Practical Paper

The reality of water quality monitoring for SDG 6: a report from a small town in India

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ABSTRACT

Based on a study of microbial water quality in a small town (Alibag) in India, we show the practical limitations of monitoring for fecal indicator bacteria to meet SDG 6. We find that even when water quality monitoring and testing infrastructure is in place, low institutional capacity and the pressure to not 'fail' the expected water quality standards can result in the failure to accurately report bacterial water quality.

Key words | Sustainable Development Goals, urban India, WASH monitoring, water quality

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HIGHLIGHTS

- Low- and middle-income country utilities are often under pressure to meet state and national drinking water quality targets, even when they are under-resourced to meet these targets.
- 'Ranking' countries on the basis of the current SDG 6 indicators may produce (indirect) pressure to inaccurately report water quality monitoring results.
- Progress along the service ladder, as measured by the Joint Monitoring Programme, should be incorporated into the indicators of SDG 6.1.

INTRODUCTION

The Sustainable Development Goals (SDGs), adopted in 2015, call for universal access to safe drinking water by 2030 through SDG 6.1. The relevant indicator is the 'proportion of the population using safely managed drinking water services,' where 'safely managed' denotes drinking water from an improved water source that is located on premises, available when needed, and free from fecal and priority chemical contamination (UN Statistics Division 2016). Data to quantify this indicator come from national censuses, household surveys, and regulatory agencies. In this paper, based on water quality monitoring in a small town in India, we show how limitations to monitoring and reporting fecal contamination translate to limitations to achieving SDG 6.1. We explain how our study town tests its drinking water for microbial contamination, and compare their results to our own tests during the same period, many of which were from the same sites. We find that though water is regularly tested, low institutional capacity and the pressure to not 'fail' by state and national water quality standards can result in the failure to accurately report contamination. Whereas low capacity and low motivation to comply are well-documented in the Water, Sanitation and Hygiene literature (Steynberg 2002; Peletz *et al.* 2018), there is less acknowledgment of the cumulative performance pressure that international benchmarks place on national and state-level utilities, which are then passed on to local utilities in low-income settings. We illustrate this with a case study of Alibag, Maharashtra.

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Alibag is a town of ~20,000, the seat for its political district (Raigad), with an economy dependent on middle-class tourists from nearby Mumbai (Supplementary material, Figure 1). The drinking water is piped, treated, and intermittently supplied twice daily by the Maharashtra Industrial Development Corporation (MIDC), an infrastructure development agency of the Government of Maharashtra (Alibag Municipal Council 2012). The MIDC treats its raw water with liquid aluminum sulfate, after which it aerates, flash mixes, flocculates, and settles the water before sand filtering and vacuum chlorinating (to 2 mg/L). The finished water is stored on-site before it is sent out for distribution. Over 95% of households in the town core have private or shared taps. Thus, all MIDC-supplied households would qualify as having improved water, available when needed.

The Alibag Department of Water Supply (DWS) is responsible for ensuring that the drinking water distributed throughout the town is safe. It collects 10 drinking water samples every 15 days, at the bus and train stations, the sump well, public taps, and selected households within at least three wards (urban India's smallest administrative units). Water samples are collected without disinfecting any taps; the samples are submitted to the District Department of Public Health (DPH) testing facility for MPN and chlorine residual testing, generating a report to both DPH and DWS (Supplementary material, Figure 2A–2H). Samples are tested for fecal indicator bacteria using a 5-tube Most Probable Number (MPN) test (GOI 1999). Per protocol, any reports showing problematic deviations from water quality standards have to be sent to the state-level DPH. We found officials to be well aware of national and WHO-recommended collection and testing protocols, but not necessarily ensuring that all employees followed these protocols.

METHODS

Sample collection and survey

We collected water samples from the distribution system over an 8-week period from June to July 2016, which captured the end of summer and the onset of the monsoon season. This period is commonly referred to as 'diarrhea season'. We collected samples once a week from the MIDC drinking water treatment plant, one of the three storage reservoirs in town, and from within the service region of the reservoir that the DWS sampled that same week. For comparability with DWS, we did not disinfect taps. Many households stored water in rooftop tanks connected to the distribution system to cope with intermittent deliveries. We took tap samples from households with in-home taps; for households collecting water from a public tap connected to the distribution system, we took tap samples during their scheduled water allocation hours on the same day as DWS (Supplementary material, Figure 1). Households were sampled over six wards such that the service area of the drinking water system was adequately covered. We had 120 water samples overall.

The sampled wards covered a range of average incomes (High/Middle/Low) and ward-level water access (High/Low; calculated by percentage of piped connections) ascertained by our own survey and an existing 2014 water audit. (Under a previous clean water campaign by the state of Maharashtra, a household consumer survey, a water audit, and GIS mapping of Alibag were conducted by a private consultancy in 2014, supervised by the municipality.) The northwest coastal portion of the town was not sampled, as that area is largely non-residential, containing governmental buildings and Alibag's observatory (Supplementary material, Figure 1).

Our research team also surveyed 60 head-of-household members in the study wards; these households were selected based on whether they had a female head-of-house present who spoke Hindi, Marathi, or Gujarati, and who was willing to participate. Participants were asked about their drinking water timing, water quality, and use of household treatment. All written surveys were translated from English to Marathi and orally administered in Hindi, Marathi, Gujarati, or English.

The Office for Protection of Human Subjects at the University of California at Berkeley approved the research protocol for ethical standards (Protocol ID 2016-04-8702).

Sample processing

Water samples for enumeration of bacteria were collected and processed using a pouch-based MPN test called the Compartment Bag Test (CBT) (Aquagenx, Chapel Hill, NC), following the CBT protocol (Gronewold Sobsey & McMahan 2017). The CBT uses a β-D-Glucuronide *Escherichia coli* medium, which is a colorimetric indicator that changes to blue in the presence of *E. coli*. Samples were transported at room temperature and processed within 6 hours of collection; duplicates and blanks were not collected due to limited resources in the field. Samples were stored between 26 °C and 32 °C, as per CBT protocol, and grown for 48 hours, scored once at 24 hours and again at 48 hours to check for any inconsistencies (of which there were none).

RESULTS AND DISCUSSION

We looked at *E. coli*, a fecal indicator bacterium, using a validated field-modified version of the 5-tube MPN test, which Alibag uses. When comparing between Membrane Filtration and the Compartment Bag Test, studies have found them to produce consistent results without a statistically significant difference in reported *E. coli* concentrations (Stauber Miller Cantrell & Kroell 2014; Wang *et al.* 2017). Based on our testing of the MIDC drinking water plant and Alibag's storage reservoirs, we determined that the water coming into Alibag each week was mainly without fecal contamination.

The municipality reported no contamination based on their bacterial testing for May–August 2016. However, our study processed ~150 samples from point-of-collection (POC) and point-of-use (POU) sources from June–July and found contamination in 30% of them (Supplementary material, Table 1) (Rayasam Ray Smith & Riley 2019). Figure 1 shows MPN water quality results of our own point of collection samples; the Alibag municipality reported no bacterial contamination using the same type of test over the same time period in the sampled area.

During Week 7, we followed a DWS employee during the municipality's collection and testing of water; we created duplicate samples and submitted one set to the municipality for quality control testing and tested one using our field test. According to the municipality's reports (Figure 2(a)), which were provided upon request, there was no bacterial contamination of the drinking water, including of our submitted samples, indicated by the recorded 0 MPN/100 mL in the red box. Our own testing, however, found one of our samples had 100 MPN/100 mL and the other 1.5 MPN/100 mL (paired samples are indicated with red boxes and arrows in Figure 2(a); Figure 2(b); Supplementary material, Table 1).

Despite clear knowledge of sampling protocols by the DWS and DPH engineers and scientists, we observed deviations between the standard protocols and the practices followed by DWS employees. For example, per DPH protocol sample bottles were internally coated with sodium thiosulfate to deactivate the chlorine. However, we consistently observed the DWS employee rinsing out bottles before filling them with water, removing the sodium thiosulfate and thus failing to deactivate the chlorine. Furthermore, samples were submitted to DPH for processing up to 24 hours after collection, longer than the allowable gap of 6 hours. Together these deviations from accepted protocol would lower the measured MPN at the DPH testing facility, though they would not bring them down to zero.

The municipality's chlorine residuals were also suspect. An MPN is often quality-checked by testing the free chlorine residual. While the MIDC-tested chlorine residuals at the treatment plant never exceeded 2 mg/L, the municipality results showed that the sump well, where Alibag receives water from the MIDC, tested at 7 mg/L (Figure 1(a), Line 1). This is consistent with DWS employees' statements of re-chlorinating the water before distribution. However, a more distal public tap sample in the municipality's results recorded >21 mg/L. The most distal sample having a residual of 21 mg/L is highly unlikely because (i) chlorine levels cannot increase from the proximal point of chlorination to more distal points and (ii) no survey participants indicated a strong smell of chlorine in their water or that their water was undrinkable due to chlorination. Therefore, it appears that the chlorine tests were incorrectly reported (assuming that the test samples did not have chlorine added to them), resulting in large reported residuals along with an MPN of 0 *E. coli*/100 mL. The CBT cannot test chlorine residuals, making us unable to provide side-by-side chlorine residual results. However, this limitation has no bearing on the improbability of the results from the municipality's report.

Inadequate capacity and low resource levels could explain some of these observations, such as the long delay between sample collection and testing, or failure of the DWS employee to follow correct sampling protocols. However, we suggest that they do not fully explain the

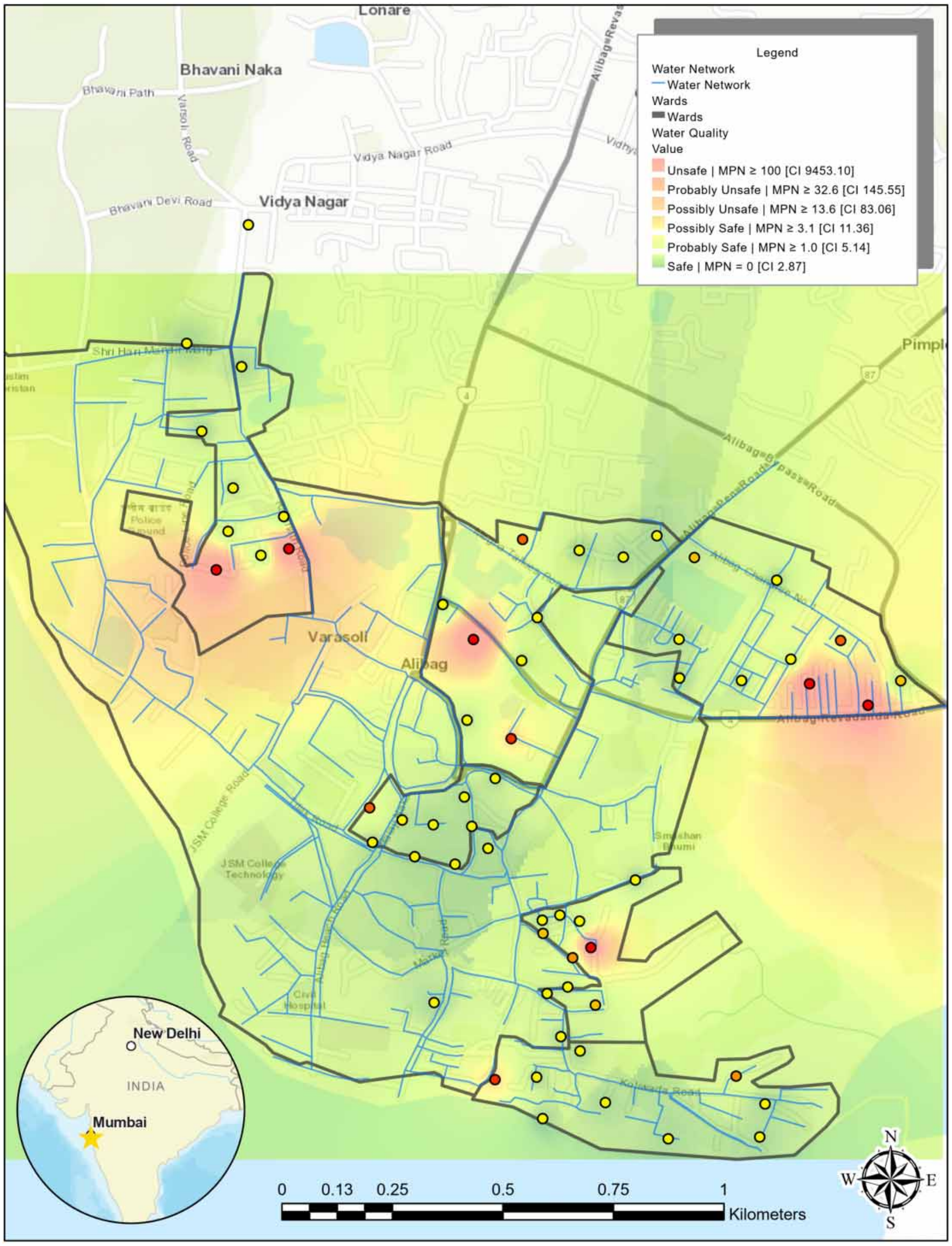

Figure 1 | Heat map of *E. coli* contamination in our study's point-of-collection samples. Calculated using inverse distance weighting.

discrepancy between our duplicate samples and the official municipality MPN counts of zero, or the high chlorine residuals of the collected water samples (Supplementary material, Table 1). We hypothesize that the DWS and the DPH leadership feel pressure to show they meet Maharashtra's safe drinking water standards, to the point of reporting abnormal chlorine levels consistent with 0 MPN *E. coli* levels, and transmit that pressure down their chains of authority. This is plausible especially because Alibag, as a town 'eminent for its fresh air, clean waters, and clean sands' according to its tourism site, is conscious of visitors' expectations for water quality and proud of its infrastructural

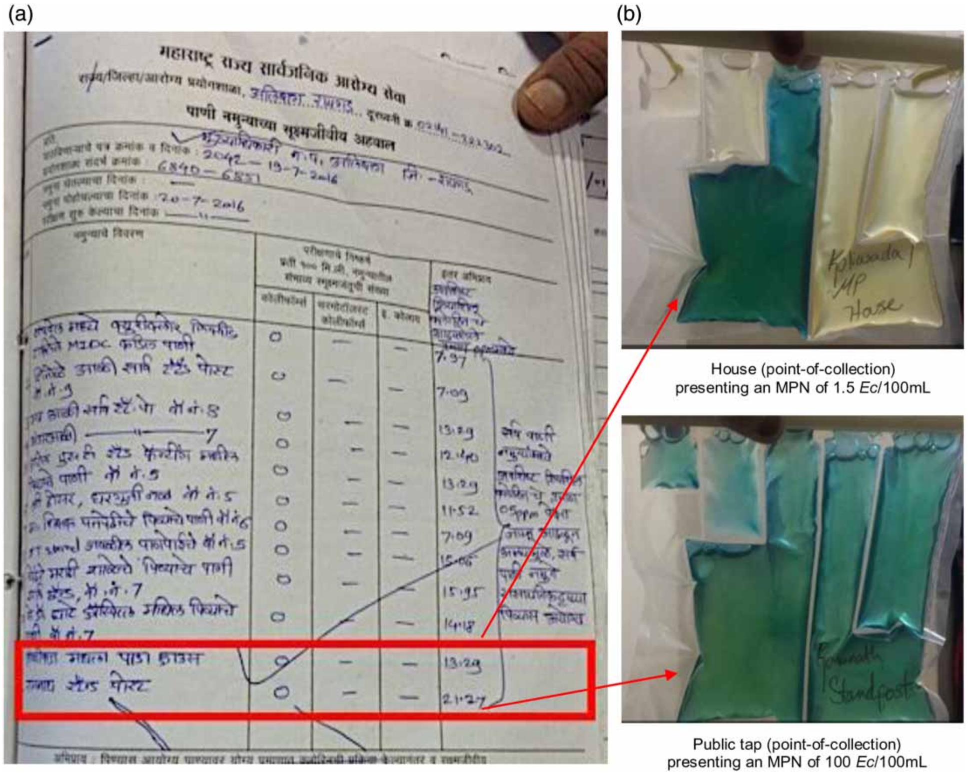

Figure 2 | (a) Alibag municipality test for July 20, 2016 (Week 7 of study) with duplicates outlined in red. First column is MPN and chlorine residuals are to the right. Line 1 of side-by-side sample says: House in Koliwada neighborhood. Line 2 says: Ramnath standpost (i.e. public tap). (b) Duplicate samples as processed by this study with the Compartment Bag Test showed MPN results of 1.5 MPN *E. coli*/100 mL for the Koliwada House and 100MPN *E. coli*/100 mL for the Ramnath standpost. Please refer to the online version of this paper to see this figure in color: http://dx.doi.org/10.2166/washdev.2020.131.

improvements overall (Gov't of Alibag 2018). The state of Maharashtra also has a well-defined and publicly announced process for continual monitoring of progress on SDG 6 (http://niti.gov.in/writereaddata/files/Mahrashtra.pdf). State water quality results become part of national data, which finally informs the SDG datasets.

Such behaviors can be dismissed as 'lacking in capacity' or 'corrupt' but these labels overlook the institutional context and expectations under which utilities in low-income countries often have to work. In reality, many city and local water agencies, working in the context of promises to provide clean water for all, understand that they are expected to meet or be 'on track' to meet state and national water quality benchmarks. They are therefore under pressure to show improving results, but are often under-resourced to actually produce such results. Our key contacts repeatedly referred to their excellent water infrastructure, good water quality, and unblemished beaches during our field study; we interpret such comments as reflecting the expectations that the utility faced.

Alibag is just one town, but the national-level data the JMP aggregates to arrive at its water quality monitoring report are provided by thousands of individual towns in each country. Our work has shown that even when the water infrastructure is functioning reliably (albeit intermittently), and even when regular sampling and monitoring take place, there may be unacknowledged pressures that produce inaccurate data. At the national and international scales, critiques of broad-brush targets and indicators have argued that the judgmental language used to track and monitor the MDGs, such as 'on track' or 'will fail to meet', increased pressure on already-poor countries and had a demoralizing effect (Vandemoortele 2009). A similar argument has been made for India's ambitious sanitation goals under SDG 6 (Gupta *et al.* 2019), i.e., impossible goals result in agencies that produce misleading data and declare progress that is not real.

We contend that a local-scale version of performance pressure, seeking to meet state and regional benchmarks, could lead to misleading or incomplete reports that eventually travel 'upstream' to create unreliable national-level data. Alibag is reporting that its water has 0 MPN *E. coli*/100 mL, which is an excellent result; in practice free chlorine residuals are rarely reported (Supplementary material, Table 1). To the extent that national-level entities want to be 'on track' to meet the SDGs, there will be little to no incentive to question good results from local municipal utilities.

CONCLUSION

Our study is of just one town, and we do not argue that our findings can or should be generalized. However, they present an illustrative case of the limitations of relying on the presence of adequate infrastructure or on official data for reports of bacterial quality for drinking water monitoring. Previous research has shown that both resources and motivated leadership are necessary for regular monitoring of water quality in low-income settings (Steynberg 2002; Peletz *et al.* 2018). We show that despite relatively good water delivery and infrastructure, knowledge of testing protocols at the leadership level, and regular water quality testing, Alibag's residents do not receive consistently safe water. We hypothesize, from our own water quality tests, and our overall observations during field research, that pressure to not 'fail' contributed at least in part to the discrepancy between what was reported and what may be happening. However, it is a limitation of our study that we have only indirect evidence for this hypothesis; open discussion of these discrepancies with agency leaders would have been difficult.

Our work makes a strong case for third-party monitoring as a form of quality control. Resource-constrained cities could partner with local colleges and labs, where students could be trained to test and record water quality; such a step could leverage citizen engagement, foster local capacity and provide independent data (for a similar exercise on mapping Alibag's sanitation system, see Narayanan Ray Gopakumar & Argade 2018).

Additionally, it is at least plausible that the (necessary) attention on monitoring and publishing national data, in effect 'ranking' countries with respect to the SDGs, is producing a chain of performance pressure within low-income countries. We suggest that, to encourage the collection of more reliable data, the SDG indicators in global reports and rankings should be consistently treated as measures of progress over time in addition to as percentages of the population served. Researchers have suggested that the pace of progress is a more helpful focus than hard targets alone with respect to monitoring water and sanitation goals (Fukuda-Parr Greenstein & Stewart 2013; Fuller Goldstick Bartram & Eisenberg 2016). When achievements are tracked only by target coverage, there may be no way to get credit when, despite making progress, target coverage has not been reached (Easterly 2009; Fukuda-Parr *et al.* 2013).

An example of tracking progress is the reporting from the Joint Monitoring Programme (JMP) of WHO/UNICEF. The JMP routinely presents access to safe water data as the progress made along a water service 'ladder'. This nuance, however, is not part of the SDG 6 indicators, and would not feature in any cross-country comparisons based on the SDGs. We argue in favor of incorporating JMP's practice into the SDG indicators, because such an interpretation motivates rather than judges, and recognizes progress in addition to target achievement. Realistic expectations in challenging contexts are more likely to produce realistic water quality data towards meeting SDG 6.

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AUTHOR CONTRIBUTIONS

Designed the study SR, BR & IR; Carried out field research: SR; Analyzed the data: SR with inputs from IR; Wrote the paper: SR & IR with inputs from BR.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on Zenodo (10.5281/zenodo.3555385). Survey information and maps are available upon request from the corresponding author.

COMPETING INTERESTS

The authors declare no competing interests.

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