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# AGROCHEMICALS AND PERSONAL CARE PRODUCTS: OCCURRENCE, EFFECTS, ANALYTICAL DETERMINATION AND TREATMENT PROCESSES

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## ABSTRACT

*Pollution caused by agrochemicals and personal care products (PCPs) remains a severe problem worldwide. Runoff of agrochemicals from farms leads to contamination of the surface water and groundwater while PCPs are discharged through laundering, washing and bathing. PCPs enter the municipal wastewater treatment plants and are incompletely removed during wastewater treatment. To reduce or eliminate the negative impact of these pollutants to human beings, animals, organisms and the environment, water should be well treated and wastewater should be treated to zero release before discharge into the environment. In this study, the occurrence, toxic effects, analytical determination and treatment processes of agrochemicals and PCPs in water and wastewater will be presented. This review will serve as valuable literature for researchers, policy makers, and environmental pollution consultants. Moreover, it will open the door to significant discussion on agrochemicals and PCPs.*

**Keywords:** Agrochemicals, Personal care products, Environmental pollution, Wastewater, Drinking water, Treatment techniques.

## Contribution/ Originality

This study documents the occurrence, toxic effects, analysis and remediation of agrochemicals and personal care products (PCPs) in water and wastewater. The review contributes in the existing literature that the use of agrochemicals and PCPs contributes to organic pollution. Therefore, it is crucial to develop rapid and sensitive analytical techniques for the determination of agrochemicals and PCPs. Excellent treatment methods are also anticipated.

## 1. INTRODUCTION

Agrochemicals (Fig. 1) are pesticides, insecticides, fungicides and herbicides used in agriculture and urban areas to control unwanted organisms such as insects, pest, fungi etc. and weeds. These chemicals are applied directly to land and can be transported to water bodies following rainfalls, while seepage and leaching processes enable infiltration directly into

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groundwater [1]. Agricultural activities such as the application of these chemicals e.g hexachlorobenzene (HCB), dichloro-diphenyl-trichloroethane (DDT), pentachlorophenol etc. to farmlands and incessant discharge of livestock effluent contaminate the environment with potentially toxic organic compounds. Other organohalogens (agrochemicals) include mirex, toxaphene, heptachlor, chlordane etc. Personal care products (PCPs; Fig. 2) on the other hand are antibacterial and antifungal agents in consumer products (toothpaste, mouthwash, medical skin creams, hand-disinfecting soaps, deodorant, household cleaners etc). PCPs are discharged through household activities such as laundering, washing and bathing. They are also not completely removed at the wastewater treatment plants (WWTPs) and are being discharged with effluent into receiving streams, thereby causing harmful effects to aquatic organisms and even humans. The physicochemical properties of selected agrochemicals and PCPs are presented in Table 1. This paper will give an overview of agrochemicals and PCPs contamination in water and wastewater. The efficiency and shortcomings of various treatment processes are also overviewed and critically compared.

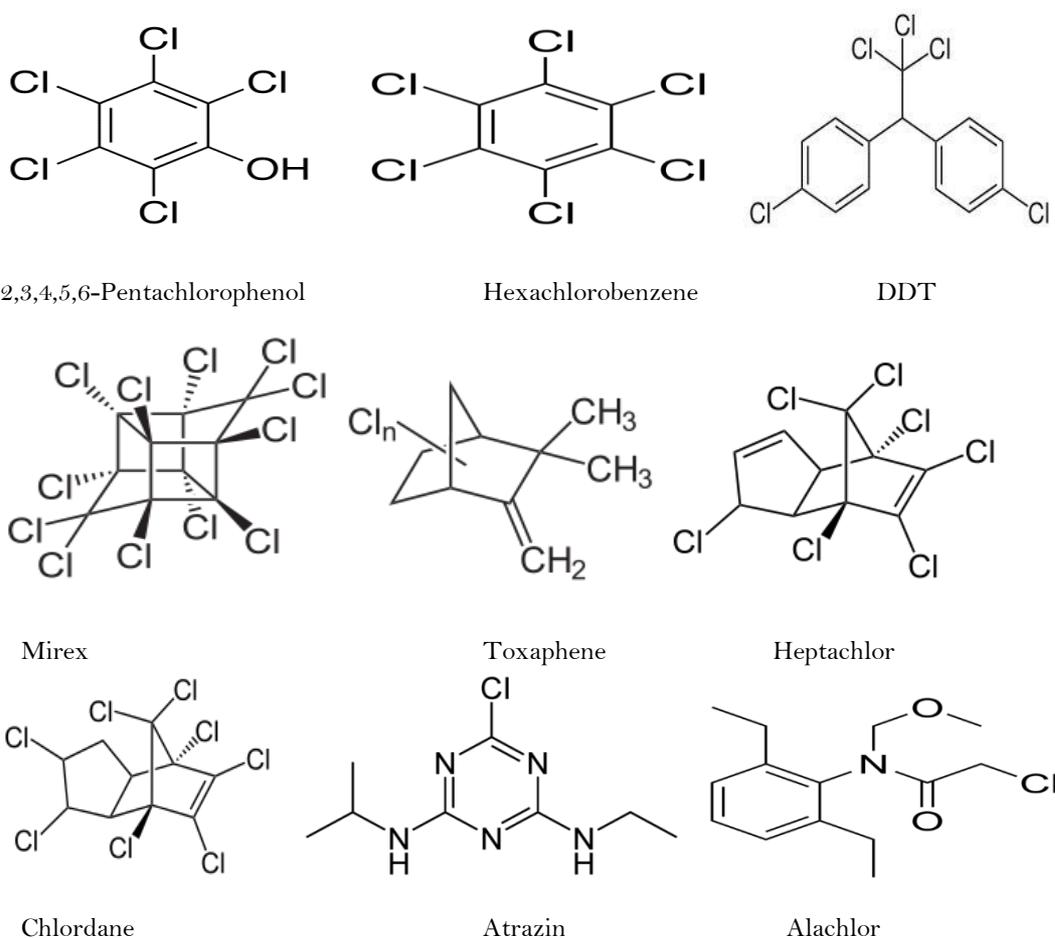


Fig-1. Agrochemicals

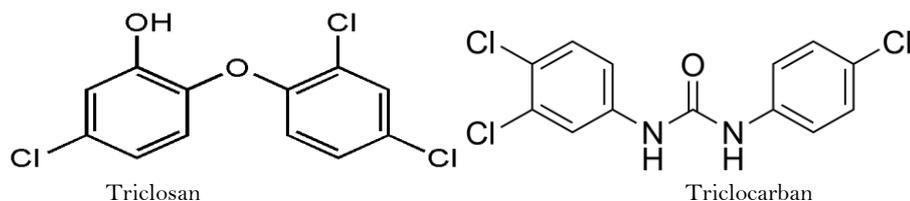


Fig-2. Personal care products

Table-1. Physicochemical properties of selected agrochemicals and PCPs

Organic pollutants	Molecular formula	Molar mass (g/mol)	Density (g/mL)	Boiling point (°C)	Melting point (°C)	Solubility in water
Pentachlorophenol	C <sub>6</sub> HCl <sub>5</sub> O	266.34	1.978 (22°C)	309-310	190-191	0.020 g/L (30°C)
Hexachlorobenzene	C <sub>6</sub> Cl <sub>6</sub>	284.80	2.04	323-326	231	6.0 X 10 <sup>-3</sup> mg/L (25°C)
DDT	C <sub>14</sub> H <sub>9</sub> Cl <sub>5</sub>	354.49	0.99	260 (decomposition)	108.5	56 µg/L (25°C)
Chlordane	C <sub>10</sub> H <sub>6</sub> Cl <sub>5</sub>	409.78	1.60	165 (2 mmHg)	106	5.6 g/100 mL
Dieldrin	C <sub>12</sub> H <sub>8</sub> Cl <sub>6</sub> O	380.91	1.75	385	175-176	140 µg/L (20°C)
Mirex	C <sub>10</sub> Cl <sub>12</sub>	545.54	2.25	421.1 (760 mmHg)	485	Less than 1mg/L (75°F)
Toxaphene	C <sub>10</sub> H <sub>10</sub> Cl <sub>8</sub> (average)	414 (average)	1.65	155 (Decomposition)	65-90	0.63 mg/L (25°C)
Triclosan	C <sub>12</sub> H <sub>7</sub> Cl <sub>3</sub> O <sub>2</sub>	289.54	1.49	120	55-57	10 mg/L (20°C)
Triclocarban	C <sub>13</sub> H <sub>9</sub> Cl <sub>3</sub> N <sub>2</sub> O	315.58	1.53	317.9 (760 mmHg)	254-256	< 0.1 g/100mL (26°C)

Pentachlorophenol is an organochlorine compound used as pesticide, disinfectant, wood preservative and as a broad spectrum biocide. It is a common toxic pollutant in aquatic environment and has been classified by the United States Environmental Protection Agency (US EPA) as a B2 probable human carcinogen [2]. Pentachlorophenol has been detected at low levels (µg/L) in rivers, streams, surface water and seawater. It is mainly bound to sediments and suspended particles in the water environment, and moderately persistent in the soil environment with a reported field half-life of 45 days [3]. Pentachlorophenol is acutely toxic and may alter the electrical conductivities of biomembranes, inhibits cellular enzymes, produces mutations in animal and human cells and may exhibit teratogenic, carcinogenic, and reproductive effects [4].

HCB is a chlorocarbon, formerly used as a seed treatment (fungicide), wood preserving agent and it is a byproduct in many industrial processes. HCB has been applied as a porosity control agent in the manufacturing of graphite anodes, as a fluxing agent in the production of aluminum, as a peptizing agent in the manufacturing of nitroso and styrene rubber for tires, and as a chemical intermediate in dye manufacturing [5]. It has been banned globally under the Stockholm Convention on persistent organic pollutants (POPs) [6, 7]. HCB has very low aqueous solubility and vapor pressure, relatively high Henry's Law constant and octanol/water partition coefficient; thus, its persistence in the aquatic medium depends on its ability to bind to organic materials [8]. HCB has carcinogenic and mutagenic effects. Exposure and ingestion of HCB in humans and animals cause damage to liver, thyroid gland, kidneys, nervous, endocrine and immune systems, reproduction, and development. HCB has very toxic effects on aquatic plant [6]. Barber, et al. [9] carried out a detailed review on the emissions, levels, distribution, trends and processes of HCB.

DDT is a colorless, crystalline, tasteless and almost odorless organochloride, known for its use as insecticides. DDT has been banned/resisted in most countries because of its environmental

impact [10], however, because of its high stability in the environment, bioaccumulation and long-distance mobility, DDT still persists in the environment [11] or it is broken down to the main metabolites dichlorodiphenylchloroethane (DDE) and dichlorodiphenyldichloroethane (DDD) [12]. DDT when introduced into the environment is transported to rivers, coastal and remote areas in different ways, including runoff from non-point sources, atmospheric transportation and sewage discharge [13]. The isomers of DDT are also released into the environment during manufacture, formulation and usage [14]. DDT is carcinogenic and has been reported to present adverse effects on reproduction due to its estrogen agonistic and neurotoxic activities [13].

Mirex is a chlorinated hydrocarbon that was used as an insecticide; it was later banned because of its negative impact on the environment. Toxaphene is an insecticide, has been considered as POP and globally banned in 2001. Heptachlor is one of the cyclodiene insecticides, it persists in the environment and the sale of heptachlor products has been limited to the fire ant control in underground transformers. Chlordane is an organochlorine compound used as a pesticide. It also persistent in the environment and its use was banned by US EPA in 1983, except for termite control. EPA later banned all uses of chlordane in 1988.

Triclosan, 5-chloro-2-(2,4-dichlorophenoxy)phenol and triclocarban, N-(4-chlorophenyl)-N-(3,4-dichlorophenyl)urea are antibacterial and antifungal agent found in consumer products; including soaps, toothpaste, mouthwash, detergents, textiles, toys, and surgical cleaning treatments. Methyltriclosan (5-chloro-2-(2,4-dichlorophenoxy)anisole) is a biodegradation product of triclosan that is formed under aerobic conditions [15]. Studies have therefore suggested that triclosan blocks lipid biosynthesis by inhibiting the enzyme enoyl-acyl carrier protein reductase and may induce bacterial resistance development [16, 17]. Triclosan and triclocarban are acutely and chronically toxic to aquatic organisms, and bioaccumulated in earthworms, fish, water fleas, snails, algae and crops grown in soil irrigated with reclaimed wastewater [15, 18, 19]. Humans are commonly exposed to triclosan and triclocarban through ingestion (e.g. toothpaste) or dermal absorption (e.g. soaps) [20]. The adverse effects include mild itching and allergic redness on sensitive skins. Triclosan has been found to cause allergy or hay fever, it has also been reported that triclosan has the potential to disrupt excitation-contraction coupling in skeletal and cardiac muscle in humans [20].

## 2. SOURCES AND PATHWAYS OF AGROCHEMICALS AND PCPS

Agrochemicals reach rivers, streams, surface water systems and seawater through farm practices. The indiscriminate use of pesticides and herbicides in agriculture to improve the production of crops has led to the contamination of surface water by agricultural runoff [21]. These chemicals might be washed into rivers and streams by rainfalls after application to farm lands. They are persistent therefore in water and soil, and may also migrate to groundwater aquifers to pose a potential risk to human beings. The emission of domestic wastewater to still water or other aquatic environments also causes the release of PCPs into the environment. As a result of their use as household cleaning agents, triclosan and triclocarban are commonly rinsed

down the drain and are transported to wastewater sewage treatment plants (STPs). Triclosan has been detected in sewage sludge, discharge effluent, receiving surface waters and sediments, rivers, lakes and the sea [22]. Fig. 3 shows the sources and pathways of organic pollutants.

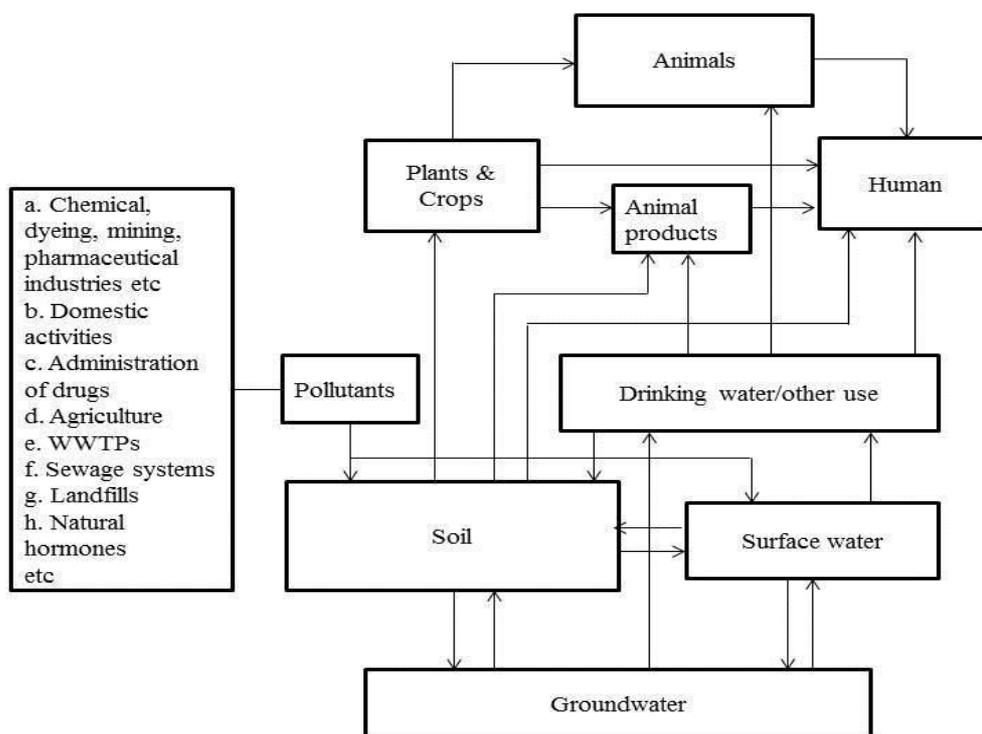


Fig-3. Sources and pathways of organic pollutants

### 3. DETECTION AND QUANTIFICATION OF AGROCHEMICALS AND PCPS

The analytical instruments commonly used for the detection and quantification of agrochemicals and PCPs are: high performance liquid chromatography (HPLC), gas chromatography isotopic dilution mass spectrometer (GC-IDMS), gas chromatography-mass spectrometer (GC-MS), gas chromatography-electron capture detector (GC-ECD) and ultraviolet (UV) visible spectrophotometer (UV-vis). Kim, et al. [4] determined pentachlorophenol and its byproducts by the use of Summit™ HPLC system equipped with a UVD340S detector, Kumar, et al. [23] analyzed pentachlorophenol concentration with HPLC Waters-2996 equipped with UV-vis detector ( $\lambda_{\max} = 280$  nm) while Wang, et al. [24] used a UV-vis. Deribe, et al. [25] carried out the determination of DDTs, endosulfans, and chlorpyrifos in fish species (from Lake Koka, Ethiopia) by the use of Agilent 6890 N gas chromatograph (GC) connected to an Agilent 5973 mass spectrometer (MS) after extraction of the fish tissue samples with acetonitrile, followed by dispersive solid phase extraction (dSPE) with a primary-secondary amino resin (PSA) to remove the fatty acids. The quantification of HCB was performed by Canas and Richter [26] with the use of Hewlett-Packard GC, model 5890 series II equipped with an ECD, after solid-phase

microextraction using octadecyl-bonded silica immobilized on the surface of a rotating disk, Zheng, et al. [27] analyzed HCB and its dechlorination intermediates by a Hewlett-Packard 6890 GC equipped with ECD, while Majoros, et al. [5] used accelerated solvent extraction (ASE) followed by column clean-up and GC-IDMS for the separation and detection of HCB. The concentration of DDT in the aqueous phase was analyzed by Cao, et al. [13] with the use of GC-ECD while Kulovaara, et al. [10], Gautam and Suresh [14] and Liu and Xu [28] used GC-MS. The determination of organochlorine and organophosphorus pesticides in marine water samples was also developed by Perez-Carrera, et al. [29] by the use of stir bar sorptive extraction (SBSE) technique and thermal desorption coupled to capillary GC-MS (SBSE-TD-GC-MS). The concentrations of pentachlorophenol and pentachlorophenol degradation byproducts (tetrachlorohydroquinone and dichloromaleic acid) were determined with a HP 5890 Series II GC-MS by Zimbron and Reardon [30]. Triclosan and 2,8-dichlorodibenzo-p-dioxin (DCDD) concentrations were analyzed by Aranami and Readman [16] by the use of GC-MS. Wu, et al. [22] reported the method development and application of the isotope dilution GC-MS/MS for the analysis of triclosan in environmental waters. All the described methods involve extraction such as liquid-liquid extraction and solid-phase extraction, followed by instrumental analysis which makes some of these analyses cumbersome, hence, to evaluate the movement, fate and global distribution of agrochemicals and PCPs, it is essential to develop a convenient, rapid and sensitive analytical method.

#### 4. TREATMENT METHODS OF AGROCHEMICALS AND PCPS

Some of the agrochemicals and PCPs treatment methods are adsorption, chlorination, membrane filtration, wetlands, oxidation, ozonation, coagulation/flocculation etc.

Constructed wetlands (CWs) wastewater treatments are systems designed to utilize natural processes to remove pollutants from contaminated water. A schematic diagram of a wetland system is presented in Fig. 4.

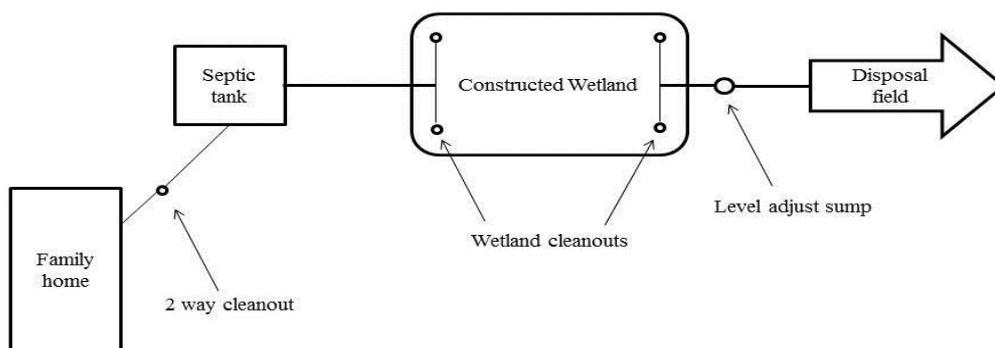


Fig-4. Schematic diagram of a wetland system

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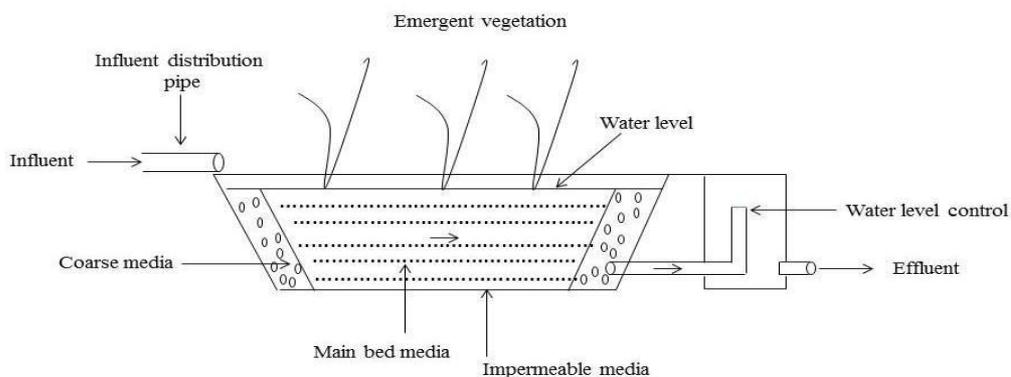


Fig-5. Vegetated submerged bed wetlands

The three major types of constructed wetland reactors include free water surface (FWS), vegetated submerged bed (VSB; Fig. 5) also known as subsurface flow and vertical flow (VF) wetlands. This technique has been used to purify agricultural effluents, tile drainage waters, acid mine drainage, industrial effluents, landfill leachates, aquaculture waters, and urban and highway runoff, however, the removal of contaminants in CWs is complex and depends on sedimentation, filtration, precipitation, volatilization, adsorption, plant uptake, and various microbial processes Wu, et al. [31]. Zhou, et al. [32] reported that CWs filled with organic-rich floodplain sediments (well mineralized peat mixed with mud) can eliminate considerable amounts of HCB residues. Wu, et al. [31] thus review recent developments in CWs technology.

The advanced oxidation processes (AOPs) have been reported to have widespread application of treating organic pollutants present in water and wastewater. These processes oxidize complex organic pollutants into simpler end products or degrade them to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  [33]. The use of combined Fenton's oxidation (combination of  $\text{H}_2\text{O}_2$  and  $\text{Fe}^{2+}$ ) and biodegradation for the treatment of pentachlorophenol-contaminated water was reported by Zimbron and Reardon [30]. They reported that the combined system achieved both pentachlorophenol and total organic carbon (TOC) degradation. Moreover, the photocatalytic activities of  $\text{Ag}_{1.4}\text{K}_{0.6}\text{Ta}_4\text{O}_{11}$  and  $\text{La-Ag}_{1.4}\text{K}_{0.6}\text{Ta}_4\text{O}_{11}$  for the degradation of pentachlorophenol in water under visible light ( $\lambda > 420$  nm) have been evaluated by Wang, et al. [24]. Lindstrom, et al. [34], and Aranami and Readman [16] investigated the photolytic degradation of triclosan in freshwater and seawater, they reported that the photolysis of triclosan is associated with the production of 2,8-DCDD. Moreover, 2,4-dichlorophenol and 2,4,6-trichlorophenol have been detected as the degradation products of triclosan in water [22]. The degradation effectiveness of pentachlorophenol by treatment with UV-A, UV-B photolysis, sunlight,  $\text{TiO}_2$  photocatalysis, and/or their combinations has been reported by Kim, et al. [4]. They reported that the  $\text{TiO}_2$  photocatalysis with UV-B photolysis was the most effective method to remove both pentachlorophenol and its toxic derivatives in the water system, and that byproducts such as PCDDs/Fs, tetrachloro- $\rho$ -benzoquinone, and other intermediates might be produced during photolysis of

pentachlorophenol. The light-induced degradation of DDT in humic water was reported by [Kulovaara, et al. \[10\]](#). Humic water spiked with DDT was subjected to UV radiation with a wavelength of 254 nm and also to intense simulated sunlight, they reported that the degradation rate was faster during UV-irradiations than during the simulated sunlight-irradiations. It should also be noted that DDT when treated with UV-radiation has been reported to undergo decomposition reaction to DDE, DDD and 4,4'-dichlorobenzophenone. [Broseus, et al. \[35\]](#) investigated the ozone ( $O_3$ ) oxidation of pesticides (cyanazine, deisopropylatrazine and deethylatrazine) during drinking water treatment. They stated that the pesticides were found to be the most recalcitrant compounds to oxidize with removals less than 65% (cyanazine) at 13.2 mg min/L. The decomposition of HCB was investigated over MgO, CaO, BaO,  $La_2O_3$ ,  $CeO_2$ ,  $MnO_2$ ,  $Fe_2O_3$ , and  $Co_3O_4$  supported on  $Al_2O_3$  by [Zhang, et al. \[36\]](#). They reported that  $Al_2O_3$  supported  $La_2O_3$  was found to be the most active and that pentachlorobenzene, tetrachlorobenzene, trichlorobenzene, and dichlorobenzene isomers were detected after the decomposition reaction, which indicated that the decomposition was mainly a dechlorination process.

The ozonation of piggery wastewater for enhanced removal of organic contaminants by a microalga *S. quadricauda* has been reported by [Kim, et al. \[37\]](#). They reported that the ozonation process converted the organic constituents in the piggery effluent to large number of biodegradable fractions; these fractions were then readily removed through biological assimilation during the mixotrophic cultivation of *S. quadricauda*. [Macauley, et al. \[38\]](#) also reported the disinfection of swine wastewater using  $Cl_2$ , UV light and  $O_3$ .

A combination of photocatalysis with other treatment processes yield excellent results, thus, [Sanches, et al. \[39\]](#) addressed the efficiency of a two-stage integrated system that combines UV direct photolysis and  $TiO_2$  photocatalysis with NF to remove pesticides (atrazine, isoproturon, diuron, alachlor, and chlorfenvinphos) from surface water collected after the sedimentation process in a water treatment utility. They reported that the combination of UV photolysis and NF allows the production of water with higher quality than the individual processes with overall removals higher than 95% for all the spiked compounds throughout the treatment. [Patel and Suresh \[40\]](#) reported the electrochemical treatment of pentachlorophenol in water and pulp bleaching effluent. Electrochemical oxidation targets the mineralization of organic pollutants by electron abstraction at the anode surface and/or by the production of highly reactive oxidants. Electrochemical AOPs are environmentally compatible, versatile, highly efficient, flexible and safe.

Sonolysis, also known as ultrasonic irradiation process has been used to destroy organic pollutants present in water or wastewater. The rate of 1,4-dichlorobenzene (1,4-DCB) degradation and mineralization in the aqueous phase was investigated by [Selli, et al. \[41\]](#) under direct photolysis, photocatalysis in the presence of  $TiO_2$ , and under sonolysis at 20 kHz with different power inputs. They reported that photocatalysis ensured faster removal of 1,4-DCB with

respect to sonolysis and direct photolysis, however, the highest degradation and mineralization rate was attained with the combined use of photocatalysis and sonolysis (sonophotocatalytic).

Based upon literature, Snyder, et al. [42] compiled a summary of the performance of pesticides and PCPs contaminated water and wastewater treatment methods (Table 2).

Adsorption has been widely used for the treatment of organic pollutants, it has been found to be superior to other techniques for water purification in terms of cost, simplicity of design and use of operation and has been used extensively in industrial processes for separation and purification [43]. Common adsorbents used are activated carbon, agricultural waste materials (biosorption), alumina, silica, zeolite, nanoparticles synthetic polymers etc. Liu, et al. [11] thus investigated the adsorption and catalytic activity of DDT by the use of  $\text{Fe}_3\text{O}_4@\text{nSiO}_2@\text{mSiO}_2$  core-shell microspheres, and reported that the magnetic mesoporous silica nanoparticles exhibited fast adsorption rate and high adsorption efficiency for DDT. The removal of selected chlorinated pesticides i.e. HCB, hexachlorobutadiene, lindane, pentachlorobenzene and heptachlor by adsorption onto granular activated carbon, zeolite and activated sludge was investigated by Valičková, et al. [44]. They reported that the highest removal efficiency was achieved by adsorption on activated sludge, follow by zeolite and then granular activated carbon. The adsorption characteristics of triclosan from aqueous solution onto cetylpyridinium bromide modified zeolites was examined by Lei, et al. [45] while Liu and Xu [28] studied the adsorption characteristics of triclosan on chitosan/Poly(vinyl alcohol) composite nanofibrous membranes.

Water chlorination is a method of water purification where  $\text{Cl}_2$  or hypochlorite is added to water. It may be added to effluent or contaminated water as a gas, but can also be applied as a liquid or solid [46]. Chlorination is inexpensive, simple to use, and widely available, it removes the majority of waterborne pathogens and can limit in-home contamination through the persistence of free  $\text{Cl}_2$  in stored water Levy, et al. [47]. Tian, et al. [48] thus revealed that the acute toxicity of dimethoate (a commonly used organophosphorus pesticide) solution increased after treatment with  $\text{Cl}_2$  due to the formation of more toxic byproducts (omethoate, phosphorothioic acid and N-methyl-2-(methylthio) acetamide). The formation of chloroform and other chlorinated byproducts by chlorination of triclosan-containing antibacterial products was also reported by Fiss, et al. [49].

Membrane filtration is one of the main technologies that have been increasingly used for water and wastewater purification in recent years. It is used for complete separation of particulate matter and microbial pathogens having a size larger than the membrane pore size [50]. Membrane technology includes microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), forward osmosis (FO) or reverse osmosis (RO). NF is a filtration technique that uses nanometer sized pore membrane for the treatment of polluted water and wastewater. It uses membranes with very small pores (<1 nm) and requires operating pressures in the 10-50 bar range [51]. NF concerns the filtration and rejection, at an artificial polymer membrane, of solutes whose size are in the region of 200–1000 Da and are either charged or neutral Shirley, et al. [52]. Pang, et al. [53] investigated the removal of DDT in drinking water by the use of NF and revealed in their

studies that DDT was easily adsorbed on the membranes and the higher the applied pressure the more rapidly saturation of the membrane was achieved. The NF treatment of atrazine, alachlor, and pentachlorophenol in different real drinking water sources was investigated by Sanches, et al. [54]. Ultrafiltration (UF) was implemented prior to the NF process to remove particulate and large colloidal organic matter that interfere in the rejection of pesticides and they reported that 67.4–99.9% rejections were obtained for the pesticides while lower rejections (57.5–83.5%) were obtained for pentachlorophenol and could be explained by pentachlorophenol increased solubility at the waters' pH. The production of potable water from isoproturon (pesticide) contaminated lake and river water was investigated by a coagulation-adsorption-nanofiltration approach by Sarkar, et al. [21]. They reported that the quality of water after inline coagulation, adsorption, NF and reverse osmosis (RO) was found comparable to the standards of drinking water.

**Table-2.** Percentage pesticides and PCPs removed by water and wastewater treatment processes

Organic pollutants		Activated carbon	Biological activated carbon	O <sub>3</sub> /advanced oxidation process	UV	Cl <sub>2</sub> /ClO <sub>2</sub>	Coagulation/flocculation	Softening/metal oxides	Nanofiltration	Reverse osmosis	Degradation (B/Ph/AS)
Pesticides		E	E	L-E	E	P-E	P	G	G	E	E [Ph]
PCPs	Synthetic musks	G-E	G-E	L-E	E	P-F	P-L	P-L	G-E	E	E [B]
	Sunscreens	G-E	G-E	L-E	F-G	P-F	P-L	P-L	G-E	E	G-E
	Antimicrobials	G-E	G-E	L-E	F-G	P-F	P-L	P-L	G-E	E	F [Ph]
	Surfactants/detergents	E	E	F-G	F-G	P	P-L	P-L	E	E	L-E

E – excellent (> 90%); G – good (70-90%); F – fair (40-70%); L – low (20-40%); P – poor (< 20%); B – biodegradation; Ph – photodegradation (solar). Adapted from Snyder, et al. [42]

## 5. CONCLUSION

The use of agrochemicals in agricultural production, and livestock effluents may facilitate the rapid dissipation of organic pollutants into receiving rivers, streams, surface water systems and seawater. PCPs are rinsed down the drain and thus, enter the WWTPs. The detection and quantitation of agrochemicals and PCPs in water and wastewater involved extraction procedure followed by instrumental analyses by GC coupled with MS, ECD, IDMS; HPLC or UV–vis spectrophotometry. AOPs have been effectively used as treatments to remove agrochemicals and PCPs in water and wastewater, however, transformation products might be formed that could sometimes be more toxic than the original pollutants. A combination of other AOPs with sonolysis thus offers better and efficient treatment. Membrane technology is limited to retain the molecules of higher masses, unable to remove all the contaminants and fouling is a major setback and another major disadvantage of membrane technique is the deterioration of membrane performance and high operating costs due to fouling. Further disinfection and organic removal may be required after treatment by membrane filtration due to the presence of organic pollutants in trace amounts. Chlorination might not be a suitable oxidant for agrochemicals and PCPs. The use of newer and/or combined water and wastewater treatment processes are required, moreover, there is the need to reduce pollutant release by agricultural and domestic activities, and lower the burden of natural water bodies through strict discharge standards and regulations. To evaluate

the movement, fate and global distribution of agrochemicals and PCPs, it is essential to develop a convenient, rapid and sensitive analytical method. Excellent treatment performance at acceptable costs of the treatment plants should be ensured and investigation on the degradation byproduct of agrochemicals and PCPs is needed.

### 5.1. Conflicts of Interest

The author declares no conflict of interest.

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