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Research Article

Performance Assessment of Full-Scale Sequencing Batch Reactor Sewage Treatment Plants and Chlorination Disinfection in Gujarat, India

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ABSTRACT

Full-scale sewage treatment performance depends not only on process selection but also on the integrity of screening, biological treatment, disinfection, instrumentation, and routine operation and maintenance. This field study assessed five sequencing batch reactor (SBR)-based sewage treatment plants (STPs) in Gujarat, India—Vemali (13 MLD), Kapurai (60 MLD), Chhani (50 MLD), Bhayali (45 MLD), and Nadiad (51.26 MLD)—during a regional monitoring campaign conducted from 26 September to 11 October 2023. Grab samples were collected from SBR decant effluent before chlorination and from final discharge after chlorination on two monitoring days, with target chlorine doses of 5.0 and 6.0 mg/L. The analytical programme included pH, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammoniacal nitrogen, nitrate-nitrogen, faecal coliforms, organic-carbon indicators, and four trihalomethanes (THMs). The four Vadodara facilities generally produced low-BOD SBR decant/final effluent and showed strong faecal-coliform reductions following chlorination. Calculated reductions for quantifiable paired observations ranged from 4.00 to 6.50 log₁₀ at the Vadodara plants, whereas Nadiad achieved only 3.16 and 2.52 log₁₀ reductions on the two monitored days. Nadiad simultaneously exhibited substantially elevated TSS, COD, BOD, and ammoniacal nitrogen and was documented to have clogged screening/grit infrastructure, plastics entering SBR basins, non-functional chlorine dosing equipment, and inadequate on-site analytical capability. Chloroform, bromodichloromethane, dibromochloromethane, and bromoform were reported as not detected above the stated analytical detection limit (<0.025 mg/L) under the monitored conditions.

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The results demonstrate that SBR technology can provide high-quality municipal effluent when supported by reliable pretreatment, process control, and disinfection, but technology selection alone cannot compensate for deficient operation and maintenance. The study also shows why THM nondetection should be interpreted condition-specifically rather than as evidence of universal toxicological safety.

INTRODUCTION

Rapid urban growth increases municipal wastewater generation and intensifies the need for treatment systems that can deliver reliable effluent quality within constrained urban footprints. Sequencing batch reactors (SBRs) are time-sequenced activated-sludge systems in which filling, biological reaction, settling, and decanting occur in the same reactor. Their operational flexibility, compact configuration, and ability to support carbon oxidation and biological nutrient transformations have led to extensive municipal application. Recent literature continues to identify reactor configuration, cycle design, loading, aeration, settling, microbial ecology, and operational control as major determinants of SBR performance ¹.

Indian full-scale studies have shown that SBR plants can achieve substantial removal of conventional sewage pollutants, but plant performance varies with influent characteristics, process loading, and operating conditions ². A broader assessment of full-scale Indian STPs also found SBR systems to perform strongly among several treatment technologies, while emphasizing that sustainability and treatment performance must be considered together ³. Thus, a nominally advanced treatment process does not guarantee satisfactory final effluent unless mechanical pretreatment, aeration, sludge management, instrumentation, laboratory control, and operator response remain functional.

Disinfection is an additional critical barrier where treated municipal effluent is discharged to receiving waters or considered for reuse. Chlorine remains attractive because of its established microbial inactivation capacity and operational familiarity. However, chlorine reacts with residual organic matter to form disinfection by-products (DBPs). Among the best-known DBPs are trihalomethanes (THMs):

chloroform, bromodichloromethane, dibromochloromethane, and bromoform. THM formation is affected by chlorine dose, contact time, pH, temperature, bromide, ammonia, and the concentration and character of dissolved organic matter ⁴⁻⁸. Research from western India has specifically shown that the nature of dissolved organic matter can strongly influence THM formation during chlorination of wastewater effluent ⁶.

Against this background, the present study evaluates five operational SBR-based municipal STPs in Gujarat using paired pre- and post-chlorination observations obtained during a CPCB regional monitoring campaign. The objectives were to: (i) characterize SBR decant and final-effluent quality across the five facilities; (ii) quantify faecal-coliform reduction across chlorination at target doses of 5.0 and 6.0 mg/L where paired data permitted calculation; (iii) assess the reported occurrence of four THMs under the monitored conditions; and (iv) interpret performance differences in relation to documented plant-level operational conditions. Particular attention is given to the contrast between four Vadodara installations and the Nadiad STP, where significant mechanical and operational deficiencies were observed.

MATERIALS AND METHODS

2.1 Study design and monitoring period

Field monitoring was carried out by the Central Pollution Control Board (CPCB), Regional Directorate, Vadodara, from 26 September to 11 October 2023. At each facility, grab samples were collected at two process boundaries: (1) pre-chlorination, representing SBR decant effluent entering the chlorine contact system; and (2) post-chlorination, representing final discharge after chlorination. Monitoring was performed on two operational days. The source record identifies target chlorine gas doses of 5.0 mg/L on Day 1 and 6.0 mg/L on Day 2. Because the available dataset contains paired observations from two monitoring days rather than a long-term replicated time series, results are interpreted as a field performance snapshot and not as a statistical estimate of annual plant performance.

2.2 Study facilities



Table 1: Characteristics of the Five Sbr-Based Sewage Treatment Plants

STP	Design capacity (MLD)	Location	Commissioned	Observed flow (MLD)	SBR basins	Discharge/reuse
Vemali	13	Vadodara	2021	4–5	2	Vishwamitri River via closed pipeline
Kapurai	60	Vadodara	2021	~23	2	Jambuwa River via open channel
Chhani	50	Vadodara	2022	~35	4	Vishwamitri River via open channel
Bhayali	45	Vadodara	2022	~30	4	Treated-water reuse; industrial partner
Nadiad	51.26	Gopalpura, Nadiad	2016	~20	4	Sedhi River via pipeline

2.3 Analytical parameters

The monitoring matrix included pH, TSS, COD, BOD, ammoniacal nitrogen ($\text{NH}_3\text{-N}$), nitrate-nitrogen ($\text{NO}_3\text{-N}$), and faecal coliforms reported as MPN/100 mL. The source manuscript also describes TOC/DOC characterization and gas-chromatographic screening for chloroform, bromodichloromethane, dibromochloromethane, and bromoform, with specialized trace-organic analysis undertaken by an accredited external laboratory. The source dataset available for reconstruction does not provide method numbers, instrument model, quality-control recoveries, chlorine contact time, or complete TOC/DOC values; these details should be added from the original CPCB laboratory/inspection record before journal submission.

2.4 Data treatment

For paired faecal-coliform observations, chlorination performance was expressed as $\log_{10}$ reduction: $\log \text{reduction} = \log_{10}(\text{Cpre}/\text{Cpost})$, where Cpre and Cpost are pre- and post-chlorination MPN/100 mL. Percentage reduction was calculated as $100 \times (\text{Cpre} - \text{Cpost})/\text{Cpre}$. Where the post-chlorination result was reported as NIL, no numerical log reduction was assigned because the analytical reporting/detection limit required for a censored-data calculation was not provided.

RESULTS

3.1 Physico-chemical and microbiological observations

Table 2: Physico-Chemical and Microbiological Observations

STP	Condition	pH	TSS	COD	BOD	$\text{NH}_3\text{-N}$	$\text{NO}_3\text{-N}$	F. coli (MPN/100 mL)
Vemali	D1 5 mg/L	8.2	4.6	10.82	4.9	0.4	3.89	1.3×10^5
Vemali	D1 post	8.38	3.4	7.22	2.5	0.54	4.3	4.5
Vemali	D2 6 mg/L	8.27	5.6	8.69	1.8	0.64	4.51	4.9×10^5
Vemali	D2 post	8.2	3.5	14.27	2.1	0.54	3.33	23
Kapurai	D1 5 mg/L	7.69	4.8	23.29	2.3	0.43	4.25	3.3×10^6
Kapurai	D1 post	7.28	5.4	27.72	1.4	0.46	3.86	79
Kapurai	D2 6 mg/L	7.83	4.7	21.97	3.9	0.27	4.06	1.3×10^6
Kapurai	D2 post	7.75	5.6	21.81	3.1	0.35	4.7	130
Chhani	D1 5 mg/L	7.31	2.3	9.9	1.0	0.31	6.64	3.5×10^7
Chhani	D1 post	7.37	1.0	7.6	1.2	0.27	6.15	11
Chhani	D2 6 mg/L	7.53	3.5	18.19	5.4	1.67	7.72	4.9×10^6
Chhani	D2 post	7.28	3.0	12.47	3.3	1.54	6.35	4.5
Bhayali	D1 5 mg/L	7.49	3.0	16.09	2.2	3.92	3.03	5.4×10^7



STP	Condition	pH	TSS	COD	BOD	NH ₃ -N	NO ₃ -N	F. coli (MPN/100 mL)
Bhayali	D1 post	7.43	6.0	12.38	2.6	4.6	2.42	NIL
Bhayali	D2 6 mg/L	7.87	5.8	9.69	1.9	0.65	3.91	2.3×10 ⁶
Bhayali	D2 post	7.81	2.1	10.82	1.4	0.3	4.11	2.0
Nadiad	D1 5 mg/L	8.23	49.0	138.4	31.3	18.1	2.47	3.5×10 ⁸
Nadiad	D1 post	8.22	38.0	127.8	61.8	17.9	2.85	2.4×10 ⁵
Nadiad	D2 6 mg/L	8.11	30.0	77.9	24.3	12.2	1.27	1.3×10 ⁷
Nadiad	D2 post	8.12	27.0	82.8	18.3	12.3	0.77	3.9×10 ⁴

The four Vadodara plants generally showed low BOD concentrations in the monitored SBR decant/final effluent. By contrast, Nadiad displayed markedly elevated solids and organic loading, including TSS of 27–49 mg/L, COD of 77.9–138.4 mg/L, and BOD of 18.3–61.8 mg/L across the reported observations. Nadiad also retained high ammoniacal nitrogen (12.2–18.1 mg/L), whereas the Vadodara plants generally showed

much lower NH₃-N values. The pattern is consistent with impaired biological treatment and nitrification at Nadiad, although definitive process-kinetic attribution would require dissolved oxygen, MLSS/MLVSS, sludge age, cycle-time, alkalinity, temperature, and influent loading data.

3.2 Faecal-coliform reduction across chlorination

Table 3: Faecal-Coliform Reduction Across Chlorination

STP	Cl ₂ target (mg/L)	Pre (MPN/100 mL)	Post (MPN/100 mL)	Log ₁₀ reduction	% reduction	Interpretation
Vemali	5.0	1.30e+05	4.5	4.46	99.99654	Quantifiable paired reduction
Vemali	6.0	4.90e+05	23	4.33	99.99531	Quantifiable paired reduction
Kapurai	5.0	3.30e+06	79	4.62	99.99761	Quantifiable paired reduction
Kapurai	6.0	1.30e+06	130	4.00	99.99000	Quantifiable paired reduction
Chhani	5.0	3.50e+07	11	6.50	99.99997	Quantifiable paired reduction
Chhani	6.0	4.90e+06	4.5	6.04	99.99991	Quantifiable paired reduction
Bhayali	5.0	5.40e+07	NIL	Not calculated	Not calculated	Complete removal to reporting limit
Bhayali	6.0	2.30e+06	2	6.06	99.99991	Quantifiable paired reduction
Nadiad	5.0	3.50e+08	240000	3.16	99.93143	Quantifiable paired reduction
Nadiad	6.0	1.30e+07	39000	2.52	99.70000	Quantifiable paired reduction

Quantifiable log reductions at Vemali, Kapurai, Chhani, and Bhayali ranged from 4.00 to 6.50 log₁₀. Bhayali Day 1 was reported as NIL after chlorination, but a numerical log reduction cannot be calculated without the laboratory reporting limit. Nadiad achieved lower reductions of 3.16 log₁₀ at the 5.0 mg/L target

dose and 2.52 log₁₀ at the 6.0 mg/L target dose. Importantly, the higher nominal chlorine dose did not consistently produce a higher log reduction across plants; the two-day observations therefore should not be interpreted as a dose-response experiment. Chlorine demand, contact time, mixing, residual chlorine, solids,



ammonia, and day-to-day influent variability were not controlled or fully reported.

3.3 Trihalomethane screening

The source monitoring record reports chloroform, bromodichloromethane, dibromochloromethane, and bromoform as not detected above an analytical detection limit of <0.025 mg/L across the monitored facilities.

This is an important negative finding for the specific samples and operating conditions examined. It should not be generalized to mean that chlorination cannot form THMs at these facilities. Published work demonstrates that THM formation in reclaimed wastewater is sensitive to chlorine dose, contact time, pH, bromide, temperature, ammonia, and DOM composition ⁴⁻⁸.

3.4 Operational observations and resource recovery

Table 4: Documented Operational and Resource-Recovery Observations

Facility	Documented field observation
Vemali	Mechanical operation reported as sound; automated gas chlorination; internal laboratory available, but microbiological capability was limited.
Kapurai	Dual chlorine-cylinder arrangement provided standby capacity; dewatered sludge production was reported at approximately 40–60 t/month for agricultural distribution.
Chhani	One chlorine flow meter was reported non-functional and the active meter showed substantial pressure fluctuation; sludge production was reported at 30–50 t/month.
Bhayali	Approximately 60,000 L/day of treated effluent was reported to be supplied to an industrial partner in Padra, demonstrating a local reuse pathway.
Nadiad	Severe screen/grit blockage, raw sewage overflow, plastics entering SBR basins, failed chlorine dosing/flow equipment, absent process logs, and inadequate on-site laboratory equipment were documented.

DISCUSSION

4.1 SBR performance and the importance of operation and maintenance

The monitored Vadodara facilities illustrate the treatment potential of full-scale SBR systems. Their generally low BOD and NH₃-N observations are consistent with the capacity of SBRs to combine carbon oxidation with nitrification when aeration, biomass retention, settling, and decant phases are appropriately managed. Full-scale literature has reported effective organic and solids removal in SBR systems and confirms the importance of microbial and operational stability ^{1,9}. Indian case studies likewise demonstrate that SBR-based municipal STPs can achieve strong pollutant removal under suitable operating conditions ^{2,10}.

The Nadiad case is particularly informative because it separates technology identity from operational reality. The plant was nominally an SBR facility, yet documented failures occurred upstream, within the biological stage, and at disinfection. Clogged screening and grit channels allowed plastics and gross solids to pass downstream; floating material in SBR basins could

interfere with settling and decanting; and chlorination equipment was initially non-functional. Such cascading failures provide a plausible systems-level explanation for the combination of high TSS, high BOD/COD, elevated ammonia, and weaker microbial reduction. Historical CPCB assessments of Indian STPs have similarly emphasized that inadequate operation and maintenance can undermine installed treatment capacity ¹¹.

Because the available data represent two monitoring days at each facility, causality should be stated cautiously. Nevertheless, the co-occurrence of documented mechanical failures and degraded water-quality indicators at Nadiad is sufficiently strong to support an engineering diagnosis of operational impairment. Future monitoring should include influent/effluent flow, dissolved oxygen profiles, MLSS/MLVSS, sludge volume index, solids retention time, cycle phase duration, oxidation-reduction potential, alkalinity, temperature, chlorine residual, contact time, and preventive-maintenance records.



4.2 Chlorination, solids, ammonia, and pathogen reduction

Chlorination performance depends on more than the applied dose. Suspended and colloidal matter can increase chlorine demand and provide physical protection to microorganisms, while ammonia consumes free chlorine and changes disinfectant speciation. In the present dataset, the four Vadodara facilities combined comparatively low solids with large faecal-coliform reductions, whereas Nadiad combined elevated TSS and ammonia with weaker log reductions. This association is operationally plausible, but the absence of measured contact time and free/total residual chlorine prevents calculation of CT exposure or direct attribution of the microbial results to chlorine dose alone. The observed decline in Nadiad log reduction from Day 1 to Day 2 despite a higher nominal target dose is a clear reason not to infer a simple 5-versus-6 mg/L dose response.

4.3 Interpretation of THM nondetection

THM nondetection is encouraging but must be interpreted within analytical and temporal boundaries. The reported detection limit (<0.025 mg/L for the individual compounds) is relatively high compared with concentrations often discussed for drinking-water DBPs, and the monitoring represents discrete grab samples rather than THM formation-potential tests over controlled contact periods. Wastewater research shows that THM formation can rise with chlorine dose and contact time and varies with precursor chemistry^{4,5,7,8}. A western-India study found that hydrophobic DOM fractions were particularly relevant to THM formation and that seasonal and matrix effects can be substantial⁶. Therefore, the defensible conclusion is that the four target THMs were not detected above the stated method limit in the samples analyzed—not that the process is universally free of DBP risk.

4.4 Water reuse and circularity

The Bhayali reuse practice demonstrates the resource value of treated municipal wastewater. Replacing a portion of industrial freshwater demand with adequately treated municipal effluent can reduce pressure on freshwater and groundwater resources. However, reuse decisions should be based on fit-for-purpose

water-quality criteria and risk management rather than on BOD or coliform performance alone. Monitoring requirements may include salinity, nutrients, pathogens, residual disinfectant, metals, and application-specific parameters. Sludge reuse, as reported at Kapurai and Chhani, similarly requires appropriate quality assurance before agricultural application.

5. Study Limitations

- Only two paired monitoring days per plant were available; seasonal and long-term variability cannot be quantified.
- The dataset begins at SBR decant/pre-chlorination rather than raw influent for the tabulated observations, so whole-plant removal efficiency cannot be calculated from these data.
- Chlorine contact time, hydraulic residence time in contact tanks, and measured free/total chlorine residuals were not available in the reconstructed source.
- Method numbers, instrument details, QA/QC recoveries, replicate analyses, and full TOC/DOC results were not present in the supplied manuscript and should be recovered from the original laboratory report.
- THM results were reported only as nondetects above the stated analytical limit; no controlled THM formation-potential test was available.
- Regulatory compliance should be assessed against the exact consent/standard applicable to each plant and discharge/reuse route; the present reconstruction avoids assigning formal compliance where that plant-specific regulatory basis was not supplied.

6. Engineering Recommendations

1. Restore and maintain robust inlet screening and grit removal, with documented cleaning frequencies and contingency procedures for blockage.
2. Implement preventive maintenance for SBR decanters, aeration equipment, valves, chlorine dosing pumps, flow meters, and online sensors, with calibration records.



3. Use flow-paced or feedback-controlled chlorination where feasible, supported by measured residual chlorine and verified contact time rather than nominal dose alone.
4. Strengthen plant laboratories to support routine TSS/MLSS, ammonia, residual chlorine, and microbiological measurements using validated methods and QA/QC.
5. Establish trend-based process control using influent/effluent flow, DO, MLSS/MLVSS, SVI, SRT, cycle times, ammonia/nitrate, and microbial indicators.
6. For reuse schemes, apply fit-for-purpose monitoring and periodic DBP surveillance; where chlorination is used, include lower-detection-limit THM/DBP testing when risk assessment warrants it.
7. Expand beneficial reuse of treated water only where consistent quality, end-use safeguards, and reliable distribution arrangements can be demonstrated.

CONCLUSION

This field assessment shows that full-scale SBR-based municipal STPs in Gujarat can produce high-quality secondary effluent and support substantial pathogen reduction when pretreatment, biological operation, and chlorination systems are functional. The four Vadodara plants generally exhibited low organic and ammoniacal-nitrogen concentrations and quantifiable faecal-coliform reductions of approximately 4.00–6.50 log₁₀ across the monitored chlorination stages. In contrast, Nadiad exhibited elevated TSS, COD, BOD, and NH₃-N together with weaker faecal-coliform reductions and multiple documented mechanical, operational, and laboratory deficiencies. The comparison indicates that operation and maintenance are decisive determinants of real-world SBR performance.

The four monitored THMs were reported as not detected above <0.025 mg/L under the sampled conditions. This finding supports the absence of quantifiable concentrations at the stated method limit but does not establish universal toxicological safety or zero THM formation. Future studies should combine longer-term sampling with measured chlorine residual/contact time,

detailed DOM characterization, lower analytical detection limits, and complete process-control variables. The principal engineering implication is that reliable municipal wastewater treatment requires an integrated chain—from screening through biological treatment, disinfection, monitoring, and maintenance—rather than reliance on treatment technology designation alone.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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The field monitoring described in the source manuscript was carried out by the Central Pollution Control Board, Regional Directorate, Vadodara. The authors should verify institutional approval, acknowledgment wording, and permission to publish internal monitoring data before submission.

Conflict of Interest

The authors declare that they have no conflicts of interest related to the publication of this manuscript

Author Contributions

Dr. Himani Pandey: Conceptualization; Methodology; Investigation; Data Curation; Formal Analysis; Validation; Writing – Original Draft; Writing – Review & Editing; Visualization.

Mr. B. D. Pandey: Methodology; Investigation; Data Curation; Validation; Resources; Writing – Review & Editing; Supervision.

Both authors have read and approved the final version of the manuscript.

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