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The Costs of Wastewater Monitoring in Low- and Middle-Income Countries

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Key findings

As pandemic relief resources wane, funding to monitor wastewater for public health threats is at risk of drying up, particularly in low- and middle-income countries. To make the case for why countries should continue to fund wastewater monitoring, government officials need reliable estimates of the costs of implementation and the potential savings that could accrue. To that end, we surveyed 12 wastewater monitoring programs in low- and middle-income countries to collect information on program costs and how those costs vary by implementation features. Analysis of the survey responses revealed the following:

- Wastewater monitoring costs were highly variable across countries, ranging from a low of $34 per sample in India to a high of $517 per sample in Costa Rica. However, costs were stable over time (with changes mainly due to pandemic-related supply chain issues that drove up prices).
- The median all-inclusive cost of wastewater monitoring (covering sample collection and storage; sample transport and testing; data management, analysis, and reporting; and other fixed and recurring costs) was $185 per sample.
- On average, recurring costs (comprising 19% to 93% of past-year costs) accounted for a greater share of costs than fixed costs (comprising 7% to 67% of past-year costs).
- The main sampling approach explained 46% of variability in per-sample costs. On average, programs that used composite sampling faced two- to three-fold higher costs than those using grab sampling (to sample from open trenches, pit latrines, and other non-centralized locations).
- Programs that monitored larger populations faced lower costs, as did programs that included some rural, suburban, or per-urban communities as opposed to urban populations only.
- Wastewater monitoring costs are likely to decrease over time as programs expand—due to economies of scale—and may also decrease as government labs ramp up capacity for testing wastewater samples.
- Monitoring wastewater for other public health biomarkers could lead to slightly higher costs than monitoring for SARS-CoV-2.
- Funding from wastewater monitoring came mainly from government sources and philanthropic funds (for 10 of 12 programs). Sustainable funding is needed.

When the World Health Organization declared COVID-19 a public health emergency of international concern, new funding channels opened that catalyzed the expansion of wastewater monitoring of public health biomarkers worldwide. By providing health officials with objective measures of SARS-CoV-2 viral entry into a community and enabling officials to track infection trends among a broader swath of the population than is captured through individual testing, wastewater data has been filling a crucial gap in traditional disease surveillance.

In low- and middle-income countries (LMICs) and disadvantaged communities worldwide, wastewater monitoring offers two key advantages related to health equity. First, it enables the collection of non-identifiable health information from people who might not have the means to visit a healthcare facility. Second, it is a more cost-effective approach to community-level disease surveillance, because a single wastewater sample and test contain information about hundreds, thousands, or even millions of people, as opposed to just one person participating in clinical testing.

The value of wastewater monitoring has borne out in diverse settings, and more than 70 countries worldwide have launched wastewater monitoring for SARS-CoV-2 (COVIDPoops19 n.d.). However, funding for this innovative methodology is at risk of drying up as pandemic relief resources wane. In many LMICs, funding has come from donors, grants, or short-term government aid (Keshaviah et al. in press).

To make the case for why countries should continue to fund wastewater monitoring, government officials need reliable estimates of the costs of implementation and the potential savings that could accrue. However, little information has been reported in the literature on the costs of wastewater monitoring, particularly in LMICs, and how those costs compare with other disease surveillance approaches.

Exhibit 1. Key characteristics of the wastewater monitoring program that provided cost information

Country	Organization	Program duration (years)	Service population size	Sampling frequency	Samples collected per month	Mode of transport to lab	Testing method
Bangladesh (BGD)	ICDDR, B	2.4	10,000,000	Once per week	92	Drive	qPCR
Brazil (BRA-1)	Oswaldo Cruz Foundation	2.8	500,000	Every two weeks	16	Drive	qPCR, genome sequencing
Brazil (BRA-2)	CETESB	2.8	13,000,000	Every two weeks	48	Drive	qPCR
Costa Rica (CRI)	Costa Rican Water and Sanitation Institute	2.6	150,000	Once per week	2	Drive	qPCR
Ecuador (ECU)	ESPOL	1.6	2,100,000	Once per week	25	Drive	RT-qPCR
Ghana (GHA)	Emory University	2.2	285,310	Multiple times per week	64	Drive	qPCR
Indonesia (IDN)		0.9	NA	NA	177	NA	NA
India (IND)	Gujarat Biotechnology Research Centre	2.7	72,000,000	Once per week	100	NA	ddPCR
Mexico (MEX)	National Institute of Public Health	0.2	15,113,938	Multiple times per week	80	Ship	qPCR
Malawi (MWI)	Malawi University of Science and technology	0.3	100,000	Once per week	88	Drive	qPCR
Peru (PER)	University of Engineering and Technology	2.0	8,358,233	Multiple times per week	90	Drive, Ship	qPCR
South Africa (ZAF)	SAMRC	2.6	18,000,000	Once per week	100	Drive	qPCR, genome sequencing

Note: Countries are sorted by 3-letter abbreviations. ICDDR, B = International Centre for Diarrhoeal Disease Research, Bangladesh; CETESB = Companhia Ambiental do Estado de Sao Paulo; ESPOL = La Escuela Superior Politécnica del Litoral; SAMRC = South African Medical Research Council; NA = not available; qPCR = quantitative polymerase chain reaction; RT-PCR = reverse transcription polymerase chain reaction; ddPCR = droplet digital polymerase chain reaction

As a first step toward a global cost-benefit analysis, we surveyed representatives of wastewater monitoring programs in LMICs to gather detailed information on the costs of wastewater monitoring and how those costs vary across different activities by program features (see the Survey and analytic methods section for details on survey fielding and cost calculations). Costs that were reported in local currency were converted to U.S. dollars (hereafter $) using the official exchange rate in 2021 for all countries, available via data.worldbank.org.

Characteristics of wastewater programs in a sample of low- or middle-income countries

After a six-week fielding period in early 2023, we received responses from 12 wastewater program representatives (16% of those invited) across 11 LMICs that monitor SARS-CoV-2 viral levels in wastewater. These wastewater programs monitor 100,000 (Malawi) to 72 million (India) people, with a median program duration of 2.3 years, though three programs were in operation for less than a year (Exhibit 1).

Funding for wastewater monitoring came from government sources for half the countries surveyed and from foundation or philanthropic sources for most others. Two programs received funding from other international or local organizations (such as UNICEF), sometimes in addition to government or philanthropic funding. In half of the countries we surveyed, the Ministry of Health and wastewater utilities were involved in wastewater monitoring. Five programs used academic labs to test wastewater samples, three used a government testing lab, and four used other or unknown types of labs. Interestingly, none of the respondents use commercial testing labs in their wastewater monitoring program.

Wastewater monitoring implementation varied by program. Three-quarters of the programs surveyed sample wastewater at least weekly (with three countries sampling multiple times per week). All programs use in-country testing labs; most drive their wastewater samples to the lab, though some use couriers to transport their samples. Most labs use quantitative polymerase chain reaction (qPCR) to quantify the SARS-CoV-2 virus, and two programs use genome sequencing for a subset of samples that test positive.

Costs of monitoring wastewater for SARS-CoV-2

Among the 12 wastewater programs that responded to the survey, total program spending over the past year ranged from $12,400 (Costa Rica) to $676,590 (South Africa). Median past-year spending on wastewater monitoring was $107,000, and apart from South Africa (which was the largest program surveyed in number of sample collection sites, and had one of the largest service populations), all countries' wastewater monitoring programs spent less than $250,000 over the past year. Dividing total program costs by the average number of samples collected per month (and also by program duration, for fixed costs that were reported for the lifetime of the program) yielded a per-sample cost (all-inclusive, covering sample collection and storage; sample transport and testing; data management, analysis, and reporting; and other fixed and recurring costs) that ranged from $34 (India) to $517 (Costa Rica) with a median of $185 (Exhibit 2).

Exhibit 2. Costs of monitoring wastewater for SARS-CoV-2 over the past year

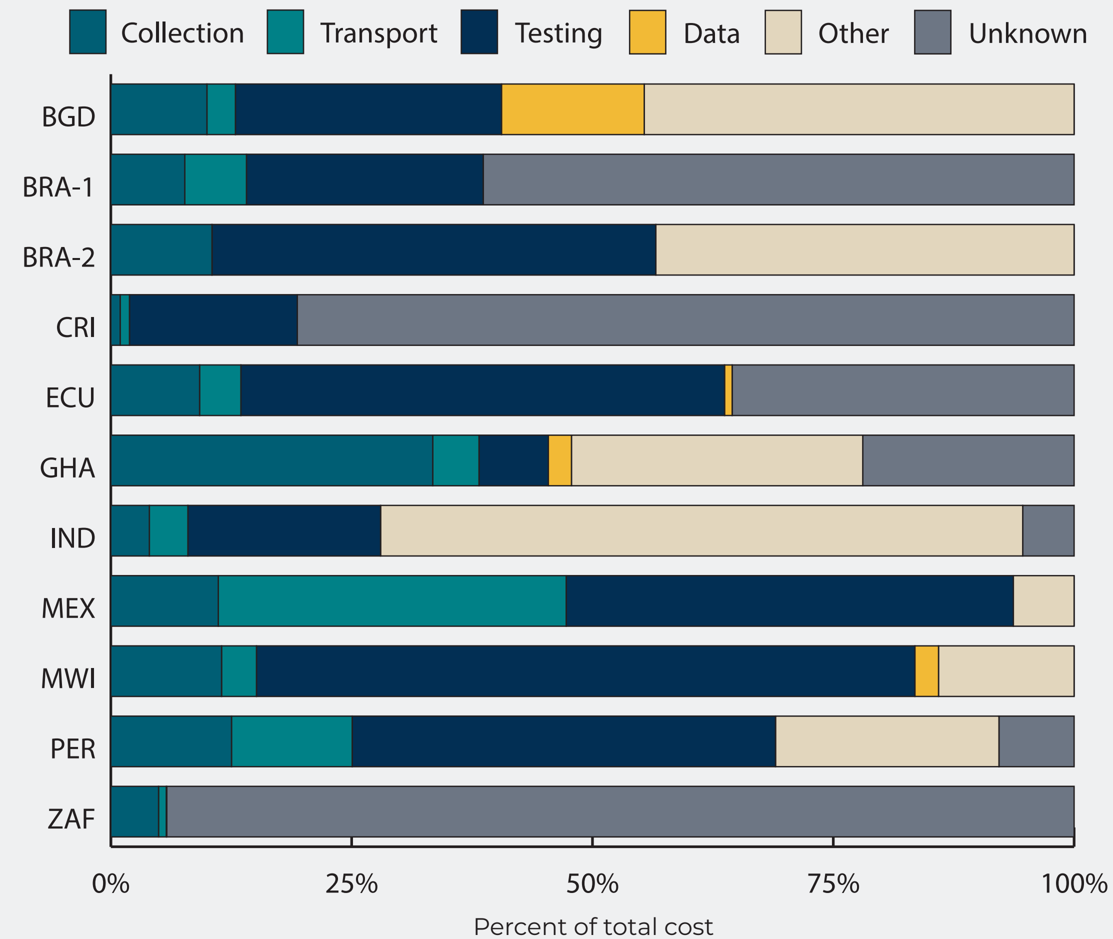
Country	Per-sample cost	Total past-year cost	Recurring costs (%)	Fixed costs (%)	Unknown costs (%)
India (IND)	$34	$40,584	$11,364 (28%)	$27,056 (67%)	$2,165 (5%)
Malawi (MWI)	$57	$20,000	$13,878 (69%)	$6,122 (31%)	
Brazil (BRA-2)	$89	$51,020	$28,853 (57%)	$22,167 (43%)	
Indonesia (IDN)	$106	$194,116	*Not reported*	*Not reported*	$194,116 (100%)
Brazil (BRA-1)	$145	$27,829	$10,758 (39%)		$17,072 (61%)
South Africa (ZAF)	$163	$676,590	$201,353 (30%)	$340,776 (50%)	$134,461 (20%)
Bangladesh (BGD)	$208	$230,000	$77,809 (34%)	$152,191 (66%)	
Peru (PER)	$231	$250,000	$148,500 (59%)	$82,000 (33%)	$19,500 (8%)
Ghana (GHA)	$326	$250,000	$102,000 (41%)	$93,151 (37%)	$54,849 (22%)
Mexico (MEX)	$463	$ 74,001	$68,748 (93%)	$5,253 (7%)	
Ecuador (ECU)	$467	$140,000	$58,200 (42%)	$32,100 (23%)	$49,700 (36%)
Costa Rica (CRI)	$517	$12,400	$2,400 (19%)		$10,000 (81%)

Note: Countries are sorted by per-sample cost, from low to high. Costs were reported in local currency or U.S. dollars (USD) and have been converted to USD using the Official exchange rate in 2021 for all countries, available via data.worldbank.org.

Drivers of SARS-CoV-2 monitoring costs

The share of total program costs resulting from different wastewater monitoring activities varied by country. However, program costs were largely driven by costs for testing and for components other than sample collection, transport, or data-related activities (Exhibit 3). For six of the 12 programs surveyed, testing costs were the largest driver of total costs (comprising 40% to 68% of past-year spending), while for three programs, other costs (which included staff salaries and training; community engagement activities such as workshops and meetings; travel unrelated to sample collection; and lab maintenance costs) were the largest driver (comprising 43% to 67%). Sample collection and sample transportation costs were typically less than 15% of total costs, with two exceptions (in Ghana, 33% of total costs came from sample collection, and in Mexico, which was one of only two programs that shipped rather than drove their samples to the lab, 41% of total costs came from sample transport). Costs for data management, analysis, and reporting were 1% (Ecuador) to 15% (Bangladesh) of past-year program costs (among the four programs that reported such costs). Unknown costs, which represent difference the between the reported total program cost and the sum of costs across specific activities that were probed in the survey, were high in Brazil-1 and Costa Rica, signaling uncertainty about the accuracy of cost reporting for these programs. Likewise, all costs for Indonesia were classified as unknown because the program did not provide a detailed cost breakdown.

Exhibit 3. Percentage of wastewater monitoring cost contributed by various components

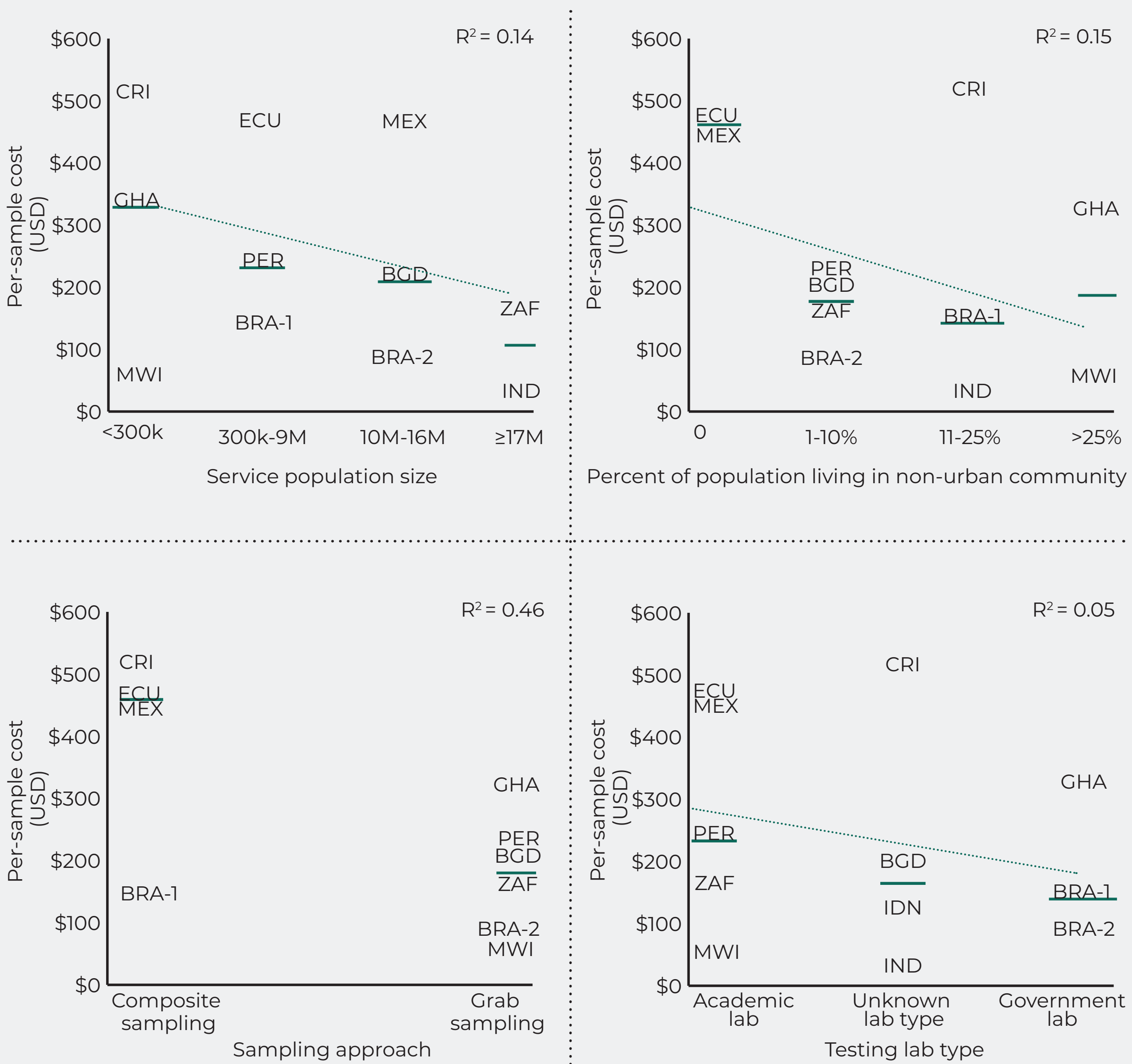


Note: Unknown costs represent differences between the reported total program cost and the sum of costs across specific activities that were probed in the survey (including sample collection, transportation, testing, data, and other). Indonesia's wastewater program is not shown in the graph because it did not provide detailed cost breakdowns.

Variability in program costs by implementation features

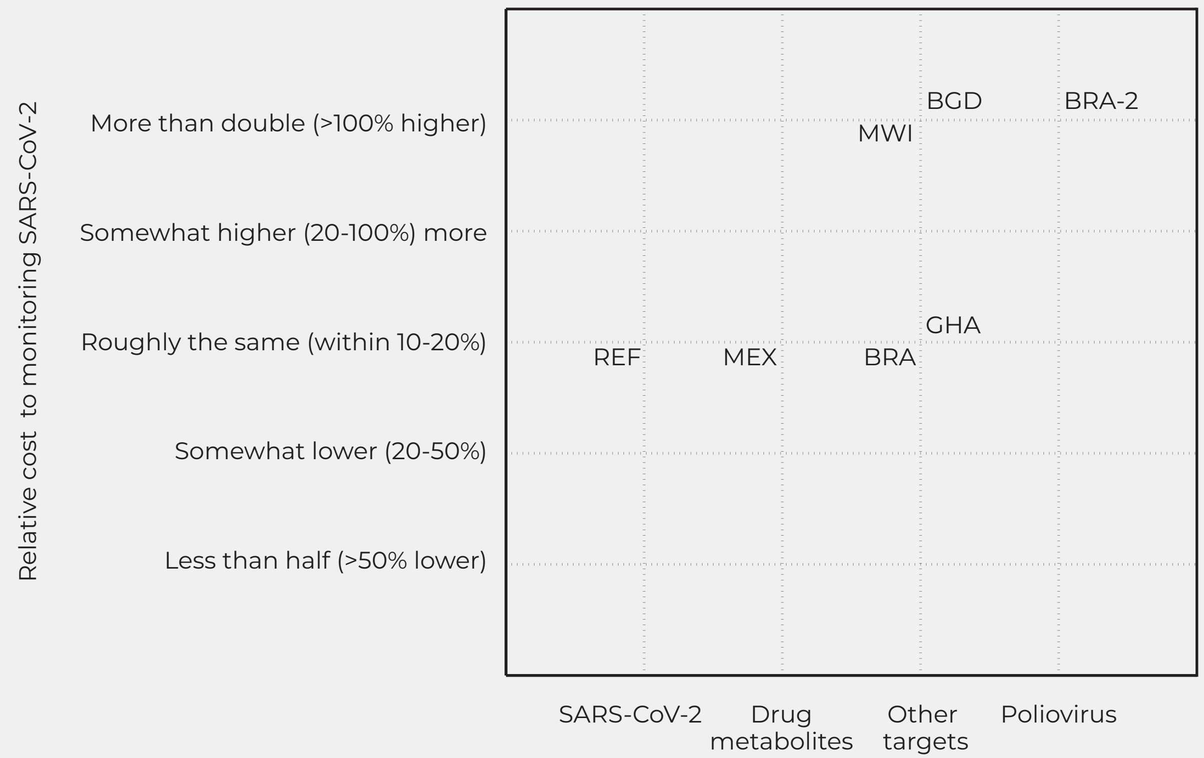
Based on information gathered through open-ended comment fields, survey respondents indicated that sample collection and transport costs are substantially higher for sites located far from the lab; sequencing of viral variants carries a much higher cost than variants detection using qPCR; and testing costs may be higher when programs are working on developing laboratory methods or quality assurance procedures to test for new biomarker targets in wastewater.

Exhibit 4. Relationship between total cost per sample and key program characteristics



Note: The dotted green line represents the linear regression line between per-sample costs and the program characteristic. The solid green lines represent the median per-sample cost in each category. The R^2 values represent the share of variability in per-sample costs (across programs) that the program characteristic explains.

Exhibit 5. Relative costs of monitoring other targets in wastewater, compared with SARS-CoV-2



Note: Other targets include Vibrio cholera, Salmonella typhi, rotavirus, measles, and other bacterial pathogens.

When we examined how the per-sample cost varied by program implementation features, we found that only some program features explained country-to-country differences in per-sample costs. With respect to program coverage, we found that per-sample costs were roughly three-fold higher among programs with smaller service populations (fewer than 300 thousand people) than larger ones (17 million people or more), and population size explained 14% of the variability in costs (Exhibit 4). This might be explained by the fact large wastewater treatment plants might be more likely than smaller plants to have the staff and equipment needed for sample collection and storage. Surprisingly, we did not find a strong association between program costs and the number of sites monitored.

Looking at the type of population monitored, we saw that per-sample costs were higher among programs that monitored only urban populations than those that also monitored some non-urban (that is, rural, suburban, or per-urban) communities ($R^2 = 0.15$). However, we did not find strong associations between costs and the share of the population connected to a centralized sewer system. This finding might be explained by the fact that most of the programs we surveyed collected samples mainly from wastewater treatment plants, and if those plants were large and extended beyond urban centers, sampling at those central plants could efficiently cover non-urban communities in the area.

With respect to sampling features, we found that programs that mainly used composite sampling faced two- to three-fold higher per-sample costs than programs that mainly used grab sampling (with a median per-sample cost of $465 versus $185, respectively), and that primary sampling approach explained 46% of the variability in program costs across surveyed countries. However, we did not find a strong association between the main sample collection location and per-sample costs ($R^2 = 0.07$), possibly because many of the programs we heard from sample from wastewater treatment plants.

When we examined how costs varied by other program features, including testing lab type, testing method, and data dissemination method, we saw either a lack of variability in these characteristics (for example, most programs used qPCR for testing), or a lack of differences in program costs across these characteristics. We did see some evidence for higher costs in academic testing labs than government testing labs, but differences were small (with a median per-sample cost of $231 vs $145) and lab type explained little variability in costs across programs ($R^2 = 0.05$).

Changes in wastewater monitoring costs over time

Of the nine programs that reported on how past-year program costs compared to earlier costs (for example, at start-up), six indicated that costs are about the same now as before. Among the three programs reporting increases in costs (by as much as 30% in two programs and more than 50% in the third program), two programs attributed the increases to inflation and supply chain issues. In fact, one respondent reported that supply chain issues led to LMICs seeing costs of reagents and test kits that were more than double the prices in high-income countries (HICs).

Comparative costs of monitoring SARS-CoV-2 versus other public health targets

Many of the countries we surveyed have been monitoring wastewater for other public health targets beyond SARS-CoV-2, including Vibrio cholera, Salmonella typhi, rotavirus, measles, other bacterial pathogens, poliovirus, and drug metabolites. These countries reported that monitoring poliovirus and other pathogenic bacteria and viruses is somewhat more costly than monitoring SARS-CoV-2, while the cost of monitoring drug metabolites is about the same as for SARS-CoV-2 (Exhibit 5).

Respondents noted various efficiencies gained when testing for multiple targets, including a reduction in time needed to collect, process, and analyze samples; decreased costs for reagents used to analyze samples; and the ability to simultaneously track other disease trends. However, respondents also reported some challenges with multi-target monitoring, including lack of government support, difficulty optimizing laboratory methodology, and the complexity associated with implementing different assay protocols for the various targets analyzed.

Implications of survey findings

Our analysis of detailed cost information from 12 LMICs yielded highly variable wastewater monitoring costs in different countries, which aligns with findings from a report produced by the European Commission's Joint Research Centre. Across Europe, per-sample costs of wastewater testing ranged from a low of $59 in Spain to a high of $647 in the Netherlands (Gawlik et al. 2021). We also found wastewater testing costs are lower in LMICs than in Europe. The median per-sample testing cost of $221 in Europe is roughly five times higher than the median testing cost among the LMICs we surveyed, which amounted to $70 (on average, one-third of total costs).

Our median cost estimate of $185 per sample is in line with the limited literature on wastewater monitoring costs in LMICs. Ali et al. (2022) reported a cost of $300 to test wastewater from one wastewater treatment plant in Ethiopia for SARS-CoV-2 RNA. Accordingly, they estimated a cost of roughly $4,200 to monitor wastewater from the 14 decentralized wastewater treatment plants that together serve roughly 210,000 residents. By comparison, the authors estimated a cost of $1,100,400 (262 times greater) to do one-time COVID-19 community mass testing of the same population. Manuel et al. (2022) also reported a cost of $300 per wastewater test for SARS-CoV-2, based largely on estimates from Europe, and estimated that clinical testing costs more than 10 times the cost of establishing wastewater surveillance. Ngwira et al. (2022) reported that the per-sample cost in Malawi ranged from a high of $74 (when 84 samples were processed per month) to a low of $25 (when 336 samples were processed per month). Likewise, the authors reported that in Nepal, per-sample costs decreased from $175 to $120 when sample processing expanded from 96 to 250 samples per month.

Wastewater monitoring costs are likely to decrease over time as programs expand, because of economies of scale, and we noted that lower costs typically occur among programs that monitor large populations. Programs may also incur lower costs if they use grab sampling, which enables sample collection from non-centralized locations and accordingly, the ability to monitor rural populations. We saw some evidence of lower costs among programs that used government testing labs than those that used academic testing labs, which indicates program costs may decrease as countries ramp up capacity for wastewater testing at government labs. An interesting finding that emerged in this small sample of LMICs is that the four countries with the highest total program costs (that is, before dividing by the number of samples collected) were all funded by foundations (rather than government or other sources).

Conclusions

This in-depth cost analysis is only the first step toward characterizing the cost-effectiveness of wastewater monitoring. A critical next step is to conduct similar analyses to characterize the monetary benefits of wastewater monitoring, including the savings it could yield compared with traditional surveillance methods. At this pivotal moment, when long-term funding for wastewater monitoring could disappear, many programs are willing to volunteer their time and efforts to providing evidence for the benefits of this innovative approach to public health surveillance. Indeed, several countries we surveyed expressed their willingness to participate in follow-on focus group discussions related to the cost-effectiveness of wastewater monitoring and the considerations that go into selecting public health biomarkers for monitoring.

As global climate change increases the threat of animal-human spillover events and pandemic-potential diseases, our public health tools must advance to better detect and contain disease outbreaks. Wastewater monitoring could be a critical tool to bolster global disease surveillance and to help close the data gaps between HICs and LMICs. With additional information on the monetary savings that wastewater monitoring yields, national governments will be better positioned to allocate the resources necessary for wastewater monitoring and reap the benefits of an early warning system that enables active prevention and rapid response to future health threats.

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Survey and analytic methods

In early 2023, the World Bank and Mathematica developed an online survey to assess the cost of monitoring wastewater for the SARS-CoV-2 virus that causes COVID-19. The survey included roughly 50 questions (with a 15- to 20-minute administration time) programmed into QuestionPro. Survey respondents were asked whether they preferred to report costs per sample or per month and the currency in which they would report costs; survey question prompts were automatically tailored to reflect respondents' preferences.

Fielding of the survey was based on a convenience sample. To create a survey dissemination list, we searched publicly available literature to identify contacts for wastewater researchers in LMICs. We also included wastewater program contacts from the World Bank, The Rockefeller Foundation, and Mathematica. In total, 73 people from 35 countries were invited to complete the survey.

The survey was active for six weeks (from January 17 to March 1, 2023). After the initial invitation email, we sent two email reminders and offered a $10 electronic gift card incentive to the first 20 survey respondents. We received 14 responses and excluded two from our analysis because of ineligibility (one respondent reported costs for a HIC, and another reported costs for wastewater targets other than SARS-CoV-2, including illicit drugs, alcohol, and cigarettes).

For costs that were not reported in U.S. dollars, including costs reported in the literature, we converted costs to U.S. dollars using the official exchange rate in 2021 for all countries, available via data.worldbank.org (local currency unit per U.S. dollar, period average).

In addition to total costs, we asked a series of questions to obtain a detailed breakdown of costs for various wastewater monitoring activities, including (1) collecting and storing samples; (2) transporting samples; (3) testing samples; (4) managing, analyzing, and reporting data; and (5) other costs. When comparing the sum of costs from the five components with the total program cost in the past year, we noticed discrepancies for some programs. Therefore, we created a sixth category for costs we categorized as unknown. For programs with large discrepancies between the total cost reported and the sum of the five component costs, we reached out to survey respondents via email to clarify costs, but we did not hear back from all of them.

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