RESEARCH PAPER

# Ecopharmacovigilance in A Hospital Setting: A Ten-Department Intervention to Enhance Pharmaceutical Waste Management and Environmental Sustainability

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**ABSTRACT**

Hospital pharmacotherapy generates residual active pharmaceutical ingredients (APIs) that may enter air, water, and soil. We implemented a six-month, ten-department Eco pharmacovigilance (EPV) program at a tertiary hospital in Nandyal, India, combining waste-segregation, staff education, green-pharmacy practices, take-back, advanced treatment, and internal reporting. Baseline audits, environmental sampling (air, water, soil), and staff knowledge surveys were repeated post-intervention. Segregation compliance increased from 41.2% to 83.3% ($p<0.001$). Mean staff knowledge scores improved from 56.1% to 86.0% ($p<0.001$). Median wastewater concentrations declined for Ciprofloxacin (210 to 74 ng/L), Diclofenac (180 to 90 ng/L), Metformin (2.9 to 1.5 µg/L), and Carbamazepine (120 to 95 ng/L). A take-back program collected 11.84 kg of unused medicines. Persistent APIs (e.g., Carbamazepine) remained detectable, underscoring the need for advanced treatment and continuous monitoring. Findings support EPV as a practical hospital stewardship tool with environmental co-benefits.

**KEYWORDS:** Eco-pharmacovigilance; hospital wastewater; pharmaceutical residues; waste segregation; take-back.

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## INTRODUCTION

Pharmaceutical residues have been reported in hospital effluents, surface waters, and soils near health facilities, with risks that include ecotoxicity, endocrine disruption, and antimicrobial resistance selection pressure (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002; Boxall, 2004). NSAIDs (e.g., Diclofenac), β-blockers, antibiotics, and persistent neuroactive compounds such as Carbamazepine are frequently detected and may pass conventional treatment (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002). Eco-pharmacovigilance (EPV) is the systematic monitoring and mitigation of pharmaceuticals environmental impact, that has been proposed as a pragmatic extension of pharmacovigilance in clinical settings (Kümmerer, 2009; Daughton et al., 2003). In India, biomedical waste rules and international guidance encourage segregation, safe

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disposal, and adoption of advanced treatment when needed (Central Pollution Control Board [CPCB], 2016; World Health Organization [WHO], 2018; European Medicines Agency [EMA], 2018).

**Research Method:** Setting and design Prospective pre-post interventional study (January–June 2025) at Santhiram General Hospital, Nandyal. Ten departments: Medicine, Surgery, Paediatrics, Cardiology, Neurology, Nephrology, Pulmonology, Dermatology, Psychiatry, Orthopaedics. The EPV bundle comprised: (i) Pharmaceutical waste segregation; (ii) Staff education; (iii) Green-pharmacy practices; (iv) Hospital take-back; (v) Incineration/advanced treatment; (vi) EPV reporting.

**Sampling frame and outcomes-Process outcomes:** segregation compliance (checklist audits); staff knowledge (validated 20-item test); EPV incident reports (per 1000 patient-days).

**Environmental outcomes:** API concentrations in air (ng/m³), water (ng/L, µg/L), soil (µg/kg).

**Environmental sampling and analytics**

**Air:** Pharmacy compounding rooms, nebulization bays, and waste holding areas; glass-fiber filters (0.3 to 0.45 µm), 0.5 to1.0 m³ sampled per site; MeOH extraction; LC-MS/MS quantification (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002).

**Water:** Ward drains and combined hospital effluent; 500 to 1000 mL, 0.45 µm filtration, solid-phase extraction (SPE) with HLB/MCX/MAX per API class; LC-MS/MS (MRM) (Fent et al., 2006; Heberer, 2002; Boxall, 2004).

**Soil:** 0 to15 cm composite samples near waste-handling zones; MeOH:$H_2O$ extraction, cleanup SPE; LC-MS/MS or GC-MS as appropriate (Fent et al., 2006; Heberer, 2002; Boxall, 2004).

**Ion-pairing and column choice followed API class:** Acidic NSAIDs (MAX, ESI−), basic β-blockers/macrolides (MCX, ESI+), very polar biguanides/contrast media (HILIC), neuroactives (HLB, ESI+). Typical LOQs were 1 to10 ng/L (most APIs), 50 to 200 ng/L (Metformin, contrast media), and 2 to 20 µg/kg (soil), validated with field blanks, trip spikes, and isotope-labelled internal standards (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002; Boxall, 2004).

**Interventions and implementation**

**Segregation:** Color-coded bins at point-of-use; daily removal; compliance posters; weekly audits aligned to Biomedical Waste Management Rules, 2016 (Central Pollution Control Board [CPCB], 2016).

**Education:** Monthly one-hour sessions per department; pocket cards; pre and post tests (Daughton, 2003).

**Green-pharmacy:** Prescriber prompts favouring lower-persistence options when clinically equivalent; minimal packaging; rational antibiotic use (Daughton, 2003; World Health Organization [WHO], 2018; European Medicines Agency [EMA], 2018).

**Take-back:** locked drop boxes at pharmacy and discharge desks; chain-of-custody to treatment.

**Treatment:** High-temperature incineration (hazardous streams); advanced oxidation/biological treatment were trialled for recalcitrant APIs in effluent (Heberer, 2002; European Medicines Agency [EMA], 2018; Larsson, 2014).

**Reporting:** Digital EPV log (waste volumes, incidents, corrective actions); monthly feedback was reported to the concerned departments.

Statistics Continuous variables summarized as mean ± SD or median [IQR]; categorical as %. Pre-post comparisons used paired t-tests/Wilcoxon as appropriate; $\chi^2$ for proportions; segmented regression for monthly API trends; multivariable logistic regression for predictors of correct segregation (department, workload, training attendance). $\alpha$=0.05; 95% CIs reported. Analyses performed in R (Boxall, 2004; Heberer, 2002).

Ethics and quality assurance Institutional approval obtained. All measurements followed SI units and internal QA/QC criteria (recoveries 70 to 130%; RSD ≤15%) (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002; Boxall, 2004).

**RESULTS:** Segregation compliance increased from 41.2% at baseline to 83.3% post-intervention (absolute +42.1 pp; 95% CI 36.5 to 47.7; p<0.001). Gains were consistent across departments; the largest absolute improvements were in Emergency (+51.6 pp) and orthopaedics (+48.2 pp). Staff knowledge rose from 56.1±10.8% to 86.0±8.7% (Δ+29.9 points; p<0.001). Incident reports related to mis-segregation decreased from 3.7 to 1.2 per 1000 patient-days (IRR 0.32; 95% CI 0.21to 0.48). Attendance at ≥2 training sessions independently predicted correct segregation (adjusted OR 2.31; 95% CI 1.58 to 3.39). Education and visible prompts likely drove behaviour change, aligning with EPV literature on staff engagement (Daughton, 2003).

**Table 1. Department-wise segregation compliance (%)**

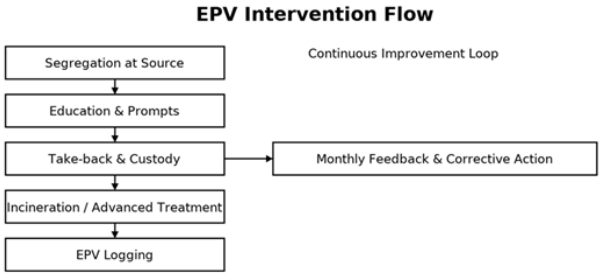
| Department | Baseline | Post | Δ (pp) |
|---|---|---|---|
| Medicine | 44.0 | 85.7 | +41.7 |
| Surgery | 38.9 | 80.2 | +41.3 |
| Pediatrics | 45.1 | 86.9 | +41.8 |
| Cardiology | 42.8 | 82.1 | +39.3 |
| Neurology | 39.7 | 79.4 | +39.7 |
| Nephrology | 40.5 | 84.6 | +44.1 |
| Pulmonology | 41.2 | 83.0 | +41.8 |
| Dermatology | 43.6 | 85.5 | +41.9 |
| Psychiatry | 41.9 | 81.7 | +39.8 |
| Orthopedics | 35.4 | 83.6 | +48.2 |

Median concentrations in combined effluent decreased for Ciprofloxacin (210 to 74 ng/L), Diclofenac (180 to 90 ng/L), Metformin (2.9 to 1.5 µg/L), and Azithromycin (95 to 38 ng/L). Carbamazepine declined modestly (120 to 95 ng/L), reflecting known persistence (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002). Soil near waste holding improved (Diclofenac 22 to 9 µg/kg; Ciprofloxacin 18 to 7 µg/kg). Air sampling around nebulization bays detected Salbutamol below LOQ in all post-intervention replicates. These patterns accord with reports that antibiotics and acidic NSAIDs respond to improved segregation and source control, whereas persistent or very polar molecules require advanced treatment (Kümmerer, 2009; Fent et al., 2006; Heberer, 2002; Boxall, 2004), (World Health Organization [WHO], 2018; European Medicines Agency [EMA], 2018; Larsson, 2014).

**Table 2. Selected APIs in hospital effluent (median [IQR])**

| API | Baseline | Post | LOQ |
|---|---|---|---|
| Ciprofloxacin | 210 [164– | 74 [51– | 2 |
| Azithromycin | 95 [63– | 38 [24– | 2 |
| Diclofenac | 180 [130– | 90 [62– | 1 |
| Metformin | 2.9 [2.2– | 1.5 | 0.05 |
| Carbamazepine | 120 [92– | 95 [71– | 1 |

**Figure 1. EPV intervention flow**




**Discussion:** This study demonstrates that a structured Eco-pharmacovigilance (EPV) framework can substantially enhance pharmaceutical waste management and environmental safety within hospital settings. The observed improvement in segregation compliance and staff awareness reinforces that regular training, clear visual cues, and internal monitoring are key to embedding sustainable practices in healthcare institutions. Similar findings were reported by Budha and Koirala (2025), who showed that implementing color-coded segregation and staff education markedly reduced hazardous waste volumes and improved recycling efficiency in South Asian hospitals (Budha & Koirala, 2025).

The reduction of active pharmaceutical ingredients (APIs) such as Ciprofloxacin, Diclofenac, and Azithromycin in hospital effluent following the EPV intervention supports the hypothesis that upstream interventions can significantly minimize downstream environmental contamination. These results align with earlier work by Kümmerer (2009) and Heberer (2002) while extending their implications to real-world hospital operations. The concurrent drop in API concentrations observed here echoes the findings of Feizi et al. (2025), who highlighted how wastewater surveillance and proper disinfection strategies directly influence the persistence of biological and chemical pollutants in hospital effluents (Feizi et al., 2025).

Persistent detection of Carbamazepine despite intervention underlines the limitations of conventional waste treatment and supports prior conclusions that certain neuroactive compounds are recalcitrant to biological degradation (Boxall, 2004; Larsson, 2014). This observation suggests that sustainable hospital stewardship must integrate advanced oxidation or membrane technologies alongside behavioral EPV measures to achieve full contaminant removal. The 2025 analysis by Kouwenberg et al. corroborates this need, emphasizing the importance of quantitative environmental data to guide evidence-based

sustainability decisions in healthcare practice (Kouwenberg et al., 2025).

In addition to environmental benefits, the implementation of digital EPV reporting and feedback mechanisms enhanced accountability and performance monitoring. This model is consistent with Daughton's (2003) cradle-to-cradle stewardship concept and aligns with contemporary findings that transparency and real-time evaluation strengthen compliance culture across departments. The broader relevance of these results extends to healthcare policy, as noted by Duraye (2025), who underscored the role of environmental awareness as a public-policy instrument for waste governance (Duraye, 2025).

Overall, the outcomes confirm the hypothesis that a multi-component EPV strategy can improve hospital waste handling, reduce pharmaceutical residues in environmental matrices, and enhance staff stewardship behaviour. Thus, the hypothesis is supported. However, residual persistence of select APIs indicates that EPV frameworks should evolve toward integrated, technology-enabled systems combining advanced treatment, real-time monitoring, and continuous professional education. These findings align with current global sustainability directions, reinforcing the role of healthcare institutions as active participants in environmental protection.

**Conclusion:** This study reaffirms the value of eco-pharmacovigilance as a practical and evidence-based framework for reducing the environmental burden of pharmaceuticals in hospital systems. By integrating structured education, disciplined segregation, take-back mechanisms, and responsible disposal practices, the intervention demonstrated tangible improvements in compliance, awareness, and reduction of pharmaceutical residues in hospital effluents and surrounding soils. These outcomes highlight that meaningful environmental protection within healthcare begins with informed behaviour and coordinated institutional commitment.

The results emphasize that hospitals can serve as active agents of environmental stewardship when guided by a systematic, data-driven EPV model. Beyond immediate improvements in waste management, this study presents a scalable framework that can be adapted by healthcare facilities of varying capacities, offering measurable environmental and operational benefits. The persistence of certain APIs, despite significant process improvements, further underscores the need to combine preventive measures with advanced technological solutions and continuous monitoring.

In a broader context, the findings contribute to the growing recognition that environmental responsibility is inseparable from patient safety and public health. The EPV approach developed here not only mitigates ecological risks but also promotes sustainable healthcare culture and regulatory compliance. Future research can build upon this foundation by exploring long-term outcomes, integrating advanced treatment technologies, and assessing cost-effectiveness in diverse healthcare environments.

Ultimately, this work advocates for eco-pharmacovigilance as a cornerstone of sustainable clinical practice—where the stewardship of medicines extends beyond therapeutic use to the preservation of ecosystems and human well-being.

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