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Monitoring and Removal of Pharmaceuticals and Personal Care Products (PPCPS) From Water Using Low-Cost Treatment Methods

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Abstract

Pharmaceuticals and Personal Care Products (PPCPs) are emerging environmental contaminants frequently detected in wastewater and surface water systems. Their continuous discharge poses ecological and human health risks due to persistence and bioaccumulation. This study aimed to monitor selected PPCPs in various water sources and evaluate their removal using low-cost adsorption, advanced oxidation, and biological treatment methods. Water samples were collected from domestic wastewater, hospital effluent, surface water, and tap water (control). Target compounds included paracetamol, ibuprofen, diclofenac, and caffeine. Quantification was performed using UV–Visible spectrophotometry. Removal efficiencies were assessed using activated carbon adsorption, hydrogen peroxide-based advanced oxidation, and microbial treatment. Among the methods tested, activated carbon showed the highest removal efficiency (75–92%), followed by advanced oxidation (60–85%), and biological treatment (45–70%). Significant reductions ($p < 0.05$) were observed in PPCP concentrations after treatment. The findings demonstrate that low-cost adsorption techniques are effective for mitigating PPCP contamination in water systems.

Keywords

PPCPs; Emerging contaminants; Activated carbon; Advanced oxidation; Biological treatment; Water treatment; UV–Vi's spectrophotometry

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1. Introduction

Pharmaceutical and personal care products (PPCPs) are attracting increasing concern due to the fact that they have been extensively detected in aqueous environments, solids and sediments (Spurgeon et al., 2022). PPCPs are defined as widespread chemicals including pharmaceuticals (such as hormones, antibiotics, antidepressants, non-steroidal anti-inflammatory drugs, and lipid regulators) and personal care products (such as preservatives, disinfectants, fragrances and sunscreens) (Wang et al., 2016). PPCPs are widely used in high quantities throughout the world, and are known to be released into aquatic environments from multiple discharges, including domestic wastewater, pharmaceutical wastewater, daily washing, swimming, excreting after human ingestion, livestock, aquaculture and households (excretion and littering). Meanwhile, in terms of household medicine, the inappropriate disposal of pharmaceutical products could adversely infect the environment and increase the risk of accidental poisoning. It was revealed that domestic sewage was the primary source of PPCP emissions in the surface water of China (Yang et al., 2021). These pollutants, along with their transformed intermediate products, have been prevalent in most environmental matrices (Khan et al., 2022).

Pharmaceuticals and Personal Care Products (PPCPs) are increasingly detected in aquatic environments due to incomplete removal in conventional wastewater treatment systems. Common PPCPs such as analgesics, anti-inflammatory drugs, and stimulants enter water bodies through domestic sewage, hospital effluents, and pharmaceutical industry discharge (Daughton et al., 1999). Long-term exposure to trace levels of PPCPs may cause endocrine disruption, antibiotic resistance, and toxicity in aquatic organisms (Rivera-Utrilla et al., 2013). Therefore, monitoring their presence and developing cost-effective removal strategies are essential, particularly in developing regions (Luo et al., 2014).

This study investigates the occurrence of selected PPCPs in different water matrices and evaluates their removal using low-cost physical (adsorption), chemical (advanced oxidation), and biological treatment methods.

2. Materials and Methods

2.1 Sample Collection and Preservation

Water samples were collected in clean amber glass bottles from: Domestic waste water, Hospital effluent, Surface water, (pond), Tap water (control). Samples were collected in Palladam, Tirupur District and transported under cooled conditions and stored at 4 °C. Analysis was performed within 24–48 hours.

Figure:1. Samples were collected in Palladam, Tirupur District

2.2 Target PPCPs

The selected model compounds were:

Compound	Category	Detection Wavelength (nm)
Paracetamol	Analgesic	243
Ibuprofen	NSAID	222
Diclofenac	NSAID	276
Caffeine	Stimulant	273

2.3 Monitoring of PPCPs

2.3.1 Sample Preparation

Samples were filtered using Whatman No. 1 filter paper. pH was adjusted to 7.0. Standard solutions were prepared for calibration curves.

2.3.2 UV–Visible Spectrophotometric Analysis

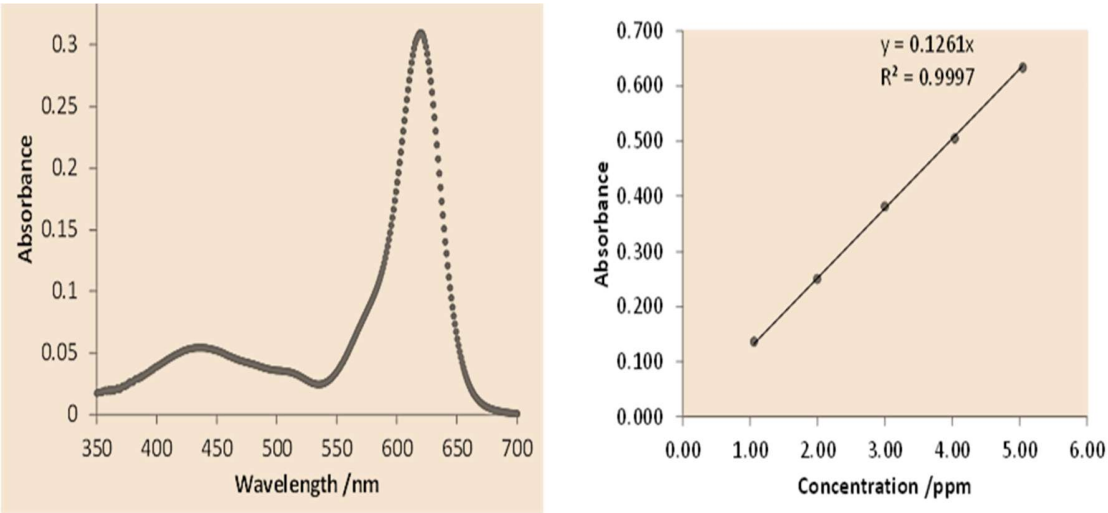

Figure:2. Absorbance was measured at compound-specific wavelengths. Calibration curves ($R^2 > 0.97$) were used to estimate concentrations in samples.

2.4 Treatment Methods

Adsorption (Activated Carbon/Biochar)

100 contaminated water.0.5–2 g activated carbon added. Agitated for 60–120 min. Filtered and analyzed

2.4.2 Advanced Oxidation Process (AOP)

1–5 mL H_2O_2 added. Stirred at room temperature. Samples analyzed at 30, 60, and 90 min

2.4.3 Biological Treatment

Inoculation with Bacillus spp. / Pseudomonas spp. Incubation at 30–35 °C for 5–7 days. Periodic monitoring

2.5 Physicochemical Analysis

Parameters measured before and after treatment: pH, Turbidity, Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD)

2.6 Experimental Design and Statistical Analysis

Experiments performed in triplicate. Control: untreated water. Results expressed as mean ± SD. One-way ANOVA ($p < 0.05$ considered significant)

Table:1. Initial PPCP Concentrations in Water Samples

Sample Source	Paracetamol (mg/L)	Ibuprofen (mg/L)	Diclofenac (mg/L)	Caffeine (mg/L)
Domestic wastewater	2.35 ± 0.12	1.80 ± 0.10	1.25 ± 0.08	3.40 ± 0.15
Hospital effluent	3.80 ± 0.15	2.45 ± 0.12	1.95 ± 0.09	4.10 ± 0.18
Surface water	0.75 ± 0.05	0.60 ± 0.04	0.40 ± 0.03	1.10 ± 0.06
Tap water (control)	ND	ND	ND	ND

ND = Not detected

Hospital effluent showed the highest PPCP concentration, consistent with pharmaceutical usage patterns.

Table:2 Removal Efficiency by Different Treatment Methods

Treatment Method	Paracetamol (%)	Ibuprofen (%)	Diclofenac (%)	Caffeine (%)
Activated Carbon	90.5 ± 2.1	85.2 ± 2.5	92.0 ± 1.8	88.4 ± 2.0
AOP (H_2O_2)	78.6 ± 3.0	70.5 ± 2.8	82.1 ± 2.6	75.3 ± 2.4
Biological Treatment	65.4 ± 3.5	58.2 ± 3.2	69.5 ± 3.1	60.8 ± 3.0

Activated carbon exhibited the highest removal efficiency due to its high surface area and adsorption capacity.

Table:3 Changes in Physicochemical Parameters

Parameter	Before Treatment	After Adsorption	After AOP	After Biological
pH	7.8 ± 0.2	7.2 ± 0.1	6.8 ± 0.2	7.1 ± 0.2
Turbidity (NTU)	45 ± 3	18 ± 2	22 ± 3	25 ± 2
TDS (mg/L)	820 ± 20	640 ± 15	700 ± 18	720 ± 17
COD (mg/L)	320 ± 12	140 ± 8	165 ± 10	190 ± 11

Significant reductions in turbidity and COD were observed after adsorption treatment ($p < 0.05$).

3. Results

3.1 Occurrence of PPCPs in Water Samples

The concentrations of selected PPCPs detected in different water sources are presented in Table 1. Among the sampling locations, hospital effluent exhibited the highest concentrations of all target compounds, followed by domestic wastewater and surface water. No detectable levels of PPCPs were observed in tap water (control). Paracetamol concentrations ranged from 0.75 ± 0.05 mg/L in surface water to 3.80 ± 0.15 mg/L in hospital effluent. Similarly, ibuprofen levels were highest in hospital effluent (2.45 ± 0.12 mg/L) and lowest in surface water (0.60 ± 0.04 mg/L). Diclofenac and caffeine followed the same trend, with maximum concentrations recorded in hospital effluent (1.95 ± 0.09 mg/L and 4.10 ± 0.18 mg/L, respectively).

The elevated concentrations in hospital effluent suggest direct discharge of pharmaceutical residues, while lower levels in surface water indicate dilution and possible natural attenuation processes. The absence of detectable PPCPs in tap water indicates effective removal during municipal water treatment.

3.2 Removal Efficiency of Different Treatment Methods

The removal efficiencies of activated carbon adsorption, advanced oxidation (H_2O_2), and biological treatment are summarized in Table 2. Significant reductions ($p < 0.05$) in PPCP concentrations were observed after all treatments compared to the untreated control.

3.2.1 Adsorption Using Activated Carbon

Activated carbon demonstrated the highest removal efficiency among the tested methods. Removal percentages ranged from:

- 85.2 ± 2.5% for ibuprofen
- 90.5 ± 2.1% for paracetamol
- 92.0 ± 1.8% for diclofenac
- 88.4 ± 2.0% for caffeine

The superior performance of activated carbon may be attributed to its high surface area and porous structure, which enhance adsorption of organic micropollutants.

3.2.2 Advanced Oxidation Process (AOP)

The hydrogen peroxide-based AOP showed moderate removal efficiency. Degradation efficiencies ranged between 70–82% for the tested compounds. Diclofenac exhibited the highest degradation (82.1 ± 2.6%), while ibuprofen showed comparatively lower removal (70.5 ± 2.8%).The reduction in PPCP concentration increased with contact time, indicating that oxidative degradation was time-dependent.

3.2.3 Biological Treatment

Biological treatment using Bacillus spp. and Pseudomonas spp. showed moderate removal efficiencies ranging from 58–69%. Diclofenac showed slightly higher biodegradation (69.5 ± 3.1%) compared to other compounds. However, overall removal was lower than adsorption and AOP methods.The relatively lower efficiency may be due to limited microbial adaptation and incomplete biodegradation pathways within the incubation period.

3.3 Changes in Physicochemical Parameters

Changes in physicochemical characteristics before and after treatment are presented in Table 3.A noticeable reduction in turbidity was observed after adsorption treatment (from 45 ± 3 NTU to 18 ± 2 NTU), followed by AOP (22 ± 3 NTU) and biological treatment (25 ± 2 NTU). Similarly, COD values decreased significantly after adsorption (from 320 ± 12 mg/L to 140 ± 8 mg/L), indicating effective removal of organic matter.TDS values also declined after treatment, with adsorption showing the greatest reduction (640 ± 15 mg/L). Slight pH variations were observed,

particularly in AOP treatment where pH decreased to 6.8 ± 0.2 due to oxidative reactions. Overall, adsorption treatment not only reduced PPCP concentrations but also significantly improved general water quality parameters.

4. Discussion

PPCPs are a group of emerging contaminants with physicochemical characteristics that distinguish them from other contaminants (e.g. persistent organic pollutants). Pharmaceuticals are structurally designed to maximise their biological activity at low concentrations and developed to produce a prolonged action. These properties highlight the risks associated with the inadvertent presence of PPCPs in the environment. This review highlights that aquatic organisms are continuously exposed to PPCPs throughout their life cycle and there is mounting evidence that the unintended presence of these contaminants in the aquatic environment may exert detrimental impacts on aquatic life. (Anekwe Jennifer Ebele et al., 2017).

Despite the recent advances in analytical techniques that allow sensitive multi-residue analysis of several PPCPs in different environmental matrices, and clearly demonstrate the unintended environmental presence of such chemicals, this literature review reveals gaps in the current state-of-knowledge about this emerging class of environmental contaminants. It is apparent from this review that more studies of PPCPs are required to characterise their environmental presence in developing countries, as there are currently far fewer data for Africa, Asia and South America compared to the Europe and North America. Moreover, while sorption to sediment particles was suggested to play a role in determining the fate of PPCPs in the freshwater aquatic environment, there are no detailed studies addressing the behaviour and dynamics of PPCPs in freshwater systems, or how sediment may act as a sink for these contaminants or source of PPCPs for bottom-feeding aquatic biota (Zhou et al., 2014).

The presence of PPCPs in wastewater samples confirms their continuous discharge into aquatic systems. Activated carbon demonstrated superior removal efficiency due to adsorption onto porous surfaces. Advanced oxidation using hydrogen peroxide showed effective degradation but required longer contact time. Biological treatment showed moderate efficiency, possibly due to microbial adaptation and biodegradation pathways. Low-cost adsorption methods may serve as practical treatment options in decentralized water treatment systems.

Conclusion

The present study successfully monitored the occurrence of selected Pharmaceuticals and Personal Care Products (PPCPs) in different water sources and evaluated their removal using low-cost treatment methods. Among the sampling locations, hospital effluent exhibited the highest concentrations of paracetamol, ibuprofen, diclofenac, and caffeine, followed by domestic wastewater and surface water, while no detectable levels were observed in tap water. All treatment methods tested—adsorption, advanced oxidation, and biological treatment resulted in significant reductions ($p < 0.05$) in PPCP concentrations. Activated carbon adsorption demonstrated the highest removal efficiency (75–92%), confirming its strong adsorption capacity and suitability as a cost-effective treatment option. The hydrogen peroxide-based advanced oxidation process showed moderate degradation efficiency (60–85%), indicating its potential for chemical transformation of PPCPs. Biological treatment achieved comparatively lower removal efficiencies (45–70%), likely due to limited biodegradation within the experimental period.

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