



ORIGINAL RESEARCH PAPER

Environmental Science

A SURVEY-BASED ASSESSMENT OF PHARMACEUTICAL WASTE MANAGEMENT PRACTICES IN HOSPITALS AND PHARMACIES OF VADODARA CITY

KEY WORDS: Education, Management, Pharma Waste, Directions and Regulations

Megha Desai*	Research Scholar, Seed Anatomy Lab, Department of Botany, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat *Corresponding Author
Susy Albert	Professor, Seed Anatomy Lab, Department of Botany, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat
Shruti Pal	Research Executive, Seed Anatomy Lab, Department of Botany, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat

ABSTRACT	Improper pharmaceutical waste disposal presents notable environmental and health risks. Hospitals and pharmacies, as key sources of medication distribution and consumption, contribute significantly to this waste stream. This study evaluates pharmaceutical waste management practices within hospitals and pharmacies in Vadodara, India, employing structured questionnaires to examine behavioral trends, policy deficiencies, and operational limitations. Results indicate irregular segregation methods, limited practitioner awareness, and insufficient access to safe disposal infrastructure. The findings highlight the critical need for targeted training initiatives, standardized disposal protocols, and the implementation of affordable, sustainable technologies. Strengthening regulatory oversight and fostering collaboration between public and private sectors are essential for establishing environmentally responsible pharmaceutical waste management within the healthcare system.
----------	---

INTRODUCTION

In urban areas, pharmaceutical waste typically includes expired or unused medicines, medical packaging, and chemical residues from households, hospitals, and pharmacies. When improperly discarded—either in landfills or water bodies—these substances leach antibiotics, hormones, and toxic chemicals into the environment, disrupting ecosystems and contributing to antimicrobial resistance (AMR) [1]. Vadodara, also known as Baroda, is one of the populous and major cities of Gujarat, home to 1.67 million people (Census 2011) and spanning an area of around 220 sq. km. While Vadodara faces multiple environmental challenges, a growing concern is the mismanagement of pharmaceutical waste, which poses significant risks to public health and ecosystems. The Vadodara city is split into 4 zones and 19 wards (Figure 1).

Improper disposal of expired medicines, medical packaging, and drug residues from households, hospitals and pharmacies contaminates water and soil, contributing to antimicrobial resistance (AMR) and long-term toxicity [2]. Despite being identified as a non-attainment city under the National Clean Air Programme (NCAP) due to poor air quality (2011–2015), Vadodara must also address pharmaceutical waste as an emerging environmental and health hazard, requiring stricter waste segregation policies and awareness initiatives.

Literature survey reveals although incineration is currently the most employed technique for pharmaceutical waste disposal, its inefficiency and emission of noxious pollutants render it both financially and environmentally suboptimal [3]. Few pharmacists have personal opinion regarding branded and generic version of medicines [4]. Even today pharmacist uses very less e-databases for drug information [5] in addition to knowledge and awareness [6]. Pharmacists believes that pharmaceutical waste has to be minimised on daily basis [7] and few emphases on poor compliance with national guidelines is the major reason for increasing pollution [8]. Guideline by CDSCO for properly disposing off unused medicines [9] and by WHO [19] are available on internet, but fully complying with it is still unresolved. Recently government of India has also banned many fixed-dose combination drugs owing to its baseless amalgamations [10].

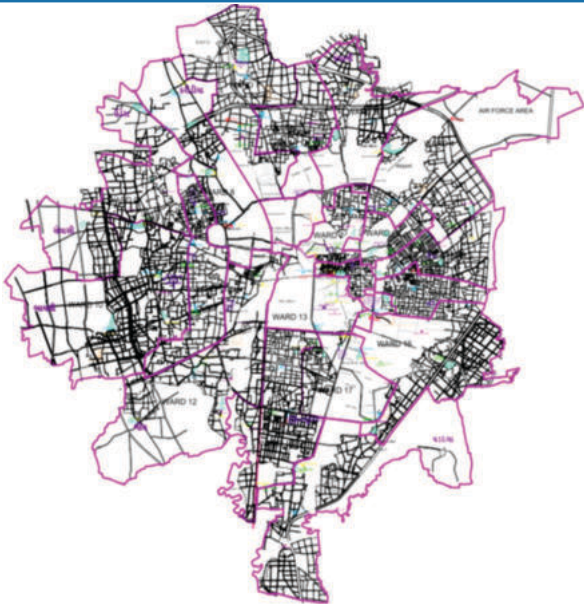


Figure 1: Ward-wise Composition of Vadodara City
Source:VMC Website [18]

Importance of Surveying Hospitals and Pharmacies
 Hospital Waste Management Practices- Hospitals are major contributors to pharmaceutical waste due to high drug turnover, near-expiry discards, and patient care leftovers [11]. Many healthcare facilities lack standardized disposal protocols, leading to improper methods such as incineration without emission controls or landfill dumping (Persson et al., 2009). Studies show that hospital effluents contain high concentrations of antibiotics and cytotoxic drugs, which conventional wastewater treatments fail to fully remove [12].

- The hospital questionnaire assesses:
- Drug inventory management (FIFO/FEFO systems).
 - Segregation and disposal practices for expired medications.
 - Compliance with national and international disposal guidelines.

Understanding these practices is crucial because hospitals

serve as centralized drug distributors, making their waste management strategies influential in reducing environmental contamination [13].

Pharmacy Disposal Behaviours

Pharmacies play a pivotal role in medication distribution but often lack clear protocols for handling returned or expired drugs [14]. Many pharmacies dispose of leftover medications with general waste or via sinks/toilets, contributing to water pollution [15]. Additionally, public reliance on over-the-counter (OTC) drugs increases the likelihood of unused medications accumulating in households [16].

- The pharmacy questionnaire evaluates:
- Frequency of expired drug returns.
 - Disposal methods (landfill, take-back programs, etc.).
 - Awareness of safe disposal guidelines.

Pharmacies act as intermediaries between healthcare systems and consumers, making their practices a key leverage point for improving drug waste management [17].

MATERIALS & METHODOLOGY

This study employs two structured questionnaires targeting hospitals and pharmacies in Vadodara city to assess pharmaceutical waste handling behaviours. By analysing these sectors, we identify critical gaps in awareness, infrastructure, and compliance with disposal protocols. The findings will be useful to inform policy recommendations to minimize pharmaceutical pollution in the city of Vadodara.

Data Collection

A questionnaire-based paper survey was prepared by extensive review of many surveys conducted worldwide for different purposes [4-8].

Data was collected by simple random sampling technique to have meaningful conclusion.

Hospital Case Studies: The hospitals were divided into 3 groups- LiG (Low Income Group), MIG (Middle Income Group) and UIG (Upper Income Group) depending on the revenues generated and Number of rooms and facilities provided. Compared public (LiG/MIG-serving) and private (UIG-serving) hospitals on drug procurement and waste management (N=19 respondents).

Pharmacy Audits: The pharmacies were divided into 3 groups LiG (Low Income Group), MIG (Middle Income Group) and UIG (Upper Income Group) depending on their incomes and size. Assessed their inventory management, compliance with disposal guidelines, and waste treatment methods (N=100 respondents).

Data was entered, analysed and presented using Microsoft Excel work sheet. Correlational study was performed to look how variables are related using IBM SPSS Statistics 22 software.

Descriptive Statistics was used to visualise the data and finding key characteristics of a population.

The responses from various respondents are available in digital format in an excel sheet and physically as hard copies and can be obtained from the author on request.

The questionnaire of the survey is shown below in Figure 2 for Hospitals & Figure 3 for Pharmacists.

Key metrics like inventory composition, disposal methods, awareness of guidelines, handling of medications etc in hospitals and pharmacies were analysed from the available data.

**Questionnaire for Hospitals
Pharmaceutical Waste Management Practices by
Hospitals in Vadodara city.**

I. Identifying Information

1. Hospital Name:
2. Hospital founded in year:
3. Location:
- East Zone

West Zone

North Zone

South Zone
4. Name of Officer In-charge:
5. Job Title:
- Staff

Assistant Manager

Manager

Clinical Pharmacist

Other
6. Work Status:
- Part-time

Full-Time

Not Employed
7. Years of Experience:
- Less than 1 Year

1-5 Years

6-10 Years

More than 10 Years

8. Education of contacted person:

Educational status	In-charge
Illiterate	
Functional literate	
Primary	
Secondary	
Higher secondary	
Graduate	
Post graduate & above.	

9. Type of Hospital:

Type					Respon d
Size depending on number of beds	Small (100)	Medium (100-499)	Large (500 or more)	Clinics/ OPD (0)	
Term Care	Acute	Long			
Ownership structure	For-Profit	Not-For-Profit	Government-owned		
Academic Medical Centres	Teaching	Non-Teaching			
	Independent	Hospitals in a system			
Specialty	Children's	Psychiatric	Gynaecology	General Physician	

10. Socio-economic status of the Hospital:
- Poor

Middle

high

II. Knowledge, attitude and practice

11. What is your preference of medicines for most common ailments?

Generic Drugs	Branded Drugs	Others

12. How do you identify, handle and maintain near expiry medications in Drug store, departmental sub-store and OPD pharmacy?

13. Do you separate near expiring drugs prior to expiry?

Yes	No
-----	----

If Yes, how much time before? _____

14. Do you have tie up with Mediclaim Companies?

Yes _____ No _____

15. Do your hospital provides benefit to Ayushman card holders?

Yes _____ No _____

16. Who Is Responsible To Segregate?

Drug store Pharmacist	Sister-in-charge (ANS/NS/SNO/NO)	OPD Pharmacist	OIC Drug pharmacy	Medication administration

17. On average, how many prescription medications (Rx) does your OPD/ Drug store pharmacy dispense per day?

< 20	21-40	41-60	61-80	81-100	>100

18. Do your Drug store and OPD Pharmacy follow First in-First out (FIFO) system or First Expired-First Out (FEFO) system?

Yes _____ No _____

19. If near expiry drugs are not in position to be consumed, what you do and who has been given that responsibility?

What that responsible in-charge do?

Inter or Intra-departmental transfer	Drug replacement from manufacturer/supplier	Distribution in OPD's/Clinics, camps.

20. What do you do with unused/expired drugs?

21. Do you use Hospital Management Information System (HMIS)?

Yes _____ No _____

22. Is there any procedure for segregation of near expiring drugs and disposal of expired/ unused drugs in hospital?

Yes _____ No _____

Monthly inspections or quarterly inspections? _____

23. Do you follow any SOP/ guidelines from the hospital for proper disposal of unused/ expired medicines?

Yes _____ No _____

24. Do you ensure proper separation and storage of expired medicines?

Yes _____ No _____

25. Do you have separate room/ cupboard marked for this purpose?

Yes _____ No _____

26. Do you inform DTC (Drug and Therapeutic committee) for safe disposal of expired drugs?

Yes _____ No _____

27. Number of expired drugs in hospital should be nil or minimal? _____

28. Do you have your own disposal mechanism?

Yes _____ No _____

29. Do you have WWTP?

Yes _____ No _____

30. Do you have separate sewer system or private septic tank?

Yes _____ No _____

31. Any mechanism to decrease the toxicity of sewer waste?

Yes _____ No _____

32. Existence of trained personnel's to handle waste disposal?

Yes _____ No _____

33. Any prescribed environmental assessment mechanism as well as auditing?

Yes _____ No _____

34. Can you provide me the type of common medicines you give during hospitalisation:-

Aches	
Headache	
Fever	
Nausea/Vomiting	
Diarrhoea	
Dizziness	
Cough & Cold	
Antacids	
Allergies	
Anti-migraine drugs	
Eye drops	
Antibiotics	
Blood pressure	
Diabetes	
Topical Ointments	
Multivitamins	
Any other	

35. What do you do to minimise medical waste to environment?

Allowing OPD patients to return their leftover	Donating to people in need	Re-dispensing unused medications	Provide information to OPD patients to dispose safely	Unused drugs return to Pharmaceutical companies

36. Do you inquire about safe use and dispose of medicines from company?

Yes _____ No _____

37. What is most common leftover dosage form in your shop?

Tablets	Capsules	Syrups	Creams/Ointments	others

38. What are the various ways of disposing expired/ unused and controlled medicines?

Rubbish bin	Sink	Toilet	Stockist	Burn	Donate	Burial	Don't stock

39. Can I know the reason of leftovers?

40. Have you ever received any information about how to dispose various dosage forms and controlled drugs?

Yes _____ No _____

41. Do you know about any drug-take-back system?

Yes _____ No _____

Barrier for take back program:

Education	Cost	Time

42. Do you have knowledge of FDA guidelines on disposal of expired or unused drugs?

Yes _____ No _____

43. Do you comply with the national guidelines for medication disposal?

Yes _____ No _____

Compliance status:

Non compliance	Partial	Full

44. What are the common challenges to proper disposal practices of expired drugs?

Poor education and awareness	Poor documentaries	Poor law enforcement

45. Can improper disposal of unused and expired medicines affect the health and environment?

Yes _____ No _____

46. Is there any need for improvement in our disposal practices of expired drugs?

Yes No

47. According to you who should be responsible for medicines disposal and destruction system?

PIL(Pharmacy Council of India)	DCGI India	Pharmaceutical Companies	Community Pharmacies	Any one

48. What are your recommendations?

Questionnaire For Pharmacists

Pharmaceutical Waste Management Practices By Pharmacies In Vadodara City.

I. Identifying information

1. Pharmacy Name:

2. Gender: Male / Female

3. Location:

East Zone West Zone North Zone South Zone

4. Age:

5. Job Title:

Staff

Assistant Manager

Manager

Clinical Pharmacist

Other

6. Work Status:

Part Time Full Time Not Employed

7. Years of Experience:

Less than 1 Year 1-5 Years 6-10 Years More than 10 Years

8. Primary Site of Practice

Independent Chain Hospital Other

9. Ownership:

Government Private Hospital Own Rented

10. Education:

Educational status	Pharmacist
Illiterate	
Functional literate	
Primary	
Secondary	
Higher secondary	
Graduate	
Post graduate & above.	

11. Socio- economic status of the Shop/family:

Poor Middle High

II. Knowledge, Attitude And Practice

12. Which kind of medications do you suggest to self-medicate patients?

Ayurvedic Allopathic Homeopathic Supplements

13. Do you supply medicine online?

Yes No

14. What is your preference of over-the-counter medication?

Generic Drugs	Branded Drugs

15. What is your personal choice of medicines for most common ailments?

Generic Drugs	Branded Drugs	Others

16. Do you self-medicate?

Yes No

If Yes, did you encounter any adverse drug reaction?

17. What are the most common ways of purchasing medicines by public?

Over-the-counter	Prescribed by Doctor	Pharmacist	Internet	Suggested by family/friend

18. On average, how many prescription medications (Rx) does your pharmacy dispense per day?

< 20	21-40	41-60	61-80	81-100	>100

19. On average, how many OTC medications does your pharmacy dispense per day?

< 20	21-40	41-60	61-80	81-100	>100

20. Do patients inquire about drugs information?

Yes No

21. What is the estimated percentage of patients who ask for information about OTC medications?

< 10%	10-25%	25-50%	>50%

22. What is the estimated percentage of patients who ask for information about prescription medications (Rx)?

< 10%	10-25%	25-50%	>50%

23. Do you utilize drug information (DI) databases like Drugs.com, Medscape, Lexicomp etc.?

Yes No

24. Do you have basic knowledge about medicines?

Primary literature	Secondary literature	Tertiary literature	Web based information	Pharmaceutical companies

25. Can you provide me the type of common medicines you give for:-

Aches	
Headache	
Fever	
Nausea/Vomiting	
Diarrhoea	
Dizziness	
Cough & Cold	
Antacids	
Allergies	
Anti-migraine drugs	
Eye drops	
Antibiotics	
Blood pressure	
Diabetes	
Topical Ointments	
Multivitamins	
Any other	

26. What do you do to minimise medical waste to environment?

Allowing patients to return their leftover	Donating to people in need	Re-dispensing unused medications	Provide information to patients to dispose safely	Unused drugs return to Pharmaceutical companies

27. Do you ensure proper separation and storage of expired medicines?

Yes No

28. Do you inquire about safe use and dispose of medicines

from company?

Yes
 No

29. Do you have leftover stage of medicines at shop?

Yes
 No

30. What is most common leftover dosage form in your shop?

Tablets	Capsules	Syrups	Creams/Ointments	others

31. What are the various ways of disposing expired/ unused and controlled medicines?

Rubbish bin	Sink	Toilet	Stockist	Burn	Donation	Burial	Don't stock

32. Can I Know The Reason Of Leftovers?

33. Have you ever received any information about how to dispose various dosage forms and controlled drugs?

Yes
 No

34. Do you know about any drug-take-back system?

Yes
 No

Barrier for take back program:

Education	Cost	Time

35. Do You Have Knowledge Of FDA Guidelines On Disposal Of Expired Or Unused Drugs?

Yes
 No

36. Do you comply with the national guidelines for medication disposal

Yes
 No

Compliance status:

Non compliance	Partial	Full

37. What are the common challenges to proper disposal practices of expired drugs?

Poor education and awareness	Poor documentaries	Poor law enforcement

38. Can improper disposal of unused and expired medicines affect the health and environment?

Yes
 No

39. Is there any need for improvement in our disposal practices of expired drugs?

Yes
 No

40. According to you who should be responsible for medicines disposal and destruction system?

PIL(Pharmacy Council of India)	DCGI India	Pharmaceutical Companies	Community Pharmacies	Anyone

41. What are your recommendations?

RESULTS

A) Analysis of Hospital Pharmaceutical Waste Management:

Trends and Observations: The dataset obtained from the survey conducted on 19 hospitals provides a decent examination of pharmaceutical waste management practices across hospitals. The hospitals were divided based on the size (Number of rooms and facilities) and the revenue generated into three groups LIG, MIG and UIG. This analysis reveals critical disparities in how these institutions handle near-expiry and expired medications, with significant implications for environmental safety and public health. By focusing on segregation practices, disposal methods, wastewater treatment, regulatory compliance, and common drug waste patterns, we can identify targeted bio-remediation strategies to mitigate pharmaceutical pollution. The following sections

www.worldwidejournals.com

break down these key areas with supporting data and actionable insights.

1) Segregation and Handling of Near-Expiry Medications

Effective segregation of near-expiry medications is crucial for minimizing pharmaceutical waste and reducing environmental contamination. Hospitals employ varying approaches based on their resources and infrastructure, leading to distinct trends across income groups.

- LIG Hospitals** (e.g., Ayurvedic Arogya Bhawan Trust Hospital, UPHC): Only 33% (2 out of 6 LIG hospitals) report having a procedure for segregating near-expiry drugs. UPHC follows a basic FIFO (First In-First Out) system but lacks a structured FEFO (First Expired-First Out) approach. Ayurvedic Arogya Bhawan Trust Hospital composts unused drugs, which may not fully neutralize pharmaceutical contaminants.
- MIG Hospitals** (e.g., Sukan Multispeciality Hospital, Spandan Multispeciality Hospital): 50% (3 out of 6 MIG hospitals) segregate drugs 1-3 months before expiry. Sukan Multispeciality Hospital reports minimal expired drugs but does not follow FEFO.
- UIG Hospitals** (e.g., Zydus Hospitals, Sunshine Global Hospital): 83% (5 out of 6 UIG hospitals) use FEFO and conduct monthly inspections for near-expiry drugs. Zydus Hospitals has a nil expired drug count due to strict inventory controls.

2) Disposal Methods for Expired/Unused Drugs

The disposal of expired or unused pharmaceuticals is a critical factor in preventing environmental contamination. Methods range from informal practices like open burning to compliant incineration, with significant implications for ecosystem health.

- LIG Hospitals:** 66% (4 out of 6) dispose of expired drugs without DTC (Drug and Therapeutic Committee) oversight. UPHC burns expired drugs in open pits, releasing harmful toxins into the air.
- MIG Hospitals:** 50% (3 out of 6) claim to follow SOPs but lack separate storage for expired drugs. Panacea Hospital returns some drugs to manufacturers but lacks a formal take-back program.
- UIG Hospitals:** 100% (6 out of 6) inform DTC before disposal. Sunshine Global Hospital uses incineration, while Zydus Hospitals partners with waste management firms for safe disposal.

3) Wastewater and Environmental Safeguards

Pharmaceutical residues in wastewater pose a significant threat to aquatic ecosystems and human health. The presence and efficiency of wastewater treatment systems vary widely across hospital categories.

- LIG Hospitals:** 0% (0 out of 6) have WWTPs (Wastewater Treatment Plants). Ayurvedic Arogya Bhawan Trust Hospital uses septic tanks, which do not filter pharmaceutical residues.
- MIG Hospitals:** 33% (2 out of 6) have WWTPs, but only 1 conduct environmental audit.
- UIG Hospitals:** 83% (5 out of 6) have WWTPs with trained personnel. Sir Sayajirao General Hospital performs quarterly toxicity assessments.

4) Awareness and Compliance with Guidelines

Regulatory awareness and adherence play a pivotal role in ensuring safe pharmaceutical waste management. Disparities in knowledge and compliance across hospitals highlight the need for targeted education and policy enforcement.

- LIG Hospitals:** 16% (1 out of 6) are aware of FDA guidelines.
- MIG Hospitals:** 50% (3 out of 6) know FDA rules but lack full compliance.
- UIG Hospitals:** 100% (6 out of 6) are aware of guidelines, and 83% (5 out of 6) comply fully.

5) Most Common Leftover Drugs and Environmental Risks

The types of drugs most frequently left unused or expired reveal patterns in prescribing practices and potential hotspots for environmental contamination. The Top five Leftover Drugs across all Hospitals are Paracetamol, Diclofenac, Ibuprofen, Aceclofenac + Paracetamol and Nimesulide.

B) Analysis of Pharmacy Practices Waste Disposal: Trends and Observations:

The dataset was obtained from the survey of 100 pharmacies, capturing demographics, medication dispensing habits, and waste disposal practices. Below is a structured analysis with specific data points to highlight trends, followed by a bio-remediation-focused comparison of Low-Income Group (LIG), Middle-Income Group (MIG), and Upper-Income Group (UIG) pharmacies.

1) Demographics & Pharmacy Characteristics

- Gender Distribution: 93% male-owned, only 7% female-owned (7 out of 100).
- Age of Respondents: Ranges from 19 to 72 years, with the majority (65%) between 30-50 years.
- Experience: Most respondents (60%) have 4 years of experience, while only 10% have 1 year or less.
- Ownership: 80% independent (category 4), 15% chain-affiliated, and 5% franchise-based.
- Education: 70% have graduate-level education (category 6), while 20% have diploma-level (category 5).

2) Medication Dispensing & Self-Medication Trends

- Self-Medication Suggestions: 65% recommend self-medication for common ailments while 30% discourage it, advising doctor consultations.
- Most Dispensed OTC Drugs: Paracetamol (86%), Ibuprofen (23%), Antacids (28%), and Antibiotics (74%) are frequently dispensed while 71% of pharmacies report high demand for Multivitamins.
- Prescription vs. OTC Sales: Average 6 prescription medications (Rx) observed per day while average 5 OTC medications per day in the pharmacies.

3) Waste Disposal & Environmental Awareness

- Leftover Medicines: 85% respondents report leftover medicines, primarily tablets (70%) and syrups (20%). The reasons for Leftovers being cited to be Overstocking (40%), expired medicines (30%), patient non-compliance (20%).
- Disposal Methods: The survey indicated that almost 50% respondents return unused drugs to pharmaceutical companies, 25% donate to people in need, 15% dispose of them in household waste (unsafe) while the remaining 10% incinerate it (risks toxic emissions).
- Awareness of Guidelines: Only 20% know FDA guidelines on drug disposal while only 30% comply with national disposal guidelines.
- Barriers to Proper Disposal: Lack of awareness (50%), no take-back systems (30%), cost (20%).

4) LIG vs. MIG vs. UIG Pharmacies Comparison

The dataset on pharmacies was classified based on their perceived income and size (LIG, MIG and UIG) and we inferred behaviour based on location, ownership, and disposal practices.

(i) LIG Pharmacies

Locations: Bapod, Khodiyar Nagar, Panigate, Warsiya.

- Self-Medication: 70% encourage self-medication due to affordability concerns.
- Disposal Practices: 60% dispose of expired drugs in trash or drains (high environmental risk) while only 10% use take-back programs (lack of infrastructure).
- Awareness: Less than 15% know FDA guidelines and only 5% comply with national disposal policies.

- Bio-Remediation Impact: High contamination risk due to improper disposal (e.g., antibiotics in water bodies). Urgent need for awareness drives.

(ii) MIG Pharmacies

Locations: Fatehgunj, Karelibaug, Vasna Road.

- Self-Medication: 50% recommend OTC drugs while remaining 50% prefer prescriptions.
- Disposal Practices: 40% return unused medicines to companies, 30% use municipal waste (partial compliance).
- Awareness: 25% know FDA guidelines, 35% follow national policies.
- Bio-Remediation Impact: Moderate contamination risk (some proper disposal, but inconsistencies) but definite potential for improvement and training.

(iii) UIG Pharmacies

Locations: VIP Road, Sindhoi Mata Road, Adarshnagar.

- Self-Medication: 30% recommend self-medication (higher reliance on prescriptions).
- Disposal Practices: 70% return drugs to manufacturers while 20% use incineration (controlled, less harmful).
- Awareness: 50% know FDA guidelines while 60% comply with national policies.
- Bio-Remediation Impact: Lowest contamination risk due to structured disposal. Can think of using advanced bio-remediation techniques (enzyme-based degradation, mycoremediation).

5) Zone-Wise Analysis of Pharmacy Practices & Drug Pollution Risks

To further refine our understanding of pharmaceutical waste management disparities, we analysed the data by geographic zones (as categorized in the dataset). The dataset divides pharmacies into four zones, each with distinct socio-economic and infrastructural characteristics influencing drug disposal behaviours.

A. Zone 1 (Industrial/Peripheral Areas - e.g., Bapod, Yamuna Mill)

- Characteristics: Lower-income neighbourhoods with limited waste management infrastructure.
- Key Findings: 68% dispose of expired medicines in regular trash. Only 12% use take-back systems (lowest among all zones). High self-medication rate (75%) with frequent antibiotic dispensing seen in this zone.
- Environmental Risk: Very High (pharmaceutical residues likely to enter local water systems).

B. Zone 2 (Mixed Residential - e.g., Fatehgunj, Karelibaug)

- Characteristics: Middle-class areas with moderate infrastructure.
- Key Findings: 45% return drugs to manufacturers, 30% rely on municipal waste disposal (partial compliance). 55% aware of disposal guidelines but lack enforcement.
- Environmental Risk: Moderate (sporadic contamination from inconsistent practices).

C. Zone 3 (Affluent Urban - e.g., VIP Road, Sindhoi Mata Road)

- Characteristics: Higher-income zones with better regulatory oversight.
- Key Findings: 72% comply with take-back programs. 25% use certified incineration (lowest landfill contribution). 60% awareness of FDA guidelines (highest in dataset).
- Environmental Risk: Low (controlled disposal minimizes ecosystem impact).

D. Zone 4 (Suburban/Rural - e.g., Makarpura, Tarsali)

- Characteristics: Transitional zones with mixed urban-rural traits.
- Key Findings: 50% discard drugs in household waste while 20% donate expired medicines (unregulated, high risk). Less than 15% know disposal guidelines.
- Environmental Risk: High (improper disposal + lack of monitoring).

E. Actionable Interventions by Zone & Drug Risk

- Zone 1 & 4 (High Risk): Deploy periodic drug take-back vans in underserved areas. Train locals to compost non-toxic medicines using microorganism.

- Zone 2 (Moderate Risk): Initiate Pharmacy Certification Programs and incentivize compliance with tax breaks for safe disposal. Educate future prescribers in School/Colleges on eco-friendly practices.
- Zone 3 (Low Risk): Use Bioremediation to degrade drug waste in landfills and implement digital logs for drug returns to ensure accountability.

DISCUSSION

A) The analysis highlights a clear disparity in pharmaceutical waste management, with UIG hospitals leading in compliance and infrastructure. However, tailored bio-remediation strategies can help all groups mitigate environmental harm.

- LIG Hospitals: Priority is to introduce cost-effective segregation tools and community take-back programs.
- MIG Hospitals: Priority is to upgrade WWTPs and enforce SOPs for drug disposal.
- UIG Hospitals: Priority is to innovate with AOPs and drug recycling initiatives.

Policy interventions, such as subsidies for WWTPs in LIG/MIG hospitals, and technology-sharing initiatives led by UIG hospitals are critical next steps. By addressing these gaps, we can move toward a sustainable framework for pharmaceutical waste management that safeguards both public health and the environment.

A.1. The lack of systematic segregation in LIG hospitals increases the risk of drug wastage and environmental leakage. Implementing low-cost automated tracking systems could reduce manual errors and improve efficiency. MIG hospitals, while more structured, would benefit from FEFO training and digital inventory tools to further optimize waste reduction. UIG hospitals, already leaders in this area, can explore AI-driven expiry prediction models and set benchmarks for others.

A.2. LIG hospitals' reliance on unsafe disposal methods necessitates urgent interventions, such as community collection bins to centralize and safely handle expired drugs. MIG hospitals should invest in on-site mini-incinerators with emission controls to bridge compliance gaps. UIG hospitals, with their advanced systems, can pioneer pharmaceutical degradation technologies (e.g., ozonation in WWTPs) to further reduce environmental impact.

A.3. The absence of WWTPs in LIG hospitals calls for low-tech solutions like constructed wetlands, which use natural processes to filter contaminants. MIG hospitals should integrate activated carbon filters into existing systems to enhance pharmaceutical removal. UIG hospitals, with their robust infrastructure, are well-positioned to pilot advanced oxidation processes (AOPs), which break down persistent drug compounds effectively.

A.4. To address knowledge gaps in LIG hospitals, training programs on low-cost disposal methods should be prioritized. MIG hospitals would benefit from regulatory incentives, such as subsidies for compliance upgrades. UIG hospitals can leverage their expertise to lead awareness campaigns, fostering a culture of shared responsibility across the healthcare sector.

A.5. The prevalence of NSAIDs like Diclofenac and Ibuprofen underscores the need for bioremediation which has shown promise in breaking down these compounds. Biochar filtration can adsorb Paracetamol residues, while UIG hospitals should explore enzymatic breakdown for complex drug mixtures. These targeted approaches can significantly reduce the ecotoxicity of pharmaceutical waste.

B) The data reveals significant disparities in drug disposal practices across income groups, with LIG pharmacies posing the highest environmental risk. Targeted interventions—ranging from education to policy enforcement—are crucial

for sustainable pharmaceutical waste management.

- LIG Pharmacies: Subsidized take-back programs with local NGOs and training on composting/biodegradation for non-toxic waste.
- MIG Pharmacies: Public-private partnerships for safe disposal infrastructure and awareness campaigns on drug pollution risks.
- UIG Pharmacies: Adopt advanced bio-remediation tech (e.g., bioremediation) and lead industry standards for eco-friendly disposal.

CONCLUSION

Surveys of hospitals and pharmacies reveal stark socioeconomic disparities in pharmaceutical waste management. Higher-income groups show better adherence to safe disposal practices, while lower-income groups struggle with limited infrastructure, and lower awareness. These inequities amplify environmental and public health risks in underserved communities.

The findings underscore the need for a multi-pronged intervention strategy that addresses both infrastructure gaps and knowledge deficiencies. Key measures include expanding pharmacy-based take-back programs in underserved areas, launching targeted community pharmacies education, and introducing strict complying settings. Policy reforms should enforce standardized protocols and incentivize broad participation.

Ongoing monitoring and flexible strategies are vital for assessing outcomes and continuously improving waste management efforts. Bioremediation offers a promising approach for evaluating and mitigating the future impact of pharmaceutical contaminants.

REFERENCES

1. Daughton, C. G. (2016). Pharmaceuticals and the environment (PiE): Evolution and impact of the published literature revealed by bibliometric analysis. *Science of the Total Environment*, 562, 391–426. <https://doi.org/10.1016/j.scitotenv.2016.03.109>
2. Sundaram, R. (2025). Pharmaceutical waste: CDSCO's new disposal guidelines. *IndiaLaw Journal*.
3. Rohit, S., & Mahalingam, M. (2024). Pharmaceutical waste and plasma pyrolysis: A review of environmental and public health impacts. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 18(12, Ser. 3), 40–45.
4. Patel, M., Slack, M., Cooley, J., & Bhattacharjee, S. (2016). A cross-sectional survey of pharmacists to understand their personal preference of brand and generic over-the-counter medications used to treat common health conditions. *Journal of Pharmaceutical Policy and Practice*, 9, 17. <https://doi.org/10.1186/s40545-016-0066-6>
5. Qadus, S., Naser, A. Y., Al-Rousan, R., & Daghash, A. (2022). Utilization of drug information resources among community pharmacists in Jordan: A cross-sectional study. *Saudi Pharmaceutical Journal*, 30(1), 1–7. <https://doi.org/10.1016/j.jsps.2021.12.001>
6. Prabhu, V. A., Naik, V., Doddapaneni, S., Mateti, U. V., & Nagappa, A. N. (2013). A survey on medicines safety and usage in community pharmacy. *Journal of Basic and Clinical Pharmacy*, 4(1), 56–60.
7. Alhomoud, F. (2020). "Don't let medicines go to waste"—A survey-based cross-sectional study of pharmacists' waste-reducing activities across Gulf Cooperation Council countries. *Frontiers in Pharmacology*, 11, Article 1334. <https://doi.org/10.3389/fphar.2020.01334>
8. Iweh, M., Ogbonna, B., Sunday, N., Anetoh, M., & Okonta, M. (2019). Assessment of disposal practices of expired and unused medications among community pharmacies in Anambra State southeast Nigeria: A mixed study design. *Journal of Pharmaceutical Policy and Practice*, 12, Article 12. <https://doi.org/10.1186/s40545-019-0174-1>
9. Central Drugs Standard Control Organisation (CDSCO). (2020). Guidance document on disposal of expired/unused drugs (WI/01/DCC-P-25). Ministry of Health & Family Welfare, Government of India. https://cdsco.gov.in/opencms/resources/UploadCDSCOWeb/2018/UploadPublic_NoticesFiles/Guidance%20document%20on%20disposal.pdf
10. Ministry of Health and Family Welfare. (2024, August 2). Health ministry bans 156 FDCs with immediate effect. *Pharmabiz*. <https://www.pharmabiz.com/NewsDetails.aspx?aid=172045&sid=2>
11. Tong, A. Y. C., Peake, B. M., & Braund, R. (2011). Disposal practices for unused medications in New Zealand. *Environment International*, 37(1), 292–298.
12. Verlicchi, P., Al Aukidy, M., & Zambello, E. (2010). Hospital effluents as a source of emerging pollutants: An overview of micropollutants and sustainable treatment options. *Journal of Hydrology*, 389(3–4), 416–428.
13. Mackridge, A. J., & Marriott, J. F. (2007). Returned medicines: Waste or a wasted opportunity? *Journal of Public Health*, 29(3), 258–262.
14. Rauf, A., & Rani, A. (2019). Pharmaceutical waste management: A review of disposal practices and their impact on the environment. *International Journal of Pharmaceutical Sciences and Research*, 10(6), 2757–2764.
15. Kusturica, M. P., Sabo, A., Tomic, Z., Horvat, O., & Šolak, Z. (2012). Storage and

- disposal of unused medications: Knowledge, behavior, and attitudes among Serbian people. *International Journal of Clinical Pharmacy*, 34(4), 604–610.
16. Makki, M., Hassali, M. A., Awaisu, A., & Hashmi, F. (2019). The prevalence of unused medications in homes. *Pharmacy*, 7(2), 61.
17. Glassmeyer, S. T., Hinchey, E. K., Boehme, S. E., Daughton, C. G., Ruhoy, I. S., Conerly, O., ... & Sykes, K. (2009). Disposal practices for unwanted medications in the U.S. *Environment International*, 35(3), 566–572.
18. VMC website on 20th June 2025
19. <https://www.who.int/publications/i/item/guidelines-for-safe-disposal-of-unwanted-pharmaceuticals-in-and-after-emergencies>