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REVIEW PAPER

Emerging Contaminants in Ghana's Wastewater Streams: A Review

Prince Kwesi Yeboah-Danso[1*], Isaac Mbir Bryant[1], Raymond Kingsford Sam[1], Philip Dotsey[1], Emmanuel Tetteh Sampeney[1], Geoffrey Botchway Saah[1], Diana Owusua Agyei[1], Ishmael Yaala[1] and Josephine Wenawi Akediwor[2]

[1]Department of Environmental Science, School of Biological Sciences, University of Cape Coast, Cape Coast, Ghana
[2]Department of Biological Science, Louisiana State University, Shreveport, United States of America

*Corresponding author: pyeboah009@stu.ucc.edu.gh (**ORCID ID:** 0009-0007-6047-9234)

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ABSTRACT

Emerging contaminants (ECs), including pharmaceutical residues, personal care products (PCPs), endocrine-disrupting compounds (EDCs), microplastics, and nanoparticles, are increasingly reported in Ghana's aquatic environments. These substances resist conventional wastewater treatment and may bioaccumulate, posing serious risks to ecosystems and public health. This review synthesizes available evidence from peer-reviewed studies, technical reports, and Environmental Protection Agency data to assess the sources, occurrence, and persistence of ECs in wastewater. Findings show that pharmaceuticals and PCP ingredients are frequently present in treated effluents, while microplastics and nanoparticles act as carriers of adsorbed pollutants. Long-term exposure to these contaminants is linked to antimicrobial resistance, endocrine disruption, reproductive disorders, and ecological toxicity. Ghana currently lacks EC-specific regulations and systematic monitoring programs, while data remain sparse and fragmented. Most treatment facilities rely on primary or secondary processes that are ineffective in eliminating trace contaminants, and advanced methods such as ozonation, activated carbon, and membrane technologies are rarely applied due to financial and technical barriers. Low-cost alternatives, such as constructed wetlands and biofiltration systems, have shown promise in other contexts but remain under-explored locally. This study identifies critical knowledge gaps, weak institutional frameworks, and technological limitations that constrain effective management of ECs in Ghana. It emphasizes the urgent need for national monitoring frameworks, clear discharge standards, affordable treatment upgrades, and public awareness initiatives, including pharmaceutical take-back schemes. Lessons from international experiences, notably the European Union's wastewater directives and Sweden's pharmaceutical stewardship programs, offer practical pathways for safeguarding Ghana's water quality, ecological integrity, and public health.

HIGHLIGHTS

- Review sources and occurrence of ECs in Ghana's wastewater.
- Highlights treatment failures and ecological and human health risks.
- Recommends low-cost treatment innovations for sustainable management.

Keywords: Emerging contaminants, pharmaceuticals, endocrine, micro plastics, environmental sustainability

Emerging contaminants (ECs) represent a diverse class of synthetic and naturally occurring compounds increasingly detected in aquatic environments but often overlooked in conventional water quality monitoring (Noguera-Oviedo & Aga, 2016). They include pharmaceuticals, personal

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care products (PCPs), endocrine-disrupting compounds (EDCs), microplastics, nanomaterials, and a range of industrial chemicals (Tijani *et al.* 2016). These substances are characterized by resistance to biodegradation and limited removal during traditional wastewater treatment, which enables them to persist in the environment. PCPs such as fragrances, ultraviolet filters, and antimicrobial agents contained in shampoos, lotions, and sunscreens are routinely washed from skin and fabrics into household wastewater (Srinivasulu *et al.* 2022). Once discharged into aquatic systems, such contaminants may bioaccumulate in organisms, disrupt endocrine and metabolic processes, and destabilize ecosystems (Chawla *et al.* 2024). Pharmaceuticals, including antibiotics, analgesics, and contraceptive hormones, also reach wastewater through excretion or the improper disposal of unused medicines. These compounds are of particular concern because they contribute to antimicrobial resistance and interfere with endocrine function (Aslam *et al.* 2018; Carnevali *et al.* 2018). In Ghana, the issue of ECs has become more pronounced due to rapid urbanization, population growth, and rising consumption of pharmaceutical and consumer products (Boahen *et al.* 2023). Many households continue to depend on untreated surface water and groundwater for drinking, farming, and industrial use, heightening exposure risks. Recent studies from Accra, Kumasi, and other major cities have confirmed the presence of ECs in wastewater and surface waters. High concentrations of triclosan, benzophenone, and parabens, commonly associated with soaps and cosmetics, have been detected in municipal effluents (Ason, 2022). These substances persist in aquatic systems and are known to cause reproductive and developmental abnormalities in wildlife (Sinicropi *et al.* 2022; Carvalho *et al.* 2023). Similarly, pharmaceutical residues such as amoxicillin, ciprofloxacin, erythromycin, paracetamol, and ibuprofen have been identified in Ghanaian wastewater (Azanu *et al.* 2021). Their continued presence raises concerns about antimicrobial resistance and chronic low-dose human exposure through drinking water supplies (Aslam *et al.* 2018; Endale *et al.* 2023). Microplastics, particularly polyethylene and polypropylene, have also been detected in effluents from wastewater treatment facilities and in receiving rivers and streams. These particles act as carriers for toxic compounds and can be ingested by aquatic organisms, amplifying ecological risks (Asori *et al.* 2024; Dhiman *et al.* 2023). Nanoparticles originating from cosmetics and industrial applications pose further hazards because their small size allows them to penetrate biological membranes and trigger oxidative stress in cells (Tee *et al.* 2016). Despite this evidence, Ghana's wastewater treatment infrastructure remains inadequate for addressing ECs. Most plants rely on primary and secondary processes such as sedimentation and activated sludge, which are designed to remove solids and organic matter but not trace organics (Ahmed *et al.* 2017). As a result, ECs persist in treated effluents and enter rivers, lakes, and groundwater. Regulatory frameworks are equally limited. Ghana lacks EC-specific water quality standards, and enforcement of general wastewater regulations is inconsistent (EPA Ghana, 2022; Kumar *et al.* 2024). Monitoring remains sporadic and fragmented, with available data largely generated by isolated academic projects. Public awareness is also low. The flushing of unused medicines and disposal of household chemicals into drains remain common practices that add significantly to contaminant loads in sewage systems (Samal *et al.* 2022). Unlike countries that have adopted pharmaceutical take-back programs or extended producer responsibility models to manage ECs at the source (Biswas *et al.* 2025), Ghana has not yet implemented structured measures to curb inputs into wastewater streams.

In light of these challenges, this review examines the occurrence, risks, and management of ECs in Ghana's wastewater. It compiles evidence from national and international research to identify major contaminant categories, their pathways, and treatment outcomes. Drawing on experiences from other regions, including European Union wastewater directives and Sweden's pharmaceutical stewardship initiatives (Cangola *et al.* 2024; Gore *et al.* 2024), it evaluates practical and cost-effective solutions that could be adapted to Ghana's context. The review also highlights urgent research and policy gaps, including the absence of baseline data on EC prevalence, weak monitoring frameworks, and limited public engagement. The overall aim is to provide evidence-based insights that can support policymakers, researchers, and practitioners in protecting Ghana's water resources and public health while advancing sustainable development goals.

MATERIALS AND METHODS

A search was conducted to identify peer-reviewed articles, theses, technical reports, and policy documents published between 2010 and 2025. Boolean combinations of keywords including "emerging contaminants," "wastewater," "pharmaceuticals," "personal care products," "endocrine-disrupting compounds," "microplastics," and "Ghana" were applied across major databases such as ScienceDirect, SpringerLink, Taylor & Francis, Elsevier, MDPI, and Google Scholar. Grey literature from the Ghana Environmental Protection Agency was also reviewed to supplement published sources. Studies were selected based on their relevance to the occurrence, sources, health and ecological risks, and management of emerging contaminants in wastewater. Extracted data were categorized thematically into pollutant types, treatment technologies, regulatory frameworks, and ecological and human health impacts. Comparative analysis was carried out with international benchmarks and best practices to highlight data gaps, technological limitations, and policy shortcomings.

RESULTS AND DISCUSSION

Occurrence of Emerging Contaminants in Wastewater

Pharmaceuticals, personal care products (PCPs), endocrine-disrupting compounds (EDCs), microplastics, and nanoparticles have been detected in wastewater streams across Ghana. Elevated concentrations of triclosan, parabens, and benzophenones have been reported in municipal effluents, particularly in Accra and Kumasi, where discharges from the cosmetics and beauty industry contribute significantly to contaminant loads (Ason, 2022). PCP residues such as ultraviolet filters and synthetic musks have also been identified, reflecting widespread consumer use and direct wash-off into sewage networks (Srinivasulu *et al.* 2022). Pharmaceuticals, including amoxicillin, ciprofloxacin, erythromycin, and diclofenac, are consistently present in hospital and domestic wastewater (Azanu *et al.* 2021). These residues enter sewage systems primarily through patient excretion and the improper disposal of unused medicines. Even at low concentrations, antibiotics in wastewater pose a concern due to their ability to promote antimicrobial resistance among microbial communities (Aslam *et al.* 2018). Veterinary pharmaceuticals and pesticides, such as sulphonamides and atrazine, have also been documented in agricultural runoff, further contributing to the contamination of surface waters (Pal *et al.* 2010). Microplastics, predominantly polyethylene and polypropylene, have been observed in effluents from wastewater treatment plants as well as in surface waters receiving municipal discharges (Asori *et al.* 2024). Their persistence is attributed to the widespread use of plastics in packaging, household items, and microbeads from cosmetic products. Nanoparticles originating from personal care products and industrial applications have also been identified as potential pollutants, with their nano-scale dimensions enabling them to bypass conventional treatment systems and persist in aquatic environments (Tee *et al.* 2016).

The coexistence of these contaminants indicates that wastewater in Ghana is a major pathway for pollutants entering rivers, streams, and groundwater. The continuous release of ECs, coupled with ineffective treatment infrastructure, has increased their prevalence in aquatic ecosystems and heightened the potential for bioaccumulation and chronic exposure risks (Chawla *et al.* 2024). Results are summarized in Table 1 and illustrated in Fig. 1.

Source: *(Osuoha, Anyanwu, & Ejileugha, 2023)*

Fig. 1: Personal Care Products (PCPs)

Ecological and Human Health Risks

Aquatic organisms exposed to pharmaceuticals and PCPs have shown reproductive, developmental, and

Table 1: Sources and Composition of Emerging Contaminants in Ghana's Wastewater

Source Category	Type of Emerging Contaminant	Typical Compounds	Pathways into Wastewater
Household Wastewater	Pharmaceuticals, Personal Care Products	Ibuprofen, Paracetamol, Triclosan, Parabens, DEET	Bathing, washing, excretion, product disposal
Hospitals & Clinics	Pharmaceuticals, Antibiotics	Amoxicillin, Ciprofloxacin, Diclofenac, Erythromycin	Improper disposal, patient excretion
Agricultural Runoff	Veterinary drugs, Pesticides	Sulfonamides, Ivermectin, Atrazine	Runoff from farms and animal husbandry operations
Industrial Effluents	Organic compounds, solvents, surfactants	Nonylphenol, phthalates, benzene derivatives	Industrial wastewater discharge
Cosmetic and Beauty Industry	Personal care and fragrance chemicals	Benzophenones, phthalates, synthetic musks	Wash-off from salons, direct disposal
Landfills and Leachates	Mixed pharmaceuticals, microplastics	Caffeine, painkillers, microbeads	Leaching into ground and surface water
Urban Stormwater Runoff	Mixed contaminants	Oil residues, metals, detergent chemicals	Surface runoff from roads and urban areas

Source: *(Pal et al. 2021).*

endocrine disruptions (Marques *et al.* 2022; Mitra *et al.* 2021). Antibiotics recorded high ecological risk quotients (RQ >1), indicating significant potential harm to aquatic life (OECD, 2019). Triclosan and parabens were linked to oxidative stress and hormonal imbalance in fish (Marques *et al.* 2022), while microplastics acted as vectors for toxic substances in aquatic environments (Dhiman *et al.* 2023). Endocrine-disrupting compounds such as bisphenol A (BPA) and synthetic estrogens, even at trace concentrations, interfere with hormonal regulation, leading to feminization of male fish, reduced fertility, and altered population dynamics in aquatic ecosystems (Carnevali *et al.* 2018; Adjei *et al.* 2025). Continuous exposure to mixtures of these compounds increases the risk of bioaccumulation and biomagnification, as contaminants accumulate in fish tissue and are transferred through the food chain to humans (Chawla *et al.* 2024). Microplastics and nanoparticles further exacerbate ecological risks by causing digestive blockages, tissue damage, and oxidative stress in aquatic organisms. Their surfaces readily adsorb heavy metals and persistent organic pollutants, enhancing pollutant transport in aquatic food webs (Al-Thawadi, 2020). In Ghana's rivers, this may accelerate toxin transfer into fish and shellfish consumed by local populations, posing food safety concerns (Asori *et al.* 2024). Alterations in microbial community structures have also been documented, disrupting nutrient cycling and facilitating the spread of antimicrobial resistance genes (Pinto *et al.* 2022; Gomes, 2025). The human health implications are equally significant. Trace levels of pharmaceuticals, endocrine disruptors, and microplastics have been detected in treated drinking water sources in Ghana (Boahen *et al.* 2023). Chronic low-level exposure is associated with hormone-related cancers, reproductive dysfunction, metabolic syndrome, and cognitive impairments (Gore *et al.* 2024; Frazier, 2023). Antibiotic residues contribute to the global rise of antimicrobial-resistant infections, recognized as one of the most urgent health crises of this century (Aslam *et al.* 2018; Endale *et al.* 2023). Microplastics ingested through drinking water and contaminated food may accumulate in human tissues, impairing immune responses and disrupting cellular processes (Kim *et al.* 2021). The combined effects of these contaminants are of particular concern. Although individual concentrations often fall below regulatory thresholds, additive and synergistic interactions intensify toxicity, leading to long-term ecological degradation and increased public health risks. The toxicological effects are summarized in Table 2 and illustrated in Fig. 2.

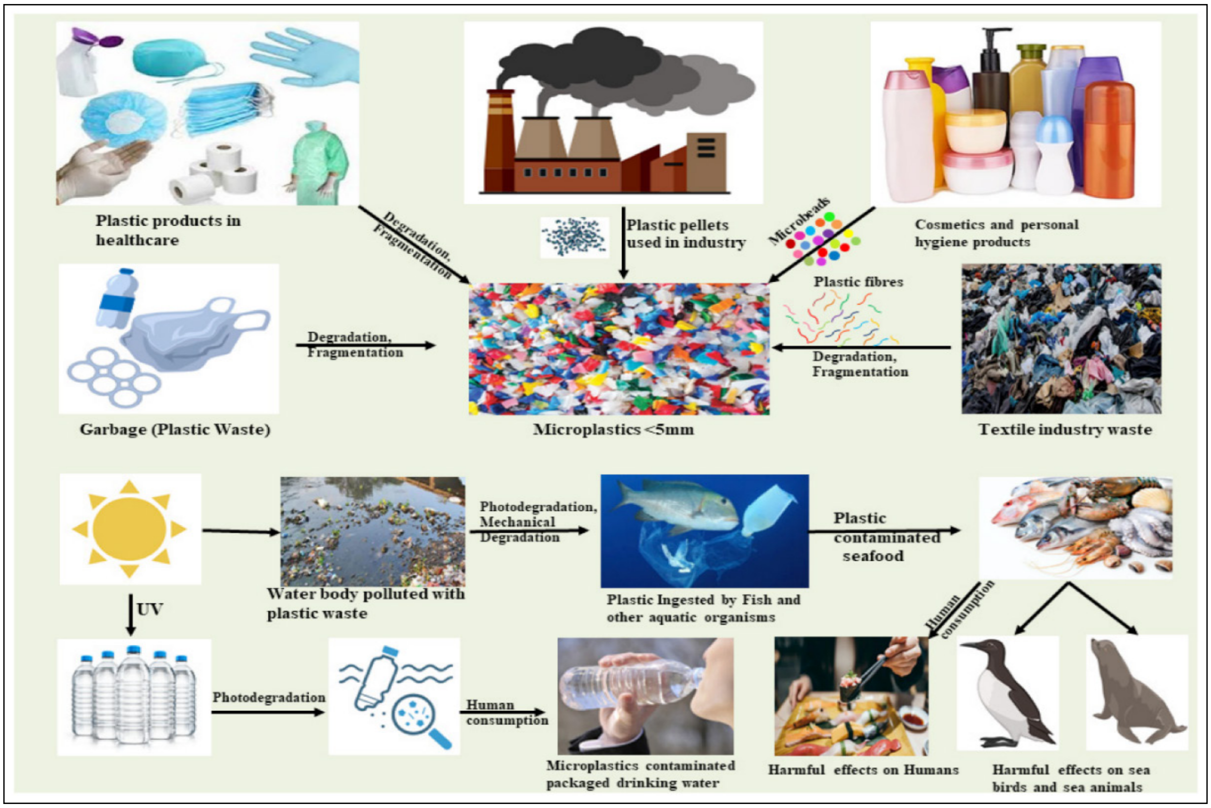
Wastewater Treatment Performance

Conventional wastewater treatment plants in Ghana, which rely primarily on sedimentation and activated sludge processes, have shown limited efficiency in removing emerging contaminants (Kvernberg,

Table 2: Ecological Risks of Detected Pharmaceuticals

Compound	Risk Quotient (RQ)	Ecological Risk Level	Affected Organisms
Amoxicillin	>1	High	Aquatic organisms
Ciprofloxacin	>1	High	Aquatic organisms
Doxycycline	>1	High	Aquatic organisms
Ibuprofen	>1	High	Fish and lower trophic level organisms
Acetaminophen	0.0–0.295	Low to Medium	Aquatic organisms

***Note:** An RQ >1 indicates a high ecological risk.*
***Source:** (Organisation for Economic Co-operation and Development, 2019).*



***Source:** (Dhiman et al. 2023).*

Fig. 2: Microplastics and Nanoparticles

2012; Ahmed *et al.* 2017). Pharmaceuticals, PCPs, and microplastics have been consistently detected in treated effluents, confirming the inadequacy of current systems (Ason, 2022; Asori *et al.* 2024). These facilities were originally designed to eliminate organic matter, nutrients, and pathogens, but not trace organic micropollutants or plastic particles. Consequently, contaminants such as triclosan, parabens, ibuprofen, and polyethylene microplastics bypass treatment barriers and are released into receiving water bodies, where they accumulate and exert toxic effects. Operational challenges further undermine treatment performance. Many facilities face poor maintenance, frequent power supply interruptions, and limited technical expertise to manage even basic processes effectively (Kvernberg, 2012). In some instances, plants operate intermittently, resulting in untreated or partially treated wastewater discharges into rivers and streams. Rapid urbanization and population growth exacerbate the problem by generating wastewater volumes that exceed the design capacities of existing infrastructure (Boahen *et al.* 2023). Advanced treatment processes such as ozonation, activated carbon adsorption, advanced oxidation, and membrane filtration are proven effective for degrading pharmaceuticals and removing micropollutants in Europe and North

America. However, these technologies are largely absent in Ghana due to high capital investment, energy demand, and operational costs (Onu, 2024; Ahmed *et al.* 2017). Even where pilot initiatives have been attempted, long-term scalability and sustainability remain constrained by limited funding and dependence on imported systems. Nature-based and hybrid approaches, including constructed wetlands, biochar filtration, and decentralized modular treatment systems, have demonstrated promise in tropical countries for removing nutrients and selected pharmaceuticals (Durdyev *et al.* 2020). Such approaches offer Ghana affordable, adaptable, and environmentally beneficial alternatives to high-cost advanced systems. Integrating these methods into wastewater management would not only enhance EC removal but also provide co-benefits such as biodiversity conservation, carbon sequestration, and improved ecosystem resilience. Fig. 3 illustrates combined conventional and tertiary treatment pathways, highlighting the limitations of Ghana's existing infrastructure and the potential benefits of adopting advanced or nature-based technologies.

Policy and Management Gaps

The absence of EC-specific regulations and monitoring programs has significantly hindered effective management of these contaminants (EPA Ghana, 2022; Kumar *et al.* 2024). At present, Ghana's Environmental Protection Agency enforces general wastewater quality standards, but these focus mainly on conventional parameters such as biochemical oxygen demand, pathogens, and suspended solids, with no provisions for pharmaceuticals, personal care products, or microplastics. Consequently, discharge permits seldom include ECs, and treatment facilities are not mandated to monitor or reduce their concentrations. Enforcement of existing standards is also weak. Many wastewater treatment plants face operational challenges and struggle to comply even with basic guidelines due to limited inspections, poor maintenance, and inadequate institutional capacity. The absence of binding requirements discourages utilities and industries from investing in advanced treatment technologies, perpetuating the release of ECs into the environment. Low public awareness further compounds the problem, as improper disposal practices such as flushing unused medicines and discarding household chemicals into drains remain common, contributing to contaminant loading in sewage systems (Samal *et al.* 2022). Institutional fragmentation exacerbates regulatory challenges. Responsibilities for water quality management, health protection, and waste regulation are shared among multiple agencies, including the EPA, Water Resources Commission, Ministry of Sanitation, and Ministry of Health, but coordination remains limited. This overlap weakens accountability and delays the formulation of a coherent national strategy. Furthermore, producers of pharmaceuticals and personal care products, along with hospitals and industries that generate ECs, are not held accountable for the downstream impacts of their products. This stands in contrast to Extended Producer Responsibility schemes widely implemented in Europe, which place part of the burden of waste management on manufacturers (Biswas *et al.* 2025). Financial and technical constraints present additional barriers. Most municipalities lack the resources to conduct advanced EC monitoring or to upgrade treatment infrastructure. Funding for universities and research institutions to study EC prevalence is scarce, leading to fragmented and sporadic studies that cannot be consolidated into a comprehensive national database. Without systematic surveillance, policymakers lack the evidence base needed to prioritize interventions, establish discharge standards, or design effective regulatory frameworks.

Management Challenges and Policy Implications

The persistence of emerging contaminants (ECs) in Ghana's wastewater represents a growing environmental and public health concern. Unlike conventional pollutants, ECs are considered pseudo-persistent because they either degrade slowly or are continuously introduced into aquatic systems through domestic sewage, hospital effluents, industrial discharges, and urban runoff (Samal *et al.* 2022). Compared with international experiences, Ghana faces significant structural and systemic barriers, including outdated wastewater infrastructure, limited financial resources, weak enforcement mechanisms, and the absence of EC-specific regulatory frameworks (Shehu *et al.* 2022; Kumar *et al.* 2024). Globally, advanced treatment technologies such as ozonation, activated carbon adsorption, and membrane processes have demonstrated high efficiency in removing pharmaceuticals, PCPs, and microplastics (Ahmed *et al.* 2017; Osuoha *et al.* 2023). However, such technologies are rarely implemented in Ghana due to prohibitive capital investment and operational costs (Onu, 2024). This underscores the need for affordable and sustainable alternatives. Nature-based and decentralized treatment systems, including constructed wetlands and biofiltration, have shown promise in tropical regions for reducing pharmaceuticals and nutrient loads (Durdyev *et al.* 2020). These systems are adaptable to local conditions, less resource-intensive, and provide co-benefits such as biodiversity conservation, carbon sequestration, and opportunities for community participation. Beyond treatment improvements, upstream interventions are essential. Pharmaceutical take-back programs, as practiced in Sweden, have been effective in reducing the entry of unused drugs into sewage networks and landfills (Gore *et al.* 2024). Ghana lacks such initiatives, but the adoption of Extended Producer Responsibility models could ensure that manufacturers and distributors share responsibility for end-of-life management of pharmaceuticals and PCPs (Biswas *et al.* 2025). Raising public awareness is equally important. Studies in Ghana reveal that low levels of environmental awareness contribute to improper disposal behaviours, including the flushing of unused medicines and household chemicals into drains (Samal *et al.* 2022). Educational programs delivered through schools, health facilities, and media campaigns could play a critical role in modifying public behaviour and reducing contaminant inputs at the source. From a governance perspective, lessons can be drawn from international frameworks. The European Union's revised Urban Waste Water Treatment Directive (2024) explicitly incorporates micropollutant removal and emphasizes producer responsibility, offering a model for regulatory reform. Similarly, Australia's integrated water governance frameworks demonstrate the importance of multi-stakeholder collaboration and cross-sectoral coordination in addressing complex water quality challenges (Jalba *et al.* 2010). For Ghana, establishing an inter-agency task force involving the Environmental Protection Agency, Water Resources Commission, Ministry of Sanitation, and Ministry of Health would strengthen institutional coordination and promote the development of coherent, long-term strategies for EC management.

CONCLUSION

Emerging contaminants are now widely recognized in Ghana's wastewater, with profound ecological and human health implications. Pharmaceuticals, personal care products, endocrine-disrupting compounds, microplastics, and nanoparticles persist in aquatic environments, where they contribute to bioaccumulation, endocrine disruption, antimicrobial resistance, and chronic human exposure. Conventional wastewater treatment systems are ill-equipped to address these pollutants, while advanced treatment technologies remain scarce due to high capital and operational demands. The lack of EC-specific discharge standards and systematic national monitoring further exacerbates the challenge, leaving a significant regulatory and institutional gap. Addressing these issues requires a coordinated national strategy that establishes clear regulatory frameworks, implements comprehensive monitoring programs, and invests in affordable and sustainable treatment options. Nature-based systems such as constructed wetlands and biofiltration offer cost-effective alternatives that are suitable for local conditions and provide additional ecological benefits. Equally important is public engagement, particularly through environmental education campaigns and pharmaceutical take-back initiatives, which can reduce contaminant loading at the source. Inter-agency collaboration, stronger accountability mechanisms, and the introduction of producer responsibility schemes would strengthen governance and mobilize resources for effective management. Long-term ecological monitoring, ecotoxicological studies, and human health risk assessments tailored to Ghana's context are urgently needed. Integrating local universities and research institutions into national monitoring frameworks will help generate reliable data to guide evidence-based policymaking. Lessons from international best practices, including the European Union's wastewater directives and Sweden's pharmaceutical stewardship programs, provide valuable models for building a robust national framework. In conclusion, tackling emerging contaminants in Ghana requires a multidimensional approach that combines technological innovation, regulatory reform, sustained research investment, and active community participation. Without timely intervention, the continued release of these pollutants will threaten the sustainability of water resources, undermine public health, and jeopardize progress toward national and global development goals.

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