistence in lakes. Chemosphere, 95, 301-309.
4. Bu, Q., Wang, B., Huang, J., Deng, S., & Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. Journal of hazardous materials, 262, 189-211.
5. Organization W. H. (2012). Pharmaceuticals in drinking-water.

6. Patel, M., Kumar, R., Kishor, K., Mlsna, T., Pittman Jr, C. U., & Mohan, D. (2019). Pharmaceuticals of emerging concern in aquatic systems: chemistry, occurrence, effects, and removal methods. Chemical reviews, 119(6), 3510-3673.
7. Obimakinde, S., Fatoki, O., Opeolu, B., & Olatunji, O. (2017). Veterinary pharmaceuticals in aqueous systems and associated effects: an update. Environmental Science and Pollution Research, 24(4), 3274-3297.
8. González Peña, O. I., López Zavala, M. Á., & Cabral Ruelas, H. (2021). Pharmaceuticals Market, Consumption Trends and Disease Incidence Are Not Driving the Pharmaceutical Research on Water and Wastewater. International Journal of Environmental Research and Public Health, 18(5), 2532.
9. Bu, Q., Wang, B., Huang, J., Deng, S., & Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. Journal of hazardous materials, 262, 189-211.
10. Khetan, S. K., & Collins, T. J. (2007). Human pharmaceuticals in the aquatic environment: a challenge to green chemistry. Chemical reviews, 107(6), 2319-2364.
11. Boethling, R., Fenner, K., Howard, P., Klečka, G., Madsen, T., Snape, J. R., & Whelan, M. J. (2009). Environmental persistence of organic pollutants: guidance for development and review of POP risk profiles. Integrated Environmental Assessment and Management: An International Journal, 5(4), 539-556.
12. Garrison, A. W. (1976). GC/MS analysis of organic compounds in domestic wastewaters. Identification and analysis of organic pollutants in water.
13. Hignite, C., & Azarnoff, D. L. (1977). Drugs and drug metabolites as environmental contaminants: chlorophenoxyisobutyrate and salicylic acid in sewage water effluent. Life Sciences, 20(2), 337-341.
14. Kolpin, D. W., Furlong, E. T., Meyer, M. T., Thurman, E. M., Zaugg, S. D., Barber, L. B., & Buxton, H. T. (2002). Response to comment on "pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999− 2000: a national reconnaissance". Environmental Science & Technology, 36(18), 4007-4008.
15. Ashton, D., Hilton, M., & Thomas, K. V. (2004). Investigating the environmental transport of human pharmaceuticals to streams in the United Kingdom. Science of the total environment, 333(1-3), 167-184.
16. Fernández-López, C., García, M. G., & Sánchez-Lozano, J. M. (2021). Analysis of WWTPs technologies based on the removal efficiency of Pharmaceutical Activated Compounds for water reuse purposes. A Fuzzy Multi-Criteria Decision Making approach. Journal of Water Process Engineering, 42, 102098.
17. Zou, H., Radke, M., Kierkegaard, A., MacLeod, M., & McLachlan, M. S. (2015). Using chemical benchmarking to determine the persistence of chemicals in a Swedish lake. Environmental science & technology, 49(3), 1646-1653.
18. Yamamoto, H., Nakamura, Y., Moriguchi, S., Nakamura, Y., Honda, Y., Tamura, I., ... & Sekizawa, J. (2009). Persistence and partitioning of eight selected pharmaceuticals in the aquatic environment: laboratory photolysis, biodegradation, and sorption experiments. Water research, 43(2), 351-362.
19. Daughton, C. G. (2003). Cradle-to-cradle stewardship of drugs for minimizing their environmental disposition while promoting human health. I. Rationale for and avenues toward a green pharmacy. Environmental Health Perspectives, 111(5), 757-774.
20. Rzymski, P., Drewek, A., & Klimaszyk, P. (2017). Pharmaceutical pollution of aquatic environment: an emerging and enormous challenge. Limnol. Rev, 17(2), 97-107.
21. Vickers, N. J. (2017). Animal communication: when i'm calling you, will you answer too?. Current biology, 27(14), R713-R715..
22. Gorovits, R., Sobol, I., Akama, K., Chefetz, B., & Czosnek, H. (2020). Pharmaceuticals in treated wastewater induce a stress response in tomato plants. Scientific reports, 10(1), 1-13.
23. Bound, J. P., & Voulvoulis, N. (2005). Household disposal of pharmaceuticals as a pathway for aquatic contamination in the United Kingdom. Environmental health perspectives, 113(12), 1705-1711.
24. Ogunbanwo, O. M., Kay, P., Boxall, A. B., Wilkinson, J., Sinclair, C. J., Shabi, R. A., ... & Brown, L. E. (2020). High Concentrations of Pharmaceuticals in a Nigerian River Catchment. Environmental Toxicology and Chemistry.
25. Giebułtowicz, J., Nałęcz-Jawecki, G., Harnisz, M., Kucharski, D., Korzeniewska, E., & Płaza, G. (2020). Environmental risk and risk of resistance selection due to antimicrobials' occurrence in two Polish wastewater treatment plants and receiving surface water. Molecules, 25(6), 1470.

26. Giebułtowicz, J., & Nałęcz-Jawecki, G. (2014). Occurrence of antidepressant residues in the sewage-impacted Vistula and Utrata rivers and in tap water in Warsaw (Poland). Ecotoxicology and Environmental Safety, 104, 103-109.
27. Kot-Wasik, A., Jakimska, A., & Śliwka-Kaszyńska, M. (2016). Occurrence and seasonal variations of 25 pharmaceutical residues in wastewater and drinking water treatment plants. Environmental monitoring and assessment, 188(12), 1-13.
28. Khetan, S. K., & Collins, T. J. (2007). Human pharmaceuticals in the aquatic environment: a challenge to green chemistry. Chemical reviews, 107(6), 2319-2364.
29. Giebułtowicz, J., Stankiewicz, A., Wroczyński, P., & Nałęcz-Jawecki, G. (2016). Occurrence of cardiovascular drugs in the sewage-impacted Vistula River and in tap water in the Warsaw region (Poland). Environmental Science and Pollution Research, 23(23), 24337-24349.
30. Santos, A. V., Couto, C. F., Lebron, Y. A. R., Moreira, V. R., Foureaux, A. F. S., Reis, E. O., ... & Lange, L. C. (2020). Occurrence and risk assessment of pharmaceutically active compounds in water supply systems in Brazil. Science of The Total Environment, 746, 141011.
31. Baranowska, I., & Kowalski, B. (2012). A rapid UHPLC method for the simultaneous determination of drugs from different therapeutic groups in surface water and wastewater. Bulletin of environmental contamination and toxicology, 89(1), 8-14.
32 Kasprzyk-Hordern, B., Dinsdale, R. M., & Guwy, A. J. (2007). Multi-residue method for the determination of basic/neutral pharmaceuticals and illicit drugs in surface water by solid-phase extraction and ultra performance liquid chromatography–positive electrospray ionisation tandem mass spectrometry. Journal of Chromatography A, 1161(1-2), 132-145.
33. Guo, Y., Qi, P. S., & Liu, Y. Z. (2017, May). A review on advanced treatment of pharmaceutical wastewater. In IOP Conference Series: Earth and Environmental Science (Vol. 63, No. 1, p. 012025). IOP Publishing.
34. Brillas, E., & Sirés, I. (2015). Electrochemical removal of pharmaceuticals from water streams: reactivity elucidation by mass spectrometry. TrAC Trends in Analytical Chemistry, 70, 112-121.
35. Shahid, M. J., Arslan, M., Ali, S., Siddique, M., & Afzal, M. (2018). Floating wetlands: a sustainable tool for wastewater treatment. Clean–Soil, Air, Water, 46(10), 1800120.
36. Abdel–Gawad, S. A., & Abd El–Aziz, H. M. (2019). Removal of pharmaceuticals from aqueous medium using entrapped activated carbon in alginate. Air, Soil and Water Research, 12, 1178622119848761.
37. Laipan, M., Yu, J., Zhu, R., Zhu, J., Smith, A. T., He, H., ... & Sun, L. (2020). Functionalized layered double hydroxides for innovative applications. Materials Horizons, 7(3), 715-745.
38. Santamaría, L., Vicente, M. A., Korili, S. A., & Gil, A. (2020). Progress in the removal of pharmaceutical compounds from aqueous solution using layered double hydroxides as adsorbents: A review. Journal of Environmental Chemical Engineering, 104577.
39 Giwa, A., Yusuf, A., Balogun, H. A., Sambudi, N. S., Bilad, M. R., Adeyemi, I., ... & Curcio, S. (2021). Recent advances in advanced oxidation processes for removal of contaminants from water: A comprehensive review. Process Safety and Environmental Protection, 146, 220-256.
40. Obotey Ezugbe, E., & Rathilal, S. (2020). Membrane technologies in wastewater treatment: a review. Membranes, 10(5), 89.
41. Jia, Z., Hao, S., & Lu, X. (2018). Exfoliated Mg–Al–Fe layered double hydroxides/polyether sulfone mixed matrix membranes for adsorption of phosphate and fluoride from aqueous solutions. Journal of Environmental Sciences, 70, 63-73.
42. Safarpour, M., Arefi-Oskoui, S., & Khataee, A. (2020). A review on two-dimensional metal oxide and metal hydroxide nanosheets for modification of polymeric membranes. Journal of Industrial and Engineering Chemistry, 82, 31-41.
43. Dhangar, K., & Kumar, M. (2020). Tricks and tracks in removal of emerging contaminants from the wastewater through hybrid treatment systems: A review. Science of the Total Environment, 738, 140320.
44. Abdel Rahman, R. O., & Hung, Y. T. (2020). Application of ionizing radiation in wastewater treatment: An overview. Water, 12(1), 19.
45. Hilal, N., Al-Zoubi, H., Darwish, N. A., Mohamma, A. W., & Arabi, M. A. (2004). A comprehensive review of nanofiltration membranes: Treatment, pretreatment, modelling, and atomic force microscopy. Desalination, 170(3), 281-308.
46. Li, J. F., Xu, Z. L., Yang, H., Yu, L. Y., & Liu, M. (2009). Effect of TiO2 nanoparticles on the surface morphology and performance of microporous PES membrane. Applied Surface Science, 255(9), 4725-4732.

47. Gonçalves, A., Órfão, J. J., & Pereira, M. F. R. (2013). Ozonation of bezafibrate promoted by carbon materials. Applied Catalysis B: Environmental, 140, 82-91.
48. Quiñones, D. H., Álvarez, P. M., Rey, A., Contreras, S., & Beltrán, F. J. (2015). Application of solar photocatalytic ozonation for the degradation of emerging contaminants in water in a pilot plant. Chemical Engineering Journal, 260, 399-410.
49. Ahmed, M. B., Zhou, J. L., Ngo, H. H., Guo, W., Johir, M. A. H., & Belhaj, D. (2017). Competitive sorption affinity of sulfonamides and chloramphenicol antibiotics toward functionalized biochar for water and wastewater treatment. Bioresource technology, 238, 306-312.
50. Gholami, P., Khataee, A., Soltani, R. D. C., Dinpazhoh, L., & Bhatnagar, A. (2020). Photocatalytic degradation of gemifloxacin antibiotic using Zn-Co-LDH biochar nanocomposite. Journal of hazardous materials, 382, 121070.
51. Escudero-Curiel, S., Penelas, U., Sanromán, M. Á., & Pazos, M. (2021). An approach towards Zero-Waste wastewater technology: Fluoxetine adsorption on biochar and removal by the sulfate radical. Chemosphere, 268, 129318.
52. Xiong, W., Zeng, Z., Li, X., Zeng, G., Xiao, R., Yang, Z., ... & Zhang, Y. (2018). Multi-walled carbon nanotube/amino-functionalized MIL-53 (Fe) composites: remarkable adsorptive removal of antibiotics from aqueous solutions. Chemosphere, 210, 1061-1069.
53. de Sousa, D. N. R., Insa, S., Mozeto, A. A., Petrovic, M., Chaves, T. F., & Fadini, P. S. (2018). Equilibrium and kinetic studies of the adsorption of antibiotics from aqueous solutions onto powdered zeolites. Chemosphere, 205, 137-146.
54. Chauhan, A., Sillu, D., & Agnihotri, S. (2019). Removal of pharmaceutical contaminants in wastewater using nanomaterials: A comprehensive review. Current drug metabolism, 20(6), 483-505.
55. Wang, X., Maeda, K., Thomas, A., Takanabe, K., Xin, G., Carlsson, J. M., ... & Antonietti, M. (2009). A metal-free polymeric photocatalyst for hydrogen production from water under visible light. Nature materials, 8(1), 76-80.
56. Muduli, S. K., Wang, S., Chen, S., Ng, C. F., Huan, C. H. A., Sum, T. C., & Soo, H. S. (2014). Mesoporous cerium oxide nanospheres for the visible-light driven photocatalytic degradation of dyes. Beilstein journal of nanotechnology, 5(1), 517-523.
57. Abe, R., Takami, H., Murakami, N., & Ohtani, B. (2008). Pristine simple oxides as visible light driven photocatalysts: highly efficient decomposition of organic compounds over platinum-loaded tungsten oxide. Journal of the American Chemical Society, 130(25), 7780-7781.
58. Dong, S., Sun, J., Li, Y., Yu, C., Li, Y., & Sun, J. (2014). ZnSnO3 hollow nanospheres/reduced graphene oxide nanocomposites as high-performance photocatalysts for degradation of metronidazole. Applied Catalysis B: Environmental, 144, 386-393.
59. Mourid, E. H., El Mersly, L., Benaziz, L., Rafqah, S., & Lakraimi, M. (2020). Development of a new recyclable nanocomoposite LDH-TiO_2 for the degradation of antibiotic sulfamethoxazole under UVA radiation: An approach towards sunlight. Journal of Photochemistry and Photobiology A: Chemistry, 396, 112530.
60. Mumtaz, R., Khan, A. A., Noor, N., & Humayun, S. (2010). Amalgam use and waste management by Pakistani dentists: an environmental perspective. EMHJ-Eastern Mediterranean Health Journal, 16 (3), 334-339, 2010.
61. Khan, a. A., kanwal, n., & khan, k. (2020). Medical solid waste generation and associated health problems in bahawalpur city of southern punjab, Pakistan, Pakistan Geographical Review, 75(2) 115-137.
62. Pruss-Ustun, A., Giroult, E., Rushbrook, P., & World Health Organization. (1999). Safe management of wastes from health-care activities. World Health Organization.
63. Jafarzadeh-Ghoushchi, S., & Dorosti, S. (2017). Effects of Exposure to a Variety of Waste on Human Health-A Review. Journal of the Liaquat University of Medical and Health Sciences, 16(1), 3-9.
64. Torkashvand, J., Pasalari, H., Jonidi-Jafari, A., Kermani, M., Nasri, O., & Farzadkia, M. (2020). Medical waste management in Iran and comparison with neighbouring countries. International Journal of Environmental Analytical Chemistry, 1-14.
65. Europeia, C. (2010). European Environmental Agency. Pharmaceuticals in the environment. Results of an EEA Workshop 2010. Office for Official Publication for the European Communities.
66. Conrad, P. (2006). Identifying hyperactive children: the medicalization of deviant behavior. Ashgate Publishing, Ltd.

67. Greely, H., Sahakian, B., Harris, J., Kessler, R. C., Gazzaniga, M., Campbell, P., & Farah, M. J. (2008). Towards responsible use of cognitive-enhancing drugs by the healthy. Nature, 456(7223), 702-705.