Scientific Research Publishing

Advances in Microbiology, 2026, 16(2), 17-28
https://www.scirp.org/journal/aim
ISSN Online: 2165-3410
ISSN Print: 2165-3402

Wastewater Surveillance in Côte d'Ivoire: An Essential Tool for Public Health in a Resource-Limited Context

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How to cite this paper: Sabine, V.N, Julien, C.K., Eric, Y.K., Cedric, Y.A.J., Fabrice, G.G., Syndou, M. and Joseph, D.A. (2026) Wastewater Surveillance in Côte d'Ivoire: An Essential Tool for Public Health in a Resource-Limited Context. *Advances in Microbiology*, **16**, 17-28.
https://doi.org/10.4236/aim.2026.162002

Received: December 3, 2025
Accepted: February 23, 2026
Published: February 26, 2026

Abstract

Wastewater surveillance represents an innovative and cost-effective approach to strengthening epidemiological surveillance systems in Côte d'Ivoire. In the face of persistent infectious diseases (COVID-19, cholera, dengue, MPox) and the limitations of conventional surveillance systems, particularly for asymptomatic infections, this method offers a promising alternative for the early detection of pathogens. This article assesses the feasibility of deploying wastewater surveillance in the Ivorian context, providing a critical analysis of adapted sampling strategies and proposing a sustainable operational framework. Through a narrative synthesis of international scientific data and local institutional reports, the available evidence is analyzed, with a particular focus on recent Ivorian case studies. Passive sampling emerges as a viable alternative to costly active methods, with a proof of concept established locally. Major identified challenges include infrastructure deficits, lack of protocol standardization, and limitations in multisectoral coordination. An operational framework progressively integrating passive sampling, local capacity building, and adapted governance is proposed to establish wastewater surveillance as a sustainable tool for the Ivorian health system.

Keywords

Wastewater Surveillance, Public Health, Côte d'Ivoire, Passive Sampling, Health Systems, Infectious Diseases

1. Introduction

Environmental wastewater surveillance represents a significant advance in monitoring pathogens within populations, particularly in resource-limited countries [1]. It is a key method, for anticipating the emergence or resurgence of infectious diseases such as poliomyelitis, cholera, or COVID-19 [1]. This approach captures symptomatic, asymptomatic, and untested infections, offering a more accurate picture of the epidemiological situation. Historically used for polio in the 1990s, it enabled the early detection of outbreak clusters, facilitating rapid interventions like targeted vaccination campaigns [2]. Detecting poliovirus RNA in wastewater has allowed for faster cluster identification compared to community-based surveillance [3].

During the COVID-19 pandemic, wastewater surveillance proved to be a complementary and cost-effective tool for tracking the spread of SARS-CoV-2, particularly in resource-limited regions [4]. This method enabled large-scale screening with lower costs and constraints than individual testing. Surveillance was based on detecting viral RNA in wastewater, shed in the feces of COVID-19 patients, both adults and children (**Figure 1**) [5]-[7]. This surveillance is all the more crucial as epidemics disproportionately affect vulnerable populations, often in low- or middle-income countries, where health and testing capacities are reduced, necessitating strict measures, particularly in prisons and detention settings [1] [8] [9].

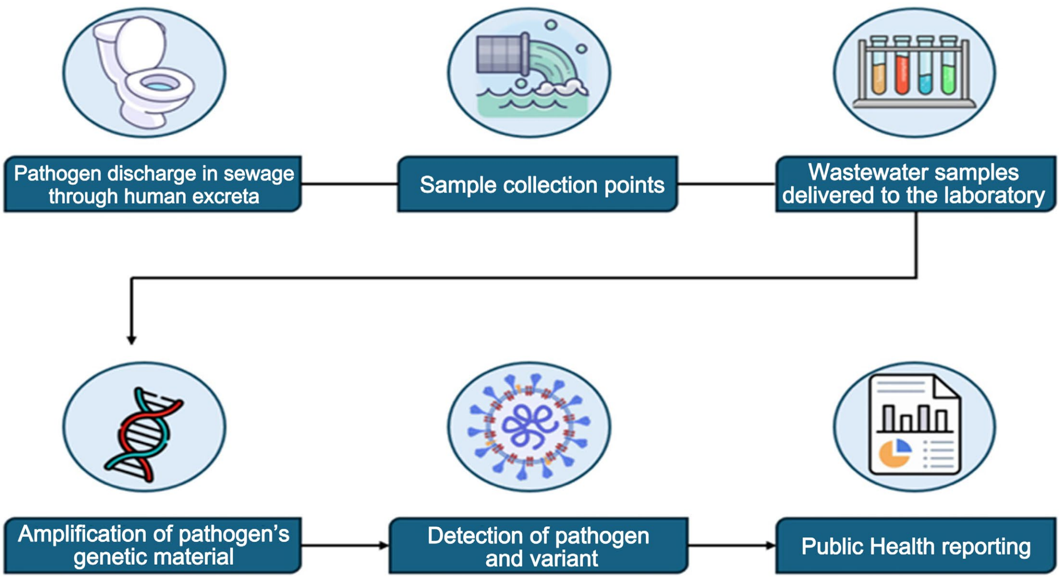

Figure 1. Wastewater surveillance scheme [7].

In Côte d'Ivoire, given the infrastructural and budgetary constraints weighing on health systems, WWS emerges as a strategic lever to strengthen epidemic preparedness. We introduce here the concept of the "Ivorian paradox": a dichotomy between the maximum utility of WWS in a context of limited clinical testing and the scale of structural challenges related to its deployment (precarious sanitation, fragmented laboratory resources). Overcoming this paradox requires adapting cutting-edge technologies to local realities through transparent multisectoral coordination involving authorities, scientists, and the public [10] [11]. This article proposes a realistic framework and a critical analysis of the strategies needed to transform WWS into a sustainable pillar of Ivorian public health.

2. Sampling Strategies Adapted to the Ivorian Context

In developing countries, urban waste management poses serious environmental challenges, exacerbated by the lack of access to adequate sanitation, which increases health risks [12] [13]. An essential component of the sensitive and accurate characterization of pathogens involved in infectious diseases via wastewater surveillance is the collection of a wastewater sample representative of the total volume of wastewater produced by the community [14] [15]. According to several authors, wastewater surveillance primarily relies on three sampling methods.

- Composite sampling, which captures variations over 24 hours, offers optimal representativeness but requires expensive equipment and adapted infrastructure [16]. Automatic samplers for composite sampling are costly and require infrastructural adaptations, limiting their use in low-resource areas.
- As an alternative to composite wastewater samples, some practitioners have used grab samples, *i.e.*, discrete samples collected from the wastewater flow at a single location and a single time [17]. Nevertheless, collecting low-volume grab samples at a single time increases the risk of erroneous results, as sampling can only be done at one point in the day, influenced by temporal variations in pathogen shedding [15].
- Facing these limitations, passive sampling emerges as an innovative alternative [18] [19]. The use of passive samplers for disease surveillance via wastewater dates back to the early days of bacteriology. After the invention of selective media to isolate *Salmonella typhi* in wastewater, grab sampling of wastewater was used to assess the epidemiology of typhoid fever [20]-[23]. This approach, dating back to the "Moore swabs" used for the detection of *Salmonella typhi*, uses absorbent materials immersed in wastewater to capture biological targets over a prolonged period [24]. It allowed for more reliable detection through continuous sampling of wastewater over two days rather than sporadic "grab sampling" [24] [25].

Research work in Côte d'Ivoire, such as the study by Yapi *et al.* (2025) [19], already demonstrates the feasibility and effectiveness of wastewater surveillance, notably via passive sampling (**Figure 2**). However, the lack of a clear relationship between flow rate, concentration, and accumulation on the absorbent material complicates the accurate quantification of contaminants and depends on the type of pathogens targeted [26]. Performance also depends on multiple factors: the nature of the material, the chemical composition of the water, the biological characteristics of the analytes, and biofouling phenomena. The development of standardized protocols and optimized materials therefore remains a research priority [27]. **Table 1** below summarises the advantages and limitations of these different sampling methods (**Table 1**).

Table 1. Comparison of sampling methods for wastewater surveillance [15] [27] [28].

Method	Benefits	Limits	Suitability for the Ivorian context
Composite	Optimal representativeness	High cost, complex infrastructure	Low
Instantaneous	Low cost, simplicity	Limited representativeness	Medium
Passive	Moderate cost, temporal integration	Standardisation required	High

Figure 2. Wastewater monitoring sites in Côte d'Ivoire [19] (A: Grap sampling; B: Open channel for the drainage of water from households; C and D: Passive sampling with sanitary tampon tied to a rope).

Côte d'Ivoire, with its complex epidemiological profile, has recently initiated major research work on wastewater surveillance. The first meeting on this topic in April 2025 laid the foundations for a comprehensive network of laboratories dedicated to the surveillance of infectious diseases, particularly enteric ones. Several studies have highlighted the impact of poor wastewater management on public health [29]-[32], as well as the effectiveness of active and passive sampling methods for the detection of pathogens like SARS-CoV-2 in Abidjan's effluents [19].

Beyond research studies, environmental surveillance is already an operational component of the epidemic response in Côte d'Ivoire, as evidenced by internal reports from national health institutions. During recent cholera epidemics, the performance of environmental sampling (surface water, wells) for the confirmation of Vibrio cholerae has been a systematic practice documented by the COUSP and INHP [33]. This existing expertise in environmental sampling and analysis constitutes a solid foundation upon which to build a more structured wastewater surveillance system.

Furthermore, the strategic willingness to extend these capacities is perceptible in national orientations. In accordance with the guidelines of the Global Polio Eradication Initiative (GPEI), Côte d'Ivoire, considered a high-risk country for poliovirus reimportation, has already established an environmental surveillance program for polioviruses (Global Polio Eradication Initiative). This program, part of the 2022-2026 eradication plan, involves regular sampling from wastewater in sentinel sites, such as those conducted by the Institut Pasteur de Côte d'Ivoire. The objective is the early detection of any virus reintroduction, thus complementing acute flaccid paralysis surveillance.

Finally, research and development activities are underway to extend this surveillance to other diseases. The National Institute of Public Hygiene (INHP) and the Public Health Emergency Operations Center (COUSP) are actively exploring the integration of wastewater surveillance into the epidemic response, notably for cholera and dengue, as evidenced by national epidemiological reports. These initiatives, although often still at the pilot stage, demonstrate a growing institutional willingness to capitalize on this tool to strengthen the resilience of the Ivorian health system.

3. Strategic Importance for the Ivorian Health System

Wastewater surveillance can target several pathogens of major public health interest, thus offering a cost-effective multi-parameter vigilance system. International studies suggest that WWS can be 10 to 100 times less expensive per person monitored. In a context where individual PCR test costs remain prohibitive, a single wastewater sample allows for the simultaneous detection of multiple agents, providing a global view of disease circulation at a fraction of the cost [1] [17].

Enteric viruses represent a prime target, notably the poliovirus for which environmental surveillance is already standardized within the global eradication initiative [2]. Hepatitis A and E, endemic in several regions of the country, can be monitored to anticipate epidemic outbreaks [34]. Dengue, with its recent resurgence (4700 suspected cases in 2022-2024) alerting health authorities [35], can also be detected early through this approach.

Among bacteria, Vibrio cholerae, responsible for cholera epidemics, remains a priority [33], as do typhoidal and non-typhoidal Salmonella, Shigella, and enterohemorrhagic *E. coli* [11]. Surveillance of MPox (monkeypox virus) could offer a valuable indicator of its silent circulation in the population [36]. Finally, from a One Health perspective, the search for zoonotic agents such as avian or swine influenzas and emerging coronaviruses would strengthen preparedness against pandemic threats [37].

This multi-target approach, impossible to implement by individual clinical tests alone for cost reasons, constitutes the entire added value of wastewater-based surveillance in a resource-limited context [1]. As demonstrated by the work of [17], a single wastewater sample can enable the simultaneous detection of multiple pathogens, thus providing a comprehensive view of the circulation of infectious diseases within a community.

In recent years, the country has faced several major health crises, illustrating the vulnerabilities of the current surveillance system:

- Cholera epidemic in 2025 (7 confirmed deaths, [33]).
- Dengue outbreak 2022-2024 (4700 suspected cases, 594 confirmed, [35]).
- Confirmed MPox cases in 2024 (43 cases across 20 districts, [36]).
- Ebola alert in 2021 in the region ([38] [39]).

To meet this challenge, wastewater surveillance must be integrated into the existing architecture of the Ivorian health system, which relies on the Public Health Emergency Operations Center (COUSP) and the National Institute of Public Hygiene (INHP). The current system covers 40 priority diseases according to the WHO integrated surveillance model, ranging from diseases with epidemic potential to endemic and neglected tropical diseases [40].

The specific points of attention for the Ivorian context are recorded in Table 2 below:

Table 2. Capitalizing on existing assets for the integration of wastewater surveillance in Côte d'Ivoire [39].

Existing achievements	Application for wastewater
Trilingual interface and local adaptation	Development of protocols adapted to field constraints
Integrated cousp-inhp platforms	Integration into existing monitoring architecture
Training of 200 agents and 50 epidemiologists	Basis for specific capacity building
Target of 50% reduction in detection times	Direct contribution through early detection
Emerging one health approach	Ideal framework for health-environment integration

4. Operational Challenges and Structural Constraints

One of the main lessons from the COVID-19 pandemic is that science alone cannot control a pandemic. Leadership is essential: decisions must be made, trust gained, clear messages maintained, control measures succinctly stated, and the public educated and inspired to act. The implementation of wastewater surveillance in Côte d'Ivoire faces several challenges:

- Infrastructure Deficits: Approximately 40% of households in Abidjan lack an adapted evacuation system, compromising the representativeness of samples

[41]. The inadequate management of domestic wastewater, with direct discharge into the environment, further complicates epidemiological monitoring [42].

- Non-Standardized Sampling and Analysis: Different protocols have been used in different jurisdictions/programs for wastewater sampling, virus concentration, RNA extraction, RT-qPCR analysis, genome sequencing, and data analysis. Unfortunately, all these protocols have led to variable virus recovery yields depending on the protocol itself and the operational personnel.
- Lack of Understanding of Viral Stability in Sewers: Studies on the impact of factors such as sewer biofilms, sediments, chemical dosing and removal in sewers, inflows/infiltration (wastewater dilution) on pathogens are very limited. These processes in sewers can lead to an underestimation or overestimation of viral concentrations in wastewater in different sewer catchments [43].
- Absence of Robust Back-Calculation Models to Estimate the Number of Infected Cases: Lack of research to improve data analysis for a range of outcomes related to infectious diseases such as incidence rate, prevalence rate, transmission rate, hospital and intensive care admissions, and early warning. Furthermore, relatively few studies have attempted to transform wastewater surveillance data into actionable information to support pandemic management [43].
- Establishment of an integrated data management system that overcomes the challenge of interoperability. This requires the implementation of data-sharing protocols to clarify information ownership among the Ministries of Health, Environment, and Sanitation. The objective is to ensure that raw environmental data are transformed into public health indicators that are actionable in real-time by decision-makers
- Technical Limitations: The lack of specialized equipment and personnel trained in microbiological analyses restricts the capacities for accurate pathogen detection in wastewater [44]. Local laboratories struggle to maintain the necessary cold chains and quality controls.
- Coordination Fragility: Collaboration between the water, health, and environment sectors remains insufficient, hindering the integration of data for decision-making [45].
- Environmental Pressures: Increasing pollution of water resources due to anthropogenic activities (mining, industrial discharges, uncontrolled agriculture), which complicates the interpretation of surveillance results and necessitates broader environmental monitoring [42] [46].
- Financial Constraints: The economic impacts of recent health crises limit investments in sanitation infrastructure and analytical capacities [47].
- Climate Variability and Demographic Pressure: These elements increase sanitation needs while putting pressure on water resources, making the adaptation of surveillance systems to local realities urgent [48].

Beyond technical obstacles, the success of wastewater surveillance in Côte d'Ivoire depends on social acceptability. In informal settlements, sample collection can trigger mistrust. It is crucial to integrate awareness campaigns explaining data anonymity and the collective interest of this surveillance in preventing local outbreaks, thereby transforming populations in "grey zones" into active participants in their own health security.

All these challenges require adapted approaches, strengthening of technical and institutional capacities, and the establishment of robust coordination networks to make wastewater surveillance an effective tool for public health in Côte d'Ivoire.

5. Conclusions

Wastewater surveillance offers a strategic opportunity to transform health risk management in Côte d'Ivoire. Its progressive deployment, supported by strong political will and effective multisectoral cooperation, could significantly improve epidemic detection and response. It could complement clinical surveillance by potentially supporting the detection of multiple pathogens through a single surveillance network, at low cost. The circulation of several pathogens, often difficult to detect relying solely on clinical surveillance, could thus be identified. This surveillance could help generate actionable data by including symptomatic and asymptomatic cases.

The One Health approach, integrating human, animal, and environmental health, constitutes the ideal framework for this deployment. Future extension (for example, the existing Public Health Emergency Operations Center (COUSP)) to the surveillance of other emerging pathogens and general environmental quality would strengthen the resilience of the Ivorian health system. A continued commitment to applied research, technological innovation, and local capacity building will be essential to guarantee the effectiveness and sustainability of this promising tool. Côte d'Ivoire has significant but vulnerable water resources, with major challenges in access, quality, and governance. The triple climate, economic, and health crisis worsens the situation, requiring SMART investments, a strengthened institutional framework, and an integrated approach. Côte d'Ivoire could thus position its regional leadership in environmental surveillance for public health.

6. Perspectives and Recommendations

To optimize this public health tool in Côte d'Ivoire, it is recommended to standardize protocols for sensitive and reproducible detection, strengthen staff technical capacities, invest in suitable analytical infrastructure, and develop an integrated data management system. A better understanding of pathogen fate in sewers could further improve monitoring. Smart wastewater surveillance, supported by AI and big data, can lead to innovative, evidence-based pandemic management that minimizes transmission and societal disruptions during outbreaks. Furthermore, surveillance should be expanded to other pathogens and across different territorial scales, particularly within universities, prisons, large buildings, aircraft, and ships. The engagement of multisectoral stakeholders (health, environment, water, and sanitation) is crucial to ensuring sustainable monitoring and a coordinated response to health risks. This system could also extend to the surveillance of other emerging pathogens and general environmental quality, contributing to a robust "One Health" framework. The integration of the "One Health" approach would involve creating a shared data platform among human health laboratories, veterinary services, and environmental agencies. For instance, the early detection of antibiotic resistance genes or zoonotic agents in urban wastewater would trigger simultaneous alerts to both animal and human health surveillance systems to investigate potential clusters within target populations, slaughterhouses, or peri-urban farms.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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