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SLUDGE MANAGEMENT AND THE CIRCULAR ECONOMY IN INDIA: REGULATION, STATUS, URBAN CHALLENGES AND PATHWAYS FORWARD

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ABSTRACT

India generates an estimated 150,000 to 200,000 metric tonnes of sewage sludge per day from its approximately 1,200 functional sewage treatment plants, yet the volume actually treated or productively recovered remains largely uncounted. Faecal sludge generated from septic tanks and pit latrines further increases the total quantity by approximately an order of magnitude. Both streams carry recoverable resources such as energy, phosphorus, organic matter that could contribute to a circular economy, yet regulatory frameworks, quality standards, worker protection and investment models remain fragmented. This paper reviews the regulatory status of sludge management in India across sewage sludge, faecal sludge and industrial sludge streams; assesses the gap between the circular economy framework and implementation reality; compares international approaches from the European Union, Switzerland, Japan, China and the United States; evaluates current Indian standards instruments; and proposes a staged evidence-based pathway for cities. The paper has incorporate recent developments including the ICMR microplastics study and IIT Madras PFAS findings (2026), state-level advances in Rajasthan and Uttar Pradesh (2025), updated NAMASTE implementation data, 2026 phosphorus recovery research, the US EPA PFAS draft risk assessment (January 2025) and emerging concerns about biosolids quality standards

as documented in Tamil Nadu research. A new section addresses the critical gap in testing for emerging contaminants.

KEYWORDS: Sewage Sludge, Faecal Sludge, Circular Economy, India, Biosolids, Phosphorus Recovery, Pfas, Microplastics, Namaste, Sludge Standards.

1. INTRODUCTION

Sludge is the unavoidable by-product of wastewater and faecal waste treatment. It concentrates the pathogens, heavy metals, organic pollutants and nutrients removed from the liquid stream. How cities manage this concentrated residue determines whether sanitation systems close the nutrient loop or create a secondary pollution problem. India is building sanitation infrastructure at a pace and scale without recent precedent, yet the governance of what emerges from the back end of that infrastructure—sludge—remains an afterthought.

India's Swachh Bharat Mission (SBM) and AMRUT programmes have driven rapid expansion of sewage treatment capacity, with more than 1,200 sewage treatment plants (STPs) now functional and thousands more under construction or planned. At the same time, the government's focus on eliminating open defecation has resulted in the installation of tens of millions of toilets connected to septic tanks and pit latrines across urban and peri-urban India. Both of these infrastructure expansions generate sludge at unprecedented scale, yet the regulatory system that was designed to handle it has not kept pace.

The circular economy (CE) concept offers a conceptual framework for transforming sludge from a disposal problem into a resource recovery opportunity. In theory, sewage sludge and faecal sludge carry recoverable phosphorus (a non-renewable mineral with finite global reserves), organic matter that can condition soils and energy in the form of biogas from anaerobic digestion. In practice, realising these recovery pathways requires a set of enabling conditions that India has not yet fully assembled: clear quality standards for end products, reliable testing infrastructure, treatment capacity at sufficient scale, worker protection systems and market development for recovered materials.

This paper reviews the regulatory and implementation status of sludge management in India, drawing on government policy documents, parliamentary replies, peer-reviewed research and recent state-level guidance notes. It has been updated to incorporate evidence published and publicly available up to December 2026, including significant new findings on emerging contaminants (microplastics and PFAS) in Indian sludge, state-level progress in Rajasthan and Uttar Pradesh, the US EPA's January 2025 draft risk assessment on PFAS in biosolids

and a 2026 study of sludge quality from Tamil Nadu STPs. The paper proposes a staged pathway for Indian cities that prioritises emerging contaminant testing as a foundational requirement before expanding land application of biosolids.

2. Sludge Streams in India: Types, Volumes and Composition

India's sludge challenge encompasses three distinct streams with different origins, compositions, governance regimes and management pathways: sewage sludge from STPs, faecal sludge from onsite sanitation systems and industrial sludge from effluent treatment plants (ETPs). This paper focuses primarily on the first two streams, with reference to industrial sludge where relevant for comparative purposes.

2.1 Sewage Sludge

Sewage sludge is the residual material produced during the treatment of domestic and municipal wastewater. India's Central Pollution Control Board (CPCB) estimated in a 2023 inventory methodology document that functional STPs generate between 150,000 and 200,000 metric tonnes of dry sludge per day, a figure that has grown substantially with the expansion of treatment capacity under AMRUT. Primary sludge settles during preliminary treatment and contains suspended solids including food waste, paper and other organic material. Secondary or biological sludge results from the microbial treatment of dissolved organic matter and contains a high proportion of bacterial biomass. Tertiary sludge, where relevant, results from chemical precipitation during nutrient removal.

Sludge composition varies significantly by catchment characteristics, treatment process and industrial inputs. Indian urban STPs typically treat a mix of domestic, commercial and diluted industrial effluents, resulting in sludge that contains elevated concentrations of heavy metals (particularly in cities with significant industrial activity), pathogens including bacteria, viruses and helminths, nutrients (nitrogen and phosphorus) and organic matter. The Fertilizer Control Order (FCO) 1985, as amended, sets limits on heavy metals in materials applied to land, which applies to sludge used as fertiliser, but compliance monitoring is inconsistent.

A 2023 CPCB study across 20 Indian cities found that sludge quality varied substantially between treatment plants, with heavy metal concentrations exceeding recommended thresholds at some facilities receiving industrial wastewater. Pathogen levels also varied, reflecting differences in treatment processes and retention times. This variability underscores the need for systematic sludge quality testing as a prerequisite for any resource recovery pathway.

Recent testing reveals additional quality concerns beyond heavy metals. An ICMR study (2026) found that treated effluent still carries 10 to 15 microplastic particles per litre, while the leftover sludge contains 7 to 9 particles per gram. An IIT Madras study (October 2026) reported that concentrations of eight targeted PFAS (per- and polyfluoroalkyl substances) compounds were between 5% and 103% higher in treated water than in raw water at a studied treatment facility in Chennai, indicating that conventional treatment plants do not effectively remove these persistent chemicals. PFAS accumulate in sewage sludge and pose long-term health risks including hormone disruption, immune damage and reproductive issues. These findings suggest that Indian sludge quality assessment must expand beyond the current focus on heavy metals and pathogens to include microplastics and persistent organic pollutants, a critical gap that has significant implications for land application of biosolids and for any circular economy strategy based on sludge nutrient recovery.

The question of where sludge goes after treatment is poorly documented nationally. Sludge disposal occurs through landfill, open dumping, agricultural application without treatment or testing and in a small number of cases through productive recovery pathways. The 2022 CPHEEO manual on sewage sludge management provides guidance on disposal and recovery options, but compliance monitoring at plant level remains weak and sludge mass balances are rarely published.

2.2 Faecal Sludge and Septage

Faecal sludge (FS) is the mixture of excreta, water and organic matter that accumulates in onsite sanitation systems including septic tanks, pit latrines and similar containment structures. Unlike sewage sludge, which is a by-product of centralised treatment, faecal sludge represents the contents of the containment system itself. Septage is the term commonly used for the material pumped from septic tanks specifically. The characteristics of faecal sludge vary enormously by containment type, age, emptying frequency and co-disposal of solid waste, making generalisation difficult.

India's onsite sanitation base is enormous. The 2023 National Annual Rural Sanitation Survey estimated that approximately 65% of rural households and a significant proportion of peri-urban households rely on pit latrines or septic tanks. Urban India is also heavily dependent on onsite systems: a 2020 National Institute of Urban Affairs (NIUA) study found that fewer than 40% of urban local bodies in India have sewer networks covering more than half their service area. This means that faecal sludge from unsewered households constitutes the dominant sludge stream in most Indian cities by volume.

Faecal Sludge and Septage Management (FSSM) has emerged as a policy priority in India following the National Policy on FSSM (2017) and the CPHEEO FSSM Manual (2018). The Swachh Bharat Mission 2.0 (2021-26) made FSSM a central component, requiring states to develop FSSM plans for urban local bodies (ULBs) and to establish faecal sludge treatment plants (FSTPs). As of 2024, approximately 500 FSTPs have been established across India, but coverage remains uneven across states and city sizes. The policy framework envisions faecal sludge being treated and recovered as biosolids for agricultural use, co-composting with municipal solid waste, or energy recovery, but implementation of these recovery pathways has been limited to pilot initiatives in a small number of cities.

Recent state-level developments show accelerating adoption. Rajasthan has decided to establish faecal sludge treatment plants in all urban local bodies (December 2025) and Uttar Pradesh has issued a Guidance Note on Reuse of Treated Biosolids from FSTPs and Co-treatment Plants (August 2025) prepared by the Centre for Science and Environment. This guidance note provides practical standards for biosolids reuse in the absence of national standards, addressing a critical regulatory gap that has impeded scale-up. By August 2025, the NAMASTE (National Action for Mechanised Sanitation Ecosystem) scheme had validated 84,902 sewer and septic tank workers (SSWs) across the country, rising to 89,114 by December 2025, reflecting sustained implementation momentum.

However, implementation gaps persist at scale. A 2024 Parliament reply noted that of 57,758 workers engaged in hazardous cleaning nationwide, only 16,791 PPE kits had been supplied, fewer than 14,000 had received health cards and only 837 safety workshops had been conducted across 4,800 urban local bodies. This translates to a PPE coverage ratio of approximately 29% and a health card coverage ratio of approximately 24% of the identified hazardous cleaning workforce. Waste pickers engaged in solid waste management were included as a component under NAMASTE in 2024, broadening the scheme's scope beyond sewers and septic tanks to encompass the full range of sanitation-related hazardous work.

The treatment and end-use of faecal sludge biosolids is constrained by quality variability and the absence of national standards. Faecal sludge from pit latrines typically has higher pathogen concentrations and lower nutrient content than sludge from septic tanks, requiring different treatment approaches. The CPHEEO FSSM Manual recommends stabilisation through lime treatment, composting, or co-digestion before any beneficial reuse, but monitoring of treatment effectiveness at installed FSTPs is inconsistent.

2.3 Industrial Sludge

Industrial sludge from effluent treatment plants is regulated under the Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016 (HWM Rules), the Environment Protection Act 1986 and sector-specific discharge standards. Industrial sludge is characterised by high concentrations of heavy metals, synthetic organic compounds and other sector-specific contaminants and generally requires secure containment or specialised treatment rather than the resource recovery pathways available for municipal sludge. This paper addresses industrial sludge briefly for comparative purposes but focuses principally on sewage sludge and faecal sludge streams, which present the greatest opportunity for circular economy approaches at urban scale.

The co-treatment of industrial effluents known as common effluent treatment plant (CETP) co-treatment, creates a mixed sludge stream that has characteristics of both municipal and industrial sludge. This co-treatment is widespread in industrial estates and creates significant complications for the characterisation and management of the resulting sludge. The regulatory responsibility for such mixed sludge streams is ambiguous, falling between the jurisdiction of CPCB industrial standards and municipal sludge guidance.

3. The Circular Economy Framework Applied to Sludge in India

The circular economy (CE) framework, as applied to sludge management, seeks to transform what is conventionally treated as a waste stream into a source of recoverable resources: energy, nutrients, water and organic matter. The Ellen MacArthur Foundation defines a circular economy as one that is designed to eliminate waste and pollution, keep products and materials in use and regenerate natural systems. Applied to sludge, this means designing the treatment and disposal chain to maximise resource recovery while minimising environmental release of pollutants.

India's Solid Waste Management Rules 2016 and the National Resource Efficiency Policy 2019 provide a general framework for resource efficiency, but neither specifically addresses the circular management of sludge. The 2022 CPHEEO manual on sewage sludge management is the closest thing to a national CE framework for sludge, but it provides guidance rather than binding requirements and its implementation is uneven. Table 1 summarises the principal recovery pathways and their current status in India.

Table 1: Circular Economy Recovery Pathways for Sludge in India.

Recovery Pathway	Resource Recovered	Status in India	Constraint
Anaerobic digestion	Biogas (energy)	Pilot/demonstration scale at select large STPs	Capital cost; digestate management
Co-composting with MSW	Organic compost	Operational in some cities (Devanahalli, select ULBs)	Quality consistency; market development
Phosphorus recovery (struvite)	Mineral fertiliser	Research and pilot stage only	No FCO standards for struvite; no subsidies
Agricultural land application	Soil organic matter, nutrients	Widespread but largely informal and untested	Quality standards; testing infrastructure
Co-processing in cement/brick kilns	Energy; mineral content	Limited; regulatory uncertainty	Cement sector standards; transport costs
Thermal treatment (gasification, pyrolysis)	Energy; biochar	Pilot stage	Technology cost; regulatory framework

3.1 Energy Recovery

Anaerobic digestion (AD) of sewage sludge produces biogas with a methane content of approximately 60-70%, which can be used for heat and electricity generation. Large STPs in Delhi and Mumbai have operational AD units, but most Indian STPs are too small to make AD economically viable at plant level. A 2023 analysis by the National Institute of Urban Affairs estimated that 78 large STPs in India (capacity exceeding 100 MLD) would be suitable for AD-based energy recovery, with a combined potential of approximately 800 MW of installed capacity. This represents less than 5% of the potential from full-scale deployment of biogas recovery.

Co-digestion of sewage sludge with organic municipal solid waste increases biogas yields significantly. Pilot projects in Nagpur and Indore have demonstrated biogas yields of 0.45 to 0.65 m3 per kilogram of volatile solids, comparable to European benchmarks. However, scaling co-digestion requires integration of solid waste and wastewater treatment infrastructure, which faces institutional coordination challenges in India where these sectors typically fall under different agencies.

3.2 Phosphorus Recovery

Phosphorus is a finite, non-renewable mineral with no synthetic substitute in agriculture. India imports approximately 90% of its phosphate fertiliser requirements, making domestic recovery from waste streams a strategic priority. Sewage sludge and faecal sludge are

significant phosphorus repositories: Indian urban sewage typically contains 6 to 10 mg/L of total phosphorus, of which 50 to 70% is captured in sludge during treatment.

Struvite (magnesium ammonium phosphate) crystallisation is the most widely researched phosphorus recovery pathway for sludge. Struvite forms spontaneously when concentrations of magnesium, ammonium and phosphate exceed the precipitation threshold, typically in the reject water from sludge dewatering. In India, the technology remains at pilot and research stage, with no commercial-scale installations operational as of 2026.

Recent research on phosphorus recovery in India shows both technical progress and economic barriers. A 2021 study established that at 80% recovery efficiency, 1 million litres per day (MLD) of sewage can generate 17.3 kg of struvite using chemical precipitation. A 2026 Frontiers in Agronomy review identified struvite crystallisation, adsorption, thermochemical processing, chemical extraction, biological treatment and hybrid approaches as viable recovery methods for Indian waste streams. Anaerobic digestion coupled with struvite precipitation achieved the highest phosphorus recovery (89 ± 7%), while thermochemical processing achieved superior potassium recovery (83 ± 6%). However, electrochemical magnesium dosing for struvite precipitation remains constrained by energy requirements, limiting its economic viability at small-scale Indian STPs.

A study of decentralised wastewater treatment systems in India (Auroville DEWATS) concluded that nutrient recovery should prioritise effluent quality improvement and system resilience over maximum recovery yields and that targeted policy support is required to enable decentralised circular phosphorus management. The absence of quality standards and subsidies for mineral recycling fertilisers such as struvite remains the primary barrier to market development, as struvite cannot currently be registered under the Fertilizer Control Order as a recognised product.

3.3 Co-composting and Organic Matter Recovery

Co-composting of faecal sludge biosolids with municipal solid waste (MSW) is the most widely implemented circular economy pathway for faecal sludge in India. The Devanahalli FSTP in Karnataka has demonstrated co-composting at operational scale, producing a compost product with characteristics broadly meeting FCO standards for organic fertilisers. Similar models have been implemented in Warangal, Telangana and several towns in Andhra Pradesh.

The important barriers to scaling co-composting are quality consistency, market development and the absence of a product standard specific to co-composted faecal sludge biosolids. Farmer acceptance depends on confidence in product quality, which requires consistent

testing and certification. A 2024 CSE study in five cities found that co-compost from faecal sludge achieved crop yield improvements comparable to chemical fertilisers in field trials, but market penetration remained limited due to absence of assured supply chains and buyer networks.

4. International Regulatory Frameworks: Lessons for India

India can draw on a range of international regulatory models for sludge management, each reflecting different institutional contexts, resource availability and risk philosophies. The European Union's precautionary approach, Japan's resource-intensive recovery model, Switzerland's phase-out of agricultural land application and China's rapid expansion of biogas recovery all offer relevant lessons. The United States represents a system in transition, with the EPA's traditional Exceptional Quality biosolids framework now being revised in light of emerging PFAS evidence.

4.1 European Union

The European Union's Sewage Sludge Directive (86/278/EEC), established in 1986 and due for revision under the proposed 2024/3019 regulation, sets limits on heavy metals and pathogens in biosolids applied to agricultural land, requires soil testing before application and mandates record-keeping by both sludge producers and land recipients. The proposed 2024 revision would significantly tighten these standards, adding limits on polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxins and controversially PFAS. The EU revision reflects a fundamental shift: biosolids policy must now address the full range of organic micropollutants, not just heavy metals and pathogens.

Member states have diverged significantly in their implementation of the Directive. Germany processes approximately 1.8 million tonnes of sludge dry matter annually, with 35% going to agriculture, 47% to incineration (often with phosphorus recovery from the ash) and 18% to other uses. Austria and Switzerland have banned agricultural land application entirely on precautionary grounds. The Netherlands has adopted a mixed approach, allowing agricultural use for high-quality sludge while investing in thermal treatment and phosphorus recovery infrastructure.

4.2 Switzerland and the Phosphorus Recovery Mandate

Switzerland is the most instructive international comparator for India's phosphorus challenge. In 2016, Switzerland enacted a mandatory phase-out of agricultural land application of sludge, effective from 2006 and completed by 2006, on the basis that long-term organic micropollutant accumulation in soils could not be excluded. This left sludge incineration (in

dedicated facilities or cement kilns) as the primary disposal route. However, the 2016 revision of the Technical Ordinance on Waste (TVA) went further, mandating phosphorus recovery from sludge incineration ash by 2026, requiring all sludge incineration facilities to implement ash-based phosphorus recovery using wet-chemical or thermochemical processes.

Switzerland's phosphorus mandate is significant for India because it demonstrates that phosphorus recovery from sludge can be made technically and economically viable at national scale through regulatory mandate, rather than waiting for market conditions to make it attractive. India's phosphorus import dependence creates a comparable policy rationale, though the institutional and financial conditions for implementing such a mandate differ substantially.

4.3 United States

The United States Environmental Protection Agency's (EPA) Part 503 Biosolids Rule (1993) established a risk-based framework for sludge management, creating pathways for land application through the Class A (pathogen-free) and Class B (reduced pathogen) designations. The Part 503 framework has been internationally influential and forms the basis for the Exceptional Quality (EQ) concept widely cited in Indian sludge management guidance. The framework sets limits on nine heavy metals and mandates pathogen reduction and vector attraction reduction, but did not originally address organic micropollutants, pharmaceutical compounds, or PFAS.

The US biosolids framework has come under increasing pressure since 2018, when the EPA began acknowledging that PFAS in biosolids represents a significant, previously unregulated risk. PFAS are used in fire-fighting foams, food packaging, stain-resistant textiles and numerous industrial processes. They enter wastewater systems through consumer products and industrial discharges and are not removed by standard biological treatment. Because PFAS are highly stable molecules, they accumulate in sludge and can transfer to soils and groundwater when biosolids are applied to land.

The EPA's **January 2025 draft risk assessment** is significant for India because it signals a global shift in biosolids regulation. The assessment found that people living on or near farms and sites using biosolids, or relying mainly on their products, may face risks from PFOA and PFOS under land application, surface disposal and incineration scenarios, with some scenarios exceeding acceptable risk thresholds by orders of magnitude. Comments closed on 17 March 2025. The document is not yet a regulation, but it reflects emerging scientific consensus that PFAS persistence in biosolids poses long-term environmental and health risks that cannot be managed through conventional risk frameworks.

India's exposure to PFAS is not simply the story of one factory's relocation. It is the product of a structural mismatch: treaty commitments to restrict PFAS chemicals exist on paper while the domestic monitoring, standards and enforcement infrastructure needed to act on them does not (The Wire, November 2026). This gap is particularly acute for sludge, where PFAS testing has barely begun. The US experience demonstrates that countries that developed extensive biosolids land application programmes without PFAS monitoring are now facing significant remediation costs and legal liability as contamination of soils and groundwater becomes documented. India has an opportunity to avoid this trajectory by establishing baseline PFAS testing before large-scale biosolids land application is normalised.

4.4 Japan

Japan is the global leader in sewage sludge resource recovery, with the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) reporting that 79% of sewage sludge is beneficially used, compared to 25-40% in most European countries and less than 10% in India. Japan's recovery model relies on a combination of thermal treatment (incineration with energy recovery), cement kiln co-processing, agricultural use of Class A biosolids and specialty applications including ceramics and construction materials. Japan has invested significantly in sludge drying and incineration infrastructure to reduce volumes before landfill.

Japan's high recovery rate reflects several enabling conditions that India has not yet assembled: mandatory reporting of sludge generation and disposal by treatment plants; clear product standards for biosolids in each end-use pathway; investment in treatment technology through national infrastructure programmes; and a culture of regulatory compliance that enables third-party certification of biosolids quality. The lesson for India is not that Japan's specific technology choices should be replicated, but that the institutional infrastructure—mandatory reporting, product standards, quality testing, compliance monitoring—is a prerequisite for achieving high recovery rates regardless of the specific technologies chosen.

4.5 China

China faces a sludge management challenge broadly comparable in scale to India's, with rapid expansion of wastewater treatment capacity creating large volumes of sludge without adequate treatment or disposal infrastructure. China's 2022 Sludge Treatment and Disposal Standard provides classification and testing requirements and the 14th Five Year Plan (2021-25) included specific targets for sludge reduction, stabilisation, harmlessness and resource utilisation. China has invested in large-scale anaerobic digestion, thermal drying and co-incineration with municipal solid waste as primary disposal pathways.

China's experience is instructive in highlighting both the potential and the risks of rapid infrastructure-led expansion. Construction of sludge treatment capacity has outpaced development of quality standards and monitoring systems in some regions, leading to products of uneven quality entering the agricultural market. PFAS contamination of agricultural soils in areas receiving biosolids has been documented in several Chinese studies, though the causal pathway from sludge to soil has not been definitively established in all cases. China's experience reinforces the argument that infrastructure expansion should be accompanied by, not preceded by, the standards and monitoring framework.

5. Regulatory Framework Assessment

India's sludge management is governed through a patchwork of rules, guidelines and standards that address different aspects of sludge generation, treatment and disposal, but do not constitute a coherent national framework. This section maps the principal regulatory instruments and assesses their adequacy, drawing on recent developments including state-level guidance notes and emerging contaminant research published through December 2026.

5.1 Primary Legislation and Rules

The Environment Protection Act 1986 (EPA 1986) provides the overarching legislative authority for environmental regulation in India, including sludge management. Under this Act, the Central Government has issued the Solid Waste Management Rules 2016 (SWMR), the Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016 (HWM Rules) and various standards for effluent discharge. The Water (Prevention and Control of Pollution) Act 1974 and the Water Cess Act 1977 provide additional legislative foundations for wastewater treatment and associated sludge management.

The SWMR 2016 includes provisions for the processing and treatment of organic waste from sewage treatment plants, requiring urban local bodies to ensure that sludge from STPs and faecal sludge from treatment plants is processed and treated as per the standards specified. However, these standards have not been notified in full, creating a regulatory gap between the requirement and the practical standard against which compliance can be assessed.

The National Policy on FSSM 2017 and the CPHEEO FSSM Manual 2018 established the policy and technical framework for faecal sludge management. The National Policy requires states to develop FSSM plans, establish desludging services and ensure that faecal sludge is treated before discharge or use. Implementation of these requirements has been uneven, with some states—notably Odisha, Maharashtra, Telangana, Tamil Nadu and increasingly Rajasthan and Uttar Pradesh—making more substantial progress than others.

5.2 Rules and Standards for Biosolids

The Fertilizer Control Order 1985 (FCO), as amended, provides the most directly relevant quality standards for sludge used in agriculture. The FCO sets limits on heavy metals (cadmium, lead, chromium, arsenic, nickel, mercury) in compost and other organic fertilisers. However, the FCO was designed primarily for compost from municipal solid waste, not for sludge-derived biosolids and its application to sludge is ambiguous. There is no specific FCO standard for sludge compost or Class A biosolids analogous to the US EPA's Part 503 standards or the EU's proposed 2024 regulation.

The CPHEEO Sewage Sludge Management Manual (2022) provides technical guidance on treatment options including anaerobic digestion, composting, thermal drying and land application and recommends quality parameters broadly aligned with EU and US standards. However, as a manual rather than a notified standard under the EPA 1986 or the FCO, it does not create enforceable obligations.

Biosolids standards development is accelerating. The Central Public Health and Environmental Engineering Organisation convened a **Biosolids Consultation Meet in 2024** that reviewed treatment options including lime stabilisation and solar drying. A National Institute of Urban Affairs (NIUA) report on the consultation noted that municipal organic waste, lime stabilisation and solar drying are among the treatment pathways being considered for standardisation. The Uttar Pradesh Guidance Note on Reuse of Treated Biosolids (August 2025) provides interim standards for biosolids from FSTPs and co-treatment plants, filling a regulatory gap until national standards are formally notified. However, these remain state-level guidance documents rather than national standards and their practical authority is limited to the state's own ULBs.

A significant constraint on standards development is the regional variability of sludge quality. A **June 2026 peer-reviewed study** of sludge from sewage treatment plants in Tamil Nadu classified sludge into Class D based on fertilizer and cleanliness indices, indicating limited suitability for direct agricultural application because nutrient concentrations were lower than the minimum requirements specified in the Fertilizer Control Order standards for compost. This finding underscores the need for sludge classification systems that account for regional variation in sludge quality and cautions against a single national standard that may not adequately reflect the diversity of Indian sludge characteristics. A classification approach, analogous to the US Class A/B system or the EU Grade A/B distinction proposed in the 2024 revision, would allow quality-differentiated end-use pathways appropriate to the actual characteristics of sludge from different sources and regions.

5.3 Assessment of Regulatory Instruments

Table 2 provides a consolidated assessment of the principal regulatory instruments applicable to sludge management in India, drawing on the analysis in Sections 5.1 and 5.2 and incorporating the most recent developments up to December 2026.

Table 2: Assessment of Regulatory Instruments for Sludge Management in India.

Instrument	Year	What it does for sludge	Gap / Limitation
Environment Protection Act	1986	Provides overarching legislative authority for environmental standards, including sludge disposal	Does not directly specify sludge management requirements; standards under rules not yet notified
Fertilizer Control Order	1985/amended	Sets heavy metal limits for organic fertilisers applied to land; covers compost	Designed for MSW compost; ambiguous application to sludge-derived biosolids; no microplastics or PFAS limits
Solid Waste Management Rules	2016	Requires STP sludge and FSTP biosolids to be treated per specified standards	Standards not yet notified; creates compliance expectation without enforceable standard
Hazardous Waste Rules	2016	Covers industrial sludge with hazardous characteristics; requires secure disposal or treatment	Does not cover municipal sludge; co-treated mixed sludge falls in regulatory gap
National Policy on FSSM	2017	Establishes policy framework for faecal sludge management; requires state FSSM plans	Policy only; no enforceable standards; implementation uneven across states
CPHEEO FSSM Manual	2018	Technical guidance on faecal sludge treatment and biosolids recovery options	Manual, not notified standard; not enforceable
CPHEEO Sewage Sludge Manual	2022	Technical guidance on sewage sludge treatment, disposal and recovery; recommends quality parameters	Manual, not notified standard; no monitoring requirement
NAMASTE scheme	2022 onwards	Validates sanitation workers; provides PPE, health cards, safety training; covers SSWs and waste pickers	Implementation gaps: 29% PPE coverage, 24% health card coverage of identified hazardous workforce (2024)
Biosolids Consultation Meet and NIUA guidance	2024	Identifies treatment pathways (lime stabilisation, solar drying) for standardisation	Standards not yet notified; state-level guidance only
UP Guidance	2025	Provides interim	Limited to one state; not a

Instrument	Year	What it does for sludge	Gap / Limitation
Note on Biosolids Reuse		standards for biosolids from FSTPs and co-treatment plants in Uttar Pradesh	national standard
ICMR microplastics study	2026	Documents microplastics in treated effluent (10-15 particles/L) and sludge (7-9 particles/g)	No standards or limits set for microplastics in Indian biosolids
IIT Madras PFAS study	2026	Documents PFAS concentration increases in treated water at Chennai STP (5-103% above raw water)	No PFAS testing protocol or limits for Indian biosolids or sludge

5.4 Emerging Contaminants and Testing Gaps

India's sludge quality framework addresses heavy metals and pathogens but has not yet incorporated testing requirements for microplastics and persistent organic pollutants, specifically per- and polyfluoroalkyl substances (PFAS). This represents critical gap given recent evidence on the presence of both classes of contaminants in Indian sludge and treated effluent.

The ICMR study (2026) found that treated effluent still carries 10 to 15 microplastic particles per litre, while the leftover sludge contains 7 to 9 particles per gram. Microplastics in sludge originate from synthetic textiles (via washing), personal care products, packaging materials and fragmentation of larger plastic items. Because microplastics are not removed by standard biological treatment, they concentrate in sludge during the treatment process. When biosolids containing microplastics are applied to agricultural land, the microplastics accumulate in the soil and can enter the food chain through plant uptake and soil fauna.

An IIT Madras study (October 2026) reported that concentrations of eight targeted PFAS compounds were between 5% and 103% higher in treated water than in raw water at a studied treatment facility in Chennai. PFAS are synthetic, highly persistent environmental contaminants increasingly recognised for their global occurrence, bioaccumulation potential and toxicological impacts. They include thousands of individual compounds grouped under the PFAS umbrella, of which PFOA and PFOS are the most extensively studied and the most tightly regulated internationally. PFAS do not degrade under aerobic or anaerobic conditions in sewage sludge, meaning that once present, they accumulate indefinitely. Standard sewage treatment processes do not remove PFAS; indeed, the IIT Madras finding that PFAS concentrations are higher in treated than in raw water suggests that some PFAS compounds

may be generated or released during biological treatment, or that PFAS bound to sludge particles are remobilised into solution during treatment.

The significance for sludge management is fundamental. A recovery route regarded as safe for decades, land application of biosolids is now being re-examined globally for contaminants that Indian sludge has barely been tested for. The EPA's January 2025 draft risk assessment found possible health risks from PFOA and PFOS in biosolids under land application scenarios, with some exposure pathways exceeding acceptable risk thresholds by orders of magnitude. Germany, the Netherlands and several other European countries have begun testing biosolids for PFAS and have found widespread contamination at varying concentrations.

India's exposure to PFAS in sludge is a structural governance problem, not simply a technical one. India is a signatory to the Stockholm Convention on Persistent Organic Pollutants, which has listed PFOA and PFOS for elimination. However, the domestic testing, standards and enforcement infrastructure needed to act on these commitments in the sludge sector does not yet exist. There is no Indian standard for PFAS in biosolids, no testing protocol for PFAS in STPs and no monitoring programme for PFAS in agricultural soils receiving biosolids.

This gap has immediate implications for the circular economy pathway. If Indian sludge carries PFAS at levels comparable to or higher than European sludge, then land application of biosolids without PFAS testing could transfer persistent chemicals to agricultural soils and food chains at scale. The appropriate policy response is not to halt all land application pending testing, which would leave sludge without a disposal pathway, but to establish a systematic baseline testing programme as a prerequisite for normalising land application and to develop quality classification criteria that incorporate PFAS limits alongside existing heavy metal and pathogen thresholds.

The pathway forward for addressing emerging contaminants in Indian sludge requires four sequential steps:

- Baseline testing of sludge from a representative sample of STPs across India for PFAS, microplastics and heavy metals, to establish a national evidence base and identify hotspots;
- Development of testing protocols and concentration limits for microplastics and PFAS in biosolids, aligned with emerging international standards including the EU's proposed 2024 Directive and the US EPA's 2025 draft risk assessment;

- Implementation of source control measures to reduce PFAS and microplastic inputs from industrial and commercial catchments into the sewer system, including improved industrial effluent pre-treatment requirements; and
- Integration of PFAS and microplastics testing requirements into the national biosolids standard when it is formally notified, so that any biosolids used in agriculture must demonstrate compliance with emerging contaminant limits, not just heavy metal and pathogen standards.

6. Staged Pathway for Indian Cities

The analysis presented in this paper points to a set of priority actions for Indian sludge management policy. The recommendations are organised as a staged pathway that acknowledges the need to build foundational evidence and standards before scaling recovery and that incorporates emerging contaminant testing as a Stage 1 requirement rather than a future consideration. This staged approach reflects the principle that circular economy adoption without quality assurance creates liabilities, not opportunities.

Stage 1: Classification, Standards and Testing (2026-2027)

The foundational requirement is to establish what is in India's sludge before determining what to do with it. Without this knowledge, any expansion of land application or other recovery pathways is premature.

- Conduct baseline testing of sludge from a representative national sample of STPs (minimum 100 plants across different city sizes, regions and industrial catchment types) for PFAS, microplastics, heavy metals and pathogens, to establish a national sludge quality evidence base and identify contamination hotspots requiring remedial attention;
- Notify national biosolids quality standards that incorporate limits for heavy metals, pathogens, microplastics and PFAS, aligned with emerging international standards from the EU (proposed 2024 Directive), the US EPA (2025 draft risk assessment) and the 2026 Frontiers in Agronomy research framework; these standards should include a classification system (Class A, B, C) to allow quality-differentiated end-use pathways;
- Classify sludge by origin (sewage sludge, faecal sludge, co-treated sludge) and quality (based on testing results) to enable matching of treatment and end-use pathways to sludge characteristics, following the principle established by the Tamil Nadu 2026 study that regional variability requires differentiated standards; and

- Establish a single national body accountable for the sludge chain from treatment plant to end use, with clear mandate for monitoring, standards compliance and public reporting of sludge generation, treatment and disposal data.

Stage 2: Source Control and Safe Treatment Routes (2027-2028)

Once the evidence base is established, regulatory attention should turn to reducing contaminant inputs and ensuring that treatment pathways deliver the quality required for safe end use.

- Implement source control measures to reduce PFAS and heavy metal inputs from industrial and commercial catchments into the sewer system, including strengthened industrial effluent pre-treatment requirements and enforcement and requirements for PFAS-using industries to characterise and reduce their discharges to municipal systems;
- Scale up faecal sludge treatment plants in all urban local bodies, following the Rajasthan model (December 2025 commitment to FSTP in all ULBs) and the UP Guidance Note on Biosolids Reuse (August 2025) as interim operational standards, with priority for co-treatment models that aggregate faecal sludge from multiple collection areas into shared treatment infrastructure;
- Expand NAMASTE implementation to close current coverage gaps, ensuring that all 57,758 identified hazardous sanitation workers receive PPE kits (addressing the current 29% coverage gap), health cards (addressing the 24% gap) and safety training, with particular attention to the 4,800 ULBs that have conducted fewer than one workshop each; and
- Pilot energy recovery routes (anaerobic digestion with biogas utilisation, gasification, co-incineration) at representative scale across different STP sizes and sludge characteristics to confirm model yields, energy balances and economics under Indian conditions.

Stage 3: Nutrient Recovery and Co-processing (2028-2029)

With quality standards in place and contaminant sources under control, India can systematically expand beneficial use pathways for the sludge streams that meet quality thresholds.

- Where sludge quality testing confirms PFAS and microplastic concentrations below the limits established in Stage 1, implement phosphorus recovery via struvite crystallisation, with targeted policy support including registration of struvite under the Fertilizer Control Order, quality certification and subsidies aligned with the avoided cost of phosphate fertiliser

imports; the 2026 Frontiers in Agronomy review confirms that anaerobic digestion coupled with struvite precipitation can achieve 89% phosphorus recovery;

- Scale co-composting of faecal sludge biosolids with municipal solid waste, following the operational models established at Devanahalli, Warangal and sites in Uttar Pradesh, with product quality certification against FCO compost standards and development of assured supply chains and buyer networks for recovered organic products;
- Expand co-processing in cement and brick kilns for sludge that does not meet land application quality thresholds, including sludge classified as Class C (elevated PFAS or heavy metals), while ensuring that cement co-processing does not create a regulatory loophole for PFAS transfer to cement products; and
- Develop certified product standards and buyer networks for recovered nutrients and organic products derived from biosolids, in partnership with the fertiliser industry, agricultural research institutions and state agriculture departments.

Stage 4: Performance-based Financing and Monitoring (Ongoing)

Sustainable scale-up requires financing mechanisms and monitoring systems that create incentives for performance rather than just infrastructure construction.

- Link government financing of STP and FSTP construction and operation to sludge treatment outcomes and biosolids quality certification, not just plant construction completion or treatment capacity, following the performance-based contracting models being piloted in several states;
- Establish monitoring systems for PFAS and microplastics in biosolids and in agricultural soils where biosolids are applied, creating a longitudinal database that enables detection of contaminant accumulation before it reaches remediation threshold levels;
- Conduct epidemiological studies of health outcomes in communities near sludge treatment and application sites, with particular attention to communities near facilities where PFAS-containing sludge has been land-applied; and
- Report annually on sludge generation, treatment and end-use pathways in a national sludge register, drawing on mandatory plant-level reporting, to enable adaptive management and evidence-based revision of standards over time.

The staged pathway proposed here is more conservative in its initial phase than some previous Indian sludge management roadmaps, because it inserts a non-negotiable evidence-gathering step before normalising land application. This conservatism is justified by the

emerging international evidence on PFAS in biosolids, the Tamil Nadu 2026 finding on sludge quality classification and the structural governance gap identified in Section 5.4. A circular economy built on inadequately tested biosolids is not a circular economy; it is a deferred pollution problem.

7. Urban Challenges and Implementation Constraints

India's sludge management challenge is not only a regulatory design problem; it is an urban governance problem with structural features that resist conventional regulatory solutions. This section identifies the principal implementation constraints that any sludge management pathway must address.

7.1 Fragmented Institutional Responsibility

Sludge management in Indian cities typically falls between multiple agencies without clear primary accountability. In most cities, the water utility or urban local body operates the STP and is responsible for sludge treatment and disposal, but lacks the technical capacity, regulatory mandate, or financial resources to do so systematically. The state pollution control board has jurisdiction over effluent standards and potentially over sludge disposal, but does not typically have operational responsibility for sludge management and has limited inspection capacity for STP operations.

This fragmentation means that no single body is accountable for ensuring that sludge is treated, tested and disposed of or recovered appropriately. Plant operators discharge sludge to landfill, open dumps, or informal land application without systematic monitoring because there is no inspecting authority with practical capacity to enforce standards that have not, in any case, been formally notified.

7.2 Financial Sustainability

Sludge treatment and resource recovery require capital investment in treatment infrastructure and operating costs for energy, chemicals and labour. In the absence of revenues from recovered products or gate fees from waste generators, these costs must be met from municipal budgets that are typically stretched. Central government schemes including AMRUT, SBM and the National Urban Development Mission provide capital funding for treatment infrastructure, but operating costs are typically expected to be met by city governments after the project period. This creates a systemic incentive to build infrastructure that minimises operating costs rather than maximises resource recovery.

7.3 Worker Health and the Sanitation Workforce

Sludge management is labour-intensive at every stage from desludging operations to composting and agricultural application. Workers in this sector face significant occupational health risks from exposure to pathogens, toxic chemicals and asphyxiant gases in confined spaces. The NAMASTE implementation data presented in Section 2.2 reveals a significant gap between policy intent and implementation reality. Of the 57,758 workers identified as engaged in hazardous sanitation work, only 16,791 PPE kits had been distributed, fewer than 14,000 health cards had been issued and only 837 safety workshops had been conducted across 4,800 ULBs by 2024. Any scale-up of sludge treatment and recovery operations must include systematic investment in occupational health protection as a non-negotiable requirement.

7.4 Technology Readiness and Scale

Several resource recovery technologies for sludge have been demonstrated at pilot scale in India but have not been scaled to commercial deployment. The gap between pilot demonstration and commercial scale reflects multiple barriers: absence of product standards and market certainty for recovered products; technology costs that exceed the financial capacity of small and medium-sized ULBs; limited domestic technical expertise in operation and maintenance; and risk aversion by financial institutions unfamiliar with sludge treatment assets. Technology selection must be appropriate to the scale and institutional capacity of the city.

8. CONCLUSION

India's sludge management is at a critical juncture. The country is building sewage treatment and faecal sludge treatment capacity at unprecedented scale, generating a growing stream of sludge that has potential value as a resource but is currently managed largely as a waste. The regulatory framework that governs what happens to this sludge is fragmented, incomplete and has not kept pace with either the scale of generation or the emerging international evidence on contaminants of concern.

This paper has documented three significant developments that reinforce the case for urgent attention to sludge management in India. First, ICMR and IIT Madras research (2026) has established that Indian sewage treatment plants are not removing microplastics or PFAS from wastewater and that sludge concentrates both classes of contaminants. This finding changes the risk calculus for land application of biosolids: a pathway that appears to offer circular economy benefits may, without adequate testing, transfer persistent contaminants to soils and

food chains at scale. Second, state-level progress in Rajasthan and Uttar Pradesh (2025) demonstrates that accelerating implementation is possible when states commit to it. Third, the UP Guidance Note on Biosolids Reuse represents an important interim measure in filling the national standards gap.

The international comparison reinforces the argument for building the standards and monitoring infrastructure before normalising land application at scale. Switzerland banned land application in 2006 after concluding that long-term micropollutant accumulation could not be excluded. The US is now grappling with PFAS contamination of soils from decades of biosolids application without PFAS testing. The EU is revising its 1986 Directive to incorporate organic micropollutant limits. India has an opportunity to learn from these trajectories rather than replicate them.

The staged pathway proposed in Section 6 provides a framework for this learning. It begins with systematic testing of sludge quality. It progresses through source control and treatment capacity expansion to nutrient recovery and co-processing for sludge streams that meet quality thresholds. It embeds performance monitoring and adaptive management as ongoing requirements. And it insists that worker protection—addressing the NAMASTE coverage gaps documented in this paper—is not separable from the technical and regulatory dimensions of sludge management.

A circular economy for sludge in India is achievable. The technologies exist. The policy framework is developing. State-level momentum is building. What remains to be assembled is the evidence base, the national standards, the institutional accountability and the monitoring infrastructure that will allow India to realise the resource recovery potential of its sludge without creating deferred pollution liabilities. That assembly is the work of the next three to five years.

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