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Editorial

Antimicrobial Disposal and Environmental Contamination: An Overlooked Pillar of One Health Action Against Antimicrobial Resistance

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INTRODUCTION

Antimicrobials remain one of the most significant public health advancements. However, widespread availability, inappropriate prescribing, self-medication, and weak regulatory oversight have contributed to excessive antimicrobial use in humans, animals, and agriculture. The absence of adequate regulation and limited awareness of Antimicrobial Resistance (AMR), have contributed to the normalization of excessive antimicrobial use. AMR is one of the major global public health threats, especially to low- and lower-middle income countries (LMICs), further amplified by the impact of other interconnected crises such as disease outbreaks, climate shocks, mass displacement, and a funding-deficient public health sector[1, 2]. Furthermore, antimicrobial disposal remains an under-recognised contributor to environmental antimicrobial exposure and the emergence of resistance in the context of the interconnected ecosystem of one-health[3-5].

India occupies a unique position in the global AMR landscape as one of the world's largest consumers and manufacturers of antimicrobials. Rapid urbanization, high population density, widespread over-the-counter access to medicines, and variable implementation of pharmaceutical waste-management practices increase the likelihood of environmental exposure to antimicrobial residues. While India's National Action Plan on AMR (2025–2029) recognises the importance of environmental dimensions of AMR, organised medicine take-back systems and community-level disposal programs remain limited[6,7]. Consequently, strengthening antimicrobial disposal practices represents a practical and scalable opportunity to advance both antimicrobial stewardship and One Health objectives in the Indian context.

ANTIMICROBIAL DISPOSAL AND THE EMERGENCE OF RESISTANCE

Antimicrobial waste mismanagement has several confounding factors in the entire pharmaceutical life cycle, which spans manufacturing, patient use, and disposal at all levels. Inadequate antimicrobial waste management is increasingly recognized as an important contributor to environmental selection pressure and AMR [5]. Pharmaceutical effluents, hospital waste, agricultural and veterinary runoff and inappropriate disposal of antimicrobials in communities are major sources contributing to this public health problem. Community level challenges include accumulation of

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unused and expired antimicrobials in homes, resulting in inappropriate disposal. Lack of adequate labelling and disposal guidance, limited take-back programs, and insufficient public education related to proper disposal of medicine contribute to increasing AMR in LMICs such as India[8]. These interconnected challenges contribute to persistent antimicrobial residues in terrestrial and aquatic ecosystems, which accelerate the emergence and spread of antimicrobial-resistant genes (ARGs) and continue to drive AMR [9].

ANTIMICROBIAL DISPOSAL & THE ONE HEALTH PERSPECTIVE

Improper antimicrobial disposal, which results in environmental contamination, is a critical transmission pathway for AMR. The selective pressure of active pharmaceutical ingredients in the environment and the human gut drives the emergence of heteroresistance and the establishment of persistent resistant clones, which are disseminated through horizontal gene transfer, resulting in an escalated public health threat. Air, water, and soil serve as transmission routes and reservoirs for ARGs in aggravating AMR. Hence, this requires the acknowledgement of the interconnectedness of human, animal, plant and environmental health and therefore a one-health approach to curb the silent pandemic of AMR[2, 4].

The World Health Organization's One Health approach integrates human, animal, and environmental health under one shared and strategic vision for the cross-sectoral collaboration and interdependent well-being of all three domains. Robust governance, transparent communication, and collaborative partnership across sectors enable communities and decision-makers to address interconnected challenges in a comprehensive manner. The resulting shared benefits from addressing potential risks and collaborative opportunities support the development of equitable and comprehensive solutions because antimicrobial disposal cannot be effectively managed with isolated sectoral approaches[3].

Recognising antimicrobial disposal as a One Health challenge necessitates coordinated interventions across policy, healthcare, community, veterinary, and environmental sectors, particularly in India[4].

DISPOSAL OF ANTIMICROBIALS: PRACTICE-CHANGING ACTIONS IN INDIA

Improper disposal of antimicrobials contributes significantly to AMR, environmental contamination, and public health risks. Addressing this issue in India requires coordinated action across multiple sectors (Box 1).

Box 1. SMART DISPOSE: A proposed framework for improving antimicrobial disposal in India.

S – Surveillance of residues and resistance genes

M – Medicine take-back programs

A – Awareness campaigns for the public

R – Regulatory enforcement (BMW Rules)

T – Training of healthcare workers

D – Disposal counselling during prescribing and dispensing

I – Integration into AMR and One Health policies

S – Sustainable waste-management technologies

P – Producer responsibility (EPR)

O – Oversight of hospital and industrial effluents

S – Strengthened wastewater treatment systems

E – Environmental stewardship in veterinary and agricultural sectors

A. Policy and Regulatory Measures

Robust policies create a clear national framework so that antimicrobial disposal is not left to individual discretion. Facilitating effective and scalable producer responsibility and take-back systems promotes accountability from manufacturers to end users. At the policy level, actions can be:

- India's National Plan on AMR (NAP-AMR) 2025-2029 has identified disposal guidelines along with organisations and timelines, which requires cross-sectoral collaboration[6].
- Strengthening enforcement of Biomedical Management Rules, including pharmaceutical waste, has been highlighted in CDSCO's guidelines, which requires resources and effective monitoring [10].
- Introducing accountability mechanisms for manufacturers and distributors through extended producer responsibility (EPR) requires stringent implementation.

B. Healthcare Sector Interventions

Healthcare facilities represent a critical interface between antimicrobial consumption and environmental release. Beyond appropriate segregation and disposal of pharmaceutical waste, hospitals should integrate antimicrobial stewardship programmes with waste-management systems and wastewater monitoring. Hospital effluents have been identified as

important reservoirs of antimicrobial residues and ARGs, which may subsequently enter municipal water systems if inadequately treated. Incorporating pharmaceutical waste audits, routine monitoring of healthcare wastewater, and adherence to Biomedical Waste Management Rules 2016, as amended, can substantially reduce environmental dissemination of antimicrobials and resistant organisms[11]. Capacity building of personnel incharge of segregation and disposal of antimicrobial waste in healthcare facilities and monitoring effluents helps prevent drug residues from entering water bodies and contributing to resistance.

C. Community and Pharmacy-Based Strategies

Community participation is indispensable for effective antimicrobial disposal. Studies have consistently demonstrated that households frequently retain unused or expired antimicrobials, creating opportunities for self-medication, inappropriate reuse, and unsafe disposal through household waste or sewage systems[8]. Medicine return programs in communities make safe disposal convenient for the public. Pharmacists play a key role in educating patients about the risks of flushing or discarding medicines in household waste. However, the national guidelines are yet to emphasise these roles as mandatory, and the professional organisations and associations are yet to take on the advocacy and capacity-building roles. While the International Pharmaceutical Federation (FIP)'s statement of policy on the control of AMR advocates 'return and disposal' programs for the appropriate disposal of unused and expired antimicrobials[12], the operationalization of these guidelines in LMICs is yet to be carried out effectively.

D. Environmental and Veterinary Sectors

The environmental dimension of AMR remains comparatively neglected despite growing evidence that environmental reservoirs contribute to the emergence and dissemination of resistant microorganisms. Antimicrobial residues released from pharmaceutical manufacturing, livestock production, aquaculture, and healthcare facilities can exert selective pressure on environmental microbiota, facilitating the persistence and spread of ARGs. The UNEP report 'Bracing for Superbugs' emphasizes that environmental interventions are indispensable components of AMR mitigation and should be integrated into national One Health strategies[3]. Strengthening environmental surveillance, regulating antimicrobial discharge, and promoting sustainable agricultural practices are therefore essential public health priorities. Key stakeholders' actions can be:

- Promoting alternatives to routine antimicrobial use in animals has to be addressed by the stakeholders.
- Improved wastewater treatment processes to remove pharmaceutical residues, and bioremediation require the attention of policymakers and implementers.

E. Surveillance and Research

Regular monitoring of antimicrobial residues and continued research support the development of safer disposal technologies for long-term impact. Furthermore, environmental AMR surveillance remains substantially weaker than clinical surveillance in most LMICs, including India. Actions can be:

- Developing national databases to track pharmaceutical waste management practices is a crucial call to action.
- A coordinated, multi-sectoral approach is essential to reduce environmental contamination and curb the spread of AMR.

CONCLUSIONS

Irrational prescribing, dispensing, and use of antimicrobials continue to dominate the AMR narrative while the consequences of unused, expired and improperly discarded antimicrobials remain inadequately addressed. When antimicrobials permeate soil, water, and farms, they quietly contribute to the spread of AMR, undermining the very systems they were meant to protect. Addressing antimicrobial disposal is therefore not merely a waste-management issue but a critical component of antimicrobial stewardship and One Health action. Effective policies, accountable pharmaceutical industry practices, responsible healthcare systems, informed communities, and strong surveillance mechanisms require intersectoral interventions. Sustained political will, regulatory clarity, community engagement and cross-sector collaborations are vital for meaningful antimicrobial stewardship. Safeguarding the effectiveness of existing antimicrobials demands that they be treated as finite shared resources, with responsible disposal (Box 1) recognised as an essential strategy for preserving their effectiveness for future generations.

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CONFLICTS OF INTEREST

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