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Operation and maintenance of sewerage systems: present challenges and possible solutions—an Indian experience

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ABSTRACT

A strong focus on increasing gross domestic product to meet demanding needs stretched the country on the brink of overstretching the ecological carrying capacity. Unfortunately, rivers are among the worst affected natural resource. The government of India thus initiated the Ganga and Yamuna action plans and spends around 20 billion rupees against this backdrop about a quarter century ago. However, the present status of these rivers is a sad testimony to carry out adequate efforts for pollution abatement. The lack of motivation, knowledge, and proficiency in operation and maintenance among technical personnel is the most crucial reason for poor functioning and underutilization of sewerage facilities. Only 31% population is covered by sewage treatment facility, out of which most of the sewage treatment plants are operating either under or over the design capacity or not in operation at all. The effluent from several plants failed to meet the disposal criteria. Therefore, multi-tier training, development of common curriculum, establishment of dedicated O&M training centers, assessment of training institutions, and preparation of very simplified user-friendly O&M manuals are identified as a plausible solution. Implementation of concept of Built Own and Operate scheme for future policy in India based on Public–Private Participation mode could also be a novel idea.

Keywords: River pollution; GAP; YAP; Operation and maintenance; STP

1. Introduction

Municipal sewage is the main source of pollution of rivers in India. The magnitude of this problem has increased in recent years due to rapid industrialization and urbanization. Due attention has not been given to tackle the sewage pollution, which ultimately contributed to the degradation of water quality in a number of stretches of several rivers in the country.

Ganges is the largest and the most important river of India as it occupies the most revered place in Indian Society [1]. The 2,525 km long river carries off the drainage of a vast basin area of 861,404 km covering

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26.2% area of India's total geographical area. The watershed of the river Ganges spreads over 10 states of India, namely Uttarakhand, Himachal Pradesh, Uttar Pradesh, Haryana, Delhi, Rajasthan, Madhya Pradesh, Bihar, Jharkhand, and West Bengal (Fig. 1).

The important tributaries of river Ganges are Kali, Ramganga, Yamuna, Gomti, Ghaghara, Son, Gandak, and Kosi. They serve as local water supply source for potable, irrigational, bathing, and various other purposes. Unfortunately, discharge of untreated sewage

Fig. 1. Pictorial view of Ganges river basin. (Source: mapsofindia.com/maps/rivers/ganges.html#.)

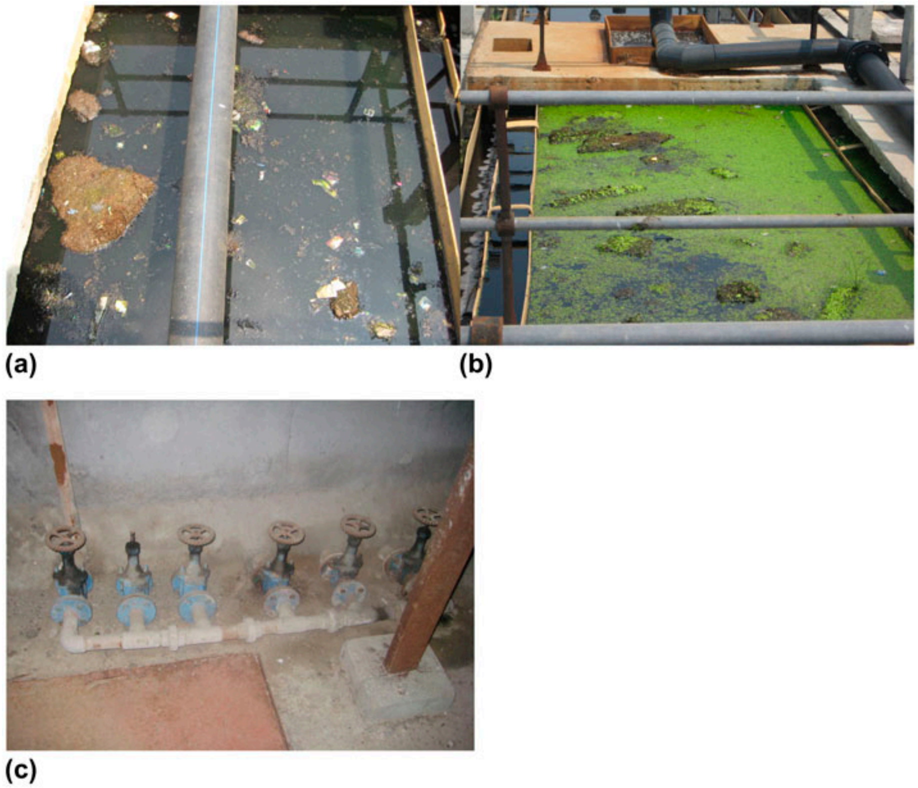

Fig. 2. Suspended material on UASB reactors (a,b) and clogged sludge valves of UASB reactors (c).

from urban centers caused the notable degradation in river water quality. On account of inability of local authorities to cope with the water pollution-associated problems due to paucity of resources. In 1985, Government of India came forward and launched Ganga action plan (GAP) to clean and restore the water quality of river Ganges.

The major emphasis was on the capacity building of sewerage networks, interception and diversion of drains, and construction of sewage treatment plants (STPs) to facilitate the improvement in the quality of water. More than 70 STPs based on different treatment technologies have been set up under GAP. However, the level of performance of these plants with regard to effluent quality, energy consumption, process stability, resource recovery, capital and operation and maintenance costs has varied considerably [2].

Despite the investment of 20 billion rupees, the water quality status of our rivers including Ganges still does not meet the water quality discharge standards. The main reason behind this situation is not only the gap between sewage generation and treatment capacity, but also improper allocation of STPs according to serving population, under and over treatment capacity operation of STPs, unrestrained and unmonitored discharges into the surface waters, poor operation and maintenance of STPs due to lack of skilled and trained operation and maintenance personnel. This amounted to futile the entire exercise due to improper operation and maintenance despite massive investment.

The objective of the present study was to review (based on secondary data) the water quality status of Ganges river basin, status of sewage treatment infrastructure and performance of the STPs established under these plans, investigate the core problems associated with operation and maintenance of STPs and propose the necessary recommendations to troubleshoot the operation and maintenance-related problems in order to achieve higher treatment performance and utmost utilization of existing sewerage facilities.

2. Water quality status of Ganges river basin

2.1. Wastewater load from different states

The Ganges basin has 234 Class I cities and 149 Class II cities with a total population of 109.8 million. The status of sewage treatment in Class I and Class II cities of Ganges basin is given in Table 1. Out of 16,000 million litres per day (MLD) of wastewater generated in the Ganges basin, the treatment facilities are

Table 1
Status of wastewater generation, collection, and treatment in Class I and Class II cities in Ganges basin [3]

S. No.	State	No. of cities	Population (year 2008)	Sewage generation (MLD)	Treatment capacity (MLD)	Capacity gap (MLD)	Percent treatment capacity (%)
A	*Class I cities*						
1	Bihar & Jharkhand	37	10,747,725	1840	136	1,704	7
2	Delhi	1	14,858,800	3,800	2,330	1,470	61
3	Haryana	20	5,494,110	627	312	315	50
4	Himachal Pradesh	1	163,490	29	36	0	100
5	Madhya Pradesh	25	10,795,000	1,249	186	1,063	15
6	Rajasthan	24	9,611,490	1,382	54	1,328	4
7	Uttar Pradesh and Uttarakhand	66	27,011,660	3,683	1,258	2,425	34
8	West Bengal	60	19,818,471	2,345	506	1839	22
	Ganga Basin	234	98,500,746	14,955	4,818	10,144	32
B	*Class II cities*						
9	Bihar & Jharkhand	24	1,940,100	186	2	184	1
10	Haryana	7	544,040	44	–	44	0
11	Madhya Pradesh	23	1,745,050	131	9	122	7
12	Rajasthan	21	1,599,260	148	–	148	0
13	Uttar Pradesh and Uttarakhand	47	3,452,010	354	19	335	5
14	West Bengal	27	2,004,440	180	62	119	34
	Ganga Basin	149	11,284,900	1,043	92	952	9

Source: Central pollution control board.

available only for 5,000 MLD of wastewater. Thus, the total gap of treatment capacity is approximately 11,000 MLD [3].

2.2. BOD load from different states

The total load in terms of the BOD originating from different sources is estimated to be as high 7.4 million kg/d (Table 2). The total urban organic pollution load in the Ganges basin is 2.5 million kg of BOD per day, of which 53.4% (1.3 million kg) is contributed by the domestic sector and remaining 46.6% (1.2 million kg) contributed by industrial sector. The largest share, of the total basin load (66.2%), comprising 4.9 million kg of BOD per day, comes from the wastes generated in the rural sector, including both human and domestic cattle sources [3]. The overall per capita production of the organic pollution loads from urban and rural sources is given in Table 2.

Within the Ganges basin, the highest contribution (53%) of urban organic pollution load (both domestic and industrial sources) comes from Uttar Pradesh (BOD: 1.3 million kg/d). While in other states, the contribution coming from the urban domestic sector is higher than the industrial sector, the pollution load of the industrial sectors (65.7%) in Uttar Pradesh is more than that of domestic sectors (34.3%). Taking the basin as a whole, the daily average comes to 64 g per person in urban areas [3].

2.3. Water quality status

2.3.1. DO and BOD level

The water quality analysis for BOD and DO at 16 stations of river Ganges from 1986 to 2008 revealed the improvement in DO levels at four locations namely up and down streams of Allahabad and Varanasi. All the 16 stations, except downstream of Patna and Rajmahal showed reduction in BOD values. The BOD level showed marked reduction at Allahabad and Varanasi, indicating improvement in the water quality over pre-GAP period. However, out of 16 sites, the BOD level does not meet standard for bathing water at seven sites. The situation was found relatively better in case of DO, which failed to meet the bathing standard at only one site [3]. Furthermore, the Yamuna river in Delhi was facing a severe pollution problem with significantly higher BOD (18.6 mg/L) values, while the DO level reduced (<1 mg/L) below the level required for the sustenance of aquatic life (5 mg/L) [4]. Here, we would like to mention that the monitoring period from 1984 to

Table 2
Organic pollution load (BOD) generated from urban and rural sector in the Ganga basin [3]

S. no.	State	BOD load (kg/d)			%Total basin load	Rate of BOD load generation per day	
		Urban sector	Rural sector	Total load		g/person	kg/km^2 area
1	Haryana	77,107	100,138	177,245	2.39	41	8.3
2	Uttar Pradesh & Uttarakhand	1,329,674	2,017,991	3,747,665	45.18	34	11.4
3	Bihar & Jharkhand	174,862	1,340,167	1,515,029	20.45	21	11
4	West Bengal	442,636	478,101	920,737	12.43	30	18.2
5	Rajasthan	75,054	410,393	485,447	6.55	39	4.7
6	Madhya Pradesh	143,303	527,488	670,791	9.05	34	3.3
7	Himachal Pradesh	4,138	18,966	23,104	0.31	47	4
8	Delhi	257,952	11,505	269,457	3.64	45	181.5
	Ganga basin load	2,504,726	4,904,749	7,809,475	100	31	9.1
	% Total basin load	33.8	66.2	100			

2008 was post-GAP implementation, which was initiated in 1985, therefore the improved river water quality vis-à-vis DO and BOD owe to treatment of effluents prior to disposal. It is also clear from the fact that despite a significant population increase in towns, which discharging the effluent into the river Ganges, the BOD level was not goes up. It shows improvement in river water quality, although very slowly.

2.3.2. Pathogenic indicators

The fecal coliforms (FC) level was monitored at 39 locations along river Ganges from 2002 to 2008. The findings revealed that FC count at Varanasi (downstream of Malviya bridge), Uttar Pradesh reached the highest level of 148,333 MPN/100 mL in 2002 and declined to a count of 81,714 MPN/100 mL in 2007. Among the 12 sampling stations in Uttar Pradesh, all showed an increased number of FC in year 2007–2008 in comparison with year 2002. Out of 10 monitoring stations in Uttarakhand, the FC count was consistently observed at acceptable level for bathing only at Rishikesh and Haridwar. In Bihar (2008), the FC count was ranged from 4,000 to 14,545 MPN/100 mL. In West Bengal during the same period, the FC count showed higher values at all the eight stations sampled with a minimum of 11,250 MPN/100 mL and a maximum of 283,333 MPN/100 mL. Thus, FC count exceeded acceptable level at major locations [3]. On other hand, FC count averaged 4.4×10^5 MPN/100 mL in severally polluted stretch of river Yamuna at National Capital Region around Delhi [4].

3. Sewage treatment infrastructure

3.1. Projects under GAP

A treatment capacity of 728 MLD was created by constructing 32 new STPs and 151 MLD capacity was augmented in 11 existing STPs under the first phase of GAP (GAP-I). The major treatment technology used in these STPs was conventional activated sludge process (ASP) at 14 plants, up-flow anaerobic sludge blanket process (UASB) at three plants, waste stabilization ponds (WSP) at 15 plants, trickling filters at six plants, facultative aerated lagoons at three plants. ASP was the most preferred technology accounting for 48% of total STP capacity created under GAP-I. If its design variants i.e. aerated lagoons are clubbed together, ASP accounted for almost 62% of the total capacity. WSP, TP, and UASB technologies accounted for 16, 15, and 6%, respectively, of total GAP-I capacity [2].

3.2. Projects under YAP

The experience under GAP-I was mixed in terms of efficiency of treatment vs. energy consumption and cost of operation and maintenance. A treatment capacity of 722 MLD was created by constructing 28 new STPs under the YAP-I. The major treatment technologies were UASB at 16 plants, WSP at 10 plants, and biological aerated filtration system (BIOFOR) at two plants. UASB technology was the preferred technology accounting for 83% of total STP capacity created under YAP due to its great advantages i.e. no electricity consumption, energy-rich methane generation, stabilized and less-sludge generation over conventional aerobic treatment processes [5]. WSP and BIOFOR system accounted 14 and 3%, respectively, of total YAP capacity [2].

3.3. Projects under the Government of Delhi

Concurrently with YAP, over 2,325 MLD of sewage treatment capacity was added in Delhi under the river pollution control program by the Government of Delhi. During last 25 years, about 30 STPs have been constructed in Delhi and they all are based on either conventional ASP or its variants e.g. Modified-Ludzack Ettinger, extended aeration process or advanced multistage aeration processes [2].

4. Status of sewerage treatment facilities

The Class I and Class II cities generated about 8,250 MLD of wastewater in the Ganges basin out of which treatment facilities are available only for 3,500 MLD of wastewater [6]. Therefore, a large gap between the wastewater generation (8,250 MLD) and treatment capacity (3,500 MLD) would remain unattended. Moreover, the existing treatment capacity is ineffectively utilized due to inadequate operation and maintenance practices. Operation and maintenance of existing plants and sewage pumping stations was found unsatisfactory, as nearly 39% plants were not conforming to the discharge standards. Auxiliary power back-up facility was found missing at all the intermediate (IPS) and main pumping stations of all the STPs [7].

4.1. Status of STPs at Delhi

According to CPCB survey [8], there were 30 STPs located at 17 locations in Delhi, but three STPs were not found in operation, 20 were running under capacity, five over capacity, three non-functional, and two were running at full capacity. The total treatment capacity of the 30 STPs was observed as 2,330 MLD, out of which only 1,478 MLD (about 63% of the treatment capacity) sewage was treated by the STPs. Most of the treatment plants working on ASP do not perform satisfactorily due to operational problems. Under-utilization of capacity of treatment is on account of deficiency in sewer connections and sewerage network (settlement/silting of trunk sewers) and improper operation and maintenance of conveyance system and pumping stations. The large network of peripheral sewers (6,000 km) is very old and some of them are under-sized and also in damaged condition.

4.2. Status of STPs along the Ganges river basin

4.2.1. Uttarakhand

The performance of two out of three STPs in Uttarakhand was found satisfactory; however, the performance of 1 STP (Swarg Ashram, Rishikesh) was observed far below the discharge standards, due to over loading and poor operation and maintenance conditions.

4.2.2. Uttar Pradesh

Out of the 9 plants established, 8 were STPs (all operational) and 1 chromium recovery plant (non-operational) at Pioneer Tannery, Kanpur. Most of these plants could achieve the prescribed norms, mainly due to the fact that they are over-designed, and the organic loading was much lower than the design loading; however, two STPs at Varanasi were operating under overloading condition. However, some of the STPs at Varanasi and Allahabad were under-loaded.

4.2.3. Bihar

Seven STPs were sanctioned by GAP in four towns of Bihar State with a total capacity of 87.5 MLD. The wastewater generation was about 143 MLD. The total sewage treatment capacity created in the town was of the order of 101.45 MLD putting together the capacity of previously existing STPs; however, due to various problems in the functioning of STPs, only 49 MLD capacities could be made operational. Thus, there was a gap of about 94 MLD, which ultimately discharged untreated into river Ganges and its tributaries.

All the mechanical components were observed corroded, most of the treatment units required special repair, insufficient/irregular sewage pumping/supply by the intermediate pumping stations, siltation of sewer lines, the capacity of sludge drying beds was inadequate as well as the plants were not working continuously due to frequent electric power failures and no standby power arrangement and facing the shortage of motivated and skilled (technical) manpower. As a result, the entire sewage from the town ended up into the river Ganges.

4.2.4. West Bengal

Performance of the STPs in West Bengal was found satisfactory but the influent strength in terms of BOD was found to be low at most of the locations. Thus the STPs were operated under low organic loading conditions. The volume of sewage to the STPs were insufficient due to heavy leakage and siltation in sewer lines.

Therefore, out of 35 STPs planned under GAP-I (3 STPs in Uttaranchal, 10 STPs in UP, 7 STPs in Bihar, and 15 STPs in West Bengal), 32 were commissioned, and 29 were found functioning. Adequate fund allocation for operation and maintenance of STPs was not provided particularly in Bihar and UP. A number of STPs were under loaded and many treatment plants needed upgradation. Inadequacy of trained personnel for operation and maintenance work was a major shortcoming. Non-availability of uninterrupted power was another problem in most of the places. In most of the cities/towns, proper sewerage system did not exist and the sewage flow in open drains causing unesthetic and odor-related problems. Inadequate pumping capacity to cater additional load of run-off water during rainy season further aggravated the stream pollution.

5. Operation and maintenance-related issues

Augmentation of sewage treatment facilities and their effective utilization was identified as the most crucial aspect for restoring the water quality of rivers and other aquatic resources [9]. Out of 175 STPs spread over 15 States, 84 STPs were studied (ASP: 36; WSP: 12; UASB + FPU: 12) based on 13 different technologies spread over nine states of India. Total scenario of STPs performance was dismal, as overall performance of 46 STPs was found poor or very poor. Performance of only 8 STPs was rated good while that of 30 other was satisfactory.

5.1. Technical problems

5.1.1. Operating under/over capacity

The survey conducted by CPCB [7] revealed that capacity utilization of the STPs was generally inadequate. Out of 55 STPs, only 18 STPs (i.e. 33%) were operating at normal flow (90–110% design flow), whereas rest 37 (67%) were either under-loaded (<50% design flow) or over-loaded (>150% design flow) conditions. This entire situation was due to disparity between the treatment capacities generated, actual sewage generation and collection and conveyed to the STP in the relevant catchment areas.

5.1.2. Poor and improper sludge handling

Sludge handling and reuse appears to be most neglected area in STPs operation. Irregular cleaning of accumulated sludge was observed at most of the STPs. In 43 ASP-based STPs, 16 sludge-handling facilities were out of order and one sludge-handling facility was partly in order. Similarly, out of 28 WSP-based STPs, cleaning of accumulated sludge was not regularly practiced in 24 cases which reduced the HRT and quality of treated effluent due to sludge flowing out with effluent (Fig. 2(a) and (b)).

Sludge in UASB reactors was not withdrawn regularly based on its level and concentration in the reactors, which results in sludge flowing out with the effluent in polishing ponds and thus causing poor quality of treated effluent. Furthermore, scum accumulated on the top of UASB reactors was not removed periodically (Fig. 3). Sato et al. [10] observed that 11 of the 15 UASB-based STPs investigated had final polishing unit (FPU) in operation for more than three years, which may explain the accumulation of too much sludge. However, most of these ponds have yet to be cleaned up even though applicable guidelines prescribed a clean up every 1–2 years, or whenever the sludge accumulation exceeds 40 cm [10–13]. These conditions ultimately result in washout of algae, and high ammonia and suspended solids concentration in the effluent [10]. The capacity of sludge drying beds was also reduced due to improper removal of filtrate from sludge drying beds as subsequent removal/withdrawal of sludge from sludge drawing beds/reactors was not possible in a desired manner [9].

5.1.3. Poor generation and utilization of biogas

It was observed that there was no gas generation and utilization in 13 plants in spite of possessing anaerobic reactors/digesters. At 14th STP, the gas generated was either flared or not utilized. At 8th STP, the gas generated was only partly utilized thus

Fig. 3. Clogged inlet of UASB reactor.

mostly flared. Out of the 12 STPs which generated gas, 5 STPs used gas as domestic fuel, 4 STPs used it as fuel for gas engine, 3 STPs used it as fuel in dual fuel generator [9].

5.1.4. Entry of solid wastes at inlet and sump

The poor operation and maintenance of screens and grit chamber led to the entry of solid waste including plastics, pouches, and heavy grit which may cause wear and tear and choking of pumps and machinery and reduced efficiency of treatment, especially in case of UASB process where the feeding pipes and overflow weirs/V-notches in division boxes/effluent gutters were chocked/obstructed, thus resulting in reduced STP capacity (Fig. 3).

5.1.5. Weak sewage strength

The sewage strength was observed weak, in general, because of infiltration and leakages, at the time of sewage flow through the open drains. Moreover, settlement and partial digestion also occurs, not just in drains but also in sewers.

5.1.6. No alternate/poor power supply

Out of 83 STPs monitored [9], only 13 STPs were registered to have operational alternate power supply arrangements, and six other STPs were not able to utilize alternate source due to financial constraints. Shortage of funds in 26 cases, mostly in Bihar, Haryana, UP, and West Bengal were observed. The acute shortage of power supply in most of the towns specially in UP, Bihar, and even Delhi further aggravated the problems as standby arrangement during power cut/failure did not generally exist to meet the power requirement for running the plant. Frequent and long power cuts and subsequent sudden discharge into the STP also caused shock load to various units of STPs, even in UASB and WSP processes, thus adversely affecting the efficiency of treatment system (Fig. 4).

5.1.7. Lack of proper laboratories and sample analysis

At 42nd STP, the testing was done at common departmental laboratories. At 16th STP the testing was outsourced. In all these cases, normal day-to-day testing was not done, which ultimately leads to the poor control on plant's performance. Mostly, no feedback was referred to the operation and maintenance staff about the testing results of effluent quality, which was the main cause of hindrance in timely control of the process. Similarly, testing of effluent for FC was not done in most of the plants, which is one of the most important indicators in abatement of pathogenic pollution of rivers [9].

5.1.8. Absence of sufficient baffle walls

Some of the STPs did not have sufficient baffle walls and also, sufficient length of overflow weirs at their final outlets particularly in case of UASB polishing ponds and WSPs, which resulted in poor effluent quality.

5.2. Administrative and financial problems

5.2.1. Frequent transfer of operation and maintenance-related staff

Sometimes, the trained and experienced staff including operators, technicians, and engineers

Fig. 4. Poor quality effluent from activated sludge plant.

engaged in operation and maintenance of the STPs were frequently transferred so that their experience and know-how were not transferred to their successors and were thus not available for operation and maintenance of the STPs [9].

5.2.2. Lack of technical know-how

Poor understanding of operational personnel regarding the wastewater treatment principles in process control of the facilities and failure of operation personnel to perform laboratory tests and to interpret and apply test results to process control was another area of major constraint. According to a survey of CPCB [9], staff/officers/engineers engaged for operation and maintenance at some STPs were not fully familiar and aware of the subject of sewage treatment.

5.2.3. Poor financial support to the sewage treatment facilities

Paucity of funds, lack of priority, and lack of means of fund generation were the major reason of poor operation and maintenance and reduced performance of STPs. The problem of fund shortage was mostly reported from states of Bihar, Haryana, UP, and West Bengal. This trend showed that the root of problem lies in less priority being given to sewage treatment facilities. As per CPCB [9] reports, majority of state governments/implementing agencies were not able to provide sufficient and regular funds for operation and maintenance of STPs resulting in their unsatisfactory performance. The annual cost of operation and maintenance of sewerage systems and STPs in a town varies from 5 to 10%, depending on the quantum of pumping (stations) and type/size of STPs. It was also observed that the revenue from STPs was negligible than the expenditure required to be incurred for proper operation and maintenance of the STPs in all cases.

5.2.4. Improper contractual conditions in case of operation and maintenance by contractors

In majority of the cases, operation of the STPs was looked after by private contractors. These contractors generally depute unqualified or less-qualified staff at site, which was also an important factor responsible for poor operation of STPs. This indicated that terms and conditions of operation contracts were not adequately framed to check this situation [9].

5.2.5. Lack of training and organizational structure

Failure of technical assistance to personnel and instructors of wastewater treatment technology courses was also a major fact responsible for poor operation and maintenance of wastewater treatment plants.

5.2.6. Lack of operation and maintenance-related documents and manuals

At present, no separate and specific operation and maintenance manual is available in the country. The manual on sewerage and sewage treatment was last revised in 1993. As per the CPCB [9] report, at most of the STPs, either operation or maintenance manual was not prepared or it was not available/used, or it was not comprehensive enough to include various steps/procedures to be followed in day-to-day operation and maintenance of the plants as per design so as to have desired quality of treated effluent. However, recently Govt. of India is preparing operation and maintenance manual with the assistance of JICA.

5.2.7. Low priority and attention given by higher-level staff

Ineffective, no motivational, and impracticable management by the administration was another reason responsible for poor performance of STPs.

5.2.8. Unqualified/less qualified or inexperienced staff and staff deployment

In some of the states, especially in UP, operation and maintenance of the STPs in some towns was done by local bodies which did not have qualified, experienced, and knowledgeable staff. Local bodies have

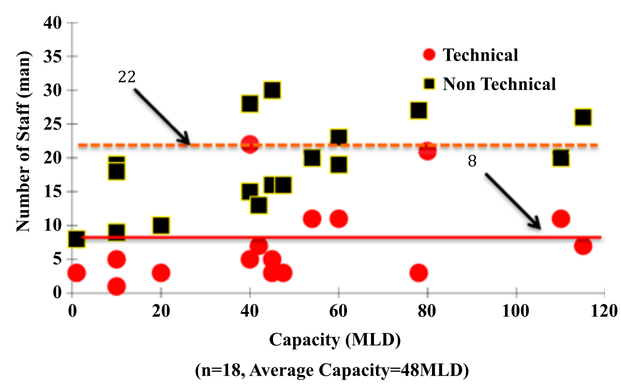

Fig. 5. Status of staff deployment for STPs. (Source: Japan International Cooperation Agency, JICA.)

Table 3
Response of chief representatives of state water supply and sewerage boards

Water supply and sewerage board	Bottlenecks in the operation and maintenance of the STPs
Punjab Water Supply and Sewerage Board	(a) Inadequate funds (b) Frequent power cuts (c) Lack of motivation for O&M staff
Andhra Pradesh (Public Health & Municipal Engineering Department)	(a) Inadequate funds (b) Insufficient manpower/staff (c) Lack of information and education on the O&M practices of sewerage works
Orissa Water Supply & Sewerage Board	(a) Funds are supplemented by the state Govt. through budget (b) Insufficient trained manpower/staff (c) Lack of information and education on the O&M practices of sewerage works (d) Regular training to grass root staff is extremely essential
Uttarakhand Peyjal Nigam	(a) Inadequate funds (b) Lack of information and education on the O&M practices of sewerage works (c) Irregular training of the O&M-related staff
Ahmadabad Municipal Corporation	(a) Insufficient manpower/staff (b) Lack of motivation for O&M-related staff (c) Lack of information and education on the O&M practices of sewerage works (d) Irregular training of the O&M-related staff

engaged private agencies on contract for operation and maintenance of these STPs but their performance was very poor [9]. According to Fig. 5, it seems likely that there is no rule for deployment. Average number of technical staff is 8 and non-technical is 22. However, the data for 18 STPs was available out of more than 170 STPs. Therefore, more data is required in order to decide the tendency of staff deployment.

Moreover, inadequate staff for O&M in most of the STPs, lack of motivation among the staff, low pay-scales, and absence of promotion policy were other issues of concern.

Apart from the above discussed concerns, several others issues were:

(1) Beneficiaries or serving population were either not charged or charged very little.
(2) Poor/improper monitoring of sewerage network.
(3) Failure of designers, manufacturers, and contractors to provide controllable and operable treatment facilities.

Chief representatives of various state water supply and sewerage boards gave their opinion (in order to assess the troubles existing in proper operation of wastewater treatment plants) on the basis of questionnaire and the response are summarized in Table 3.

6. Suggestive measures

Since operation and maintenance of interception of sewage from sewer lines and pumping stations was the weakest part in sewage management, therefore CPCB addressed these issues on priority basis [8]. A holistic approach for abatement of pollution of rivers need to be adopted as the population and industrialization are increasing and the problems further get compounded due to declining minimum flow, as a significant quantity of water is abstracted at the upstream of towns for irrigation/drinking purposes [9].

6.1. Technical solutions

6.1.1. Solution to prevent the entry of solids waste material into the treatment system

As an immediate solution to the problem, fine/mesh screens can be put at inlet in place of ordinary bar screens. Larger size of feeding pipes with more frequent cleaning can also solve this problem [9].

6.1.2. Proper sludge management

Sludge levels should be checked regularly (6–12 months) and the deposited sludge should be cleaned off from the ponds, accordingly. Also, in case of big ponds/channels, wide and long partition/baffle walls need to be provided for easy access for inspection/repairs. In UASB systems, regular checking of sludge level and its concentration profile in the reactors is essential for proper sludge withdrawal. In order to better utilize the capacity of sludge drying beds, the filtrate from the beds and sludge from the reactors/sludge drying beds need to be taken out regularly in a proper way. The STPs should have adequate digestion facilities and the useful by-product of the digestion i.e. biogas, should be collected and utilized to fulfill STPs' energy requirement. The sludge after drying in sludge drying beds should be removed frequently for utilization as manure so as to make space available for fresh sludge [8,9].

6.1.3. Prevention of corrosion

The items like railings, screens, platforms, and others should be manufactured of stainless steel. Moreover, small electric installations such as motors, flow meters, and starters used for operation of aerators, screens, grit removal mechanism, and gates should be covered with temporary sheds (PVC) to protect against rain water and dust [9].

6.1.4. Alternates of power supply

Alternative standby arrangement in the form of diesel generators along with sufficient funds for fuel needed to be provided to ensure continuous operation of STPs and desired effluent quality.

6.1.5. Well-equipped laboratory, continuous analysis, and proper reporting of water quality

There should be a well-equipped laboratory at each STP site, which should have basic facilities for analyzing pH, conductivity, BOD, COD, TSS, DO, and FC for prompt control in case of malfunctioning [9].

6.1.6. Proper monitoring of STPs for performance and operation and maintenance

Every treatment plant should be monitored for its performance on daily basis. The monitoring results should be compiled on monthly basis and submitted to the concerned state or central pollution control board or nodal office in the form of a monthly report. In case of any problem in operation and maintenance of STPs or its performance, the nodal officer should discuss it with in-charge of the treatment plant and suggest remedial measures. There should be a nodal office in each of the states to monitor and to review the operation and maintenance works of all the STPs and pumping stations. There should be a separate cell in the state pollution control board for monitoring management of STPs. This cell should constantly interact with the nodal officer on operation and maintenance of the STPs and other related issues. The cell should also conduct vigilance monitoring of the STPs at least once in a month. The monitoring should include checking of records of STPs and their functioning along with collection of samples and analysis of BOD, COD, and SS to evaluate their performance and compliance of standards. In case of unsatisfactory results, the cell should issue notice to the nodal officer under Water Act, 1974 [8].

An annual report on the performance of STPs and operation and maintenance record should be prepared state wise and submitted to the State Boards, CPCB, and NRCD, highlighting all the important points including deficiencies and annual expenditure. It may be useful to involve local communities in monitoring the functioning of assets created under NRCD. Regular monitoring of all the STPs for their performance evaluation at central level (CPCB) twice a year through independent sampling/testing of wastewater needs to be carried out for bringing improvement in operation and maintenance of STPs and get the desired quality of treated effluent [8]. Proper analysis of data in terms of correlation between various parameters such as pH, BOD, COD, and SS with process operational parameters should be carried out. Online monitoring of DO, mixed liquor suspended solids, and sludge volume index should be practiced in routine.

6.1.7. Optimum utilization of treatment capacity

The new STPs should be located close to sewage generating areas to avoid long transportation/conveyance. In order to avoid under-utilization of STPs due to lack of sewerage system in their catchments areas, proper planning of collection system shall be done [4]. At the same time, overloading should also be avoided and gap between wastewater generations should also be minimized by in-time augmentation of treatment facilities so that untreated wastewater should not find its way to surface waters.

6.1.8. Decentralized treatment for new settlements

Decentralized approach in management of sewage needs to be encouraged. Cooperative group housing societies, multi-storied housing complexes, big hotels, etc. are required to set up appropriate on-site waste water treatment facilities for recycling of wastewater for gardening and other nondomestic uses to the extent feasible [6].

6.1.9. Proper biogas utilization

It is understood that projects based on generation of electric power from biogas, which is being produced as a result of digestion of sludge in STPs, are eligible for clean development mechanism (CDM under the Kyoto Protocol), as it will help in reducing and stabilizing the emissions due to methane, which is a green house gas. Based on the potential of biogas/power generation from STPs, expenditure on operation and maintenance can be offset by earning "carbon credits" on recurring basis. Therefore, it is recommended that a feasibility study should be performed for taking up a CDM project as it can be a perennial source of revenue generation [8]. Furthermore, anaerobic digesters should be operated in mesophilic mode (35˚C) in order to maximize gas production.

6.2. Administrative solution

6.2.1. Concept of Built Own and Operate scheme

Concept for future policy in India based on conversion of water industry as a profit making industry in the private sector monitored by the public and treated water of desired quality to be purchased by the state government.

Tirupur, the textile city of India, faced problems associated with shortage of water supply and wastewater treatment. To address the acute shortage of water supply and to facilitate wastewater treatment, a project was started in the year 2002 through Public–Private Partnership (PPP). It was the first of its kind in the water sector in India. The project proved to be a great success. Dynamic pricing system for different service users takes care of social issues and at the same time ensures financial viability of a project in the long run. On the other hand wastewater treatment facility would enhance environmental quality in and around Tirupur. This project has improved living standards of about 800,000 residents including 80,000 slum inhabitants in Tirupur town and it surrounding areas. More than 600 textile firms in and around Tirupur are relieved of tanker dependency and receive water from the project on continuous basis. The project also increased the supply of water to domestic consumers as it provides 185 million liters of potable water per day. It also provided the town with its first sewerage system. Moreover, cost sanitation for slum areas has been built as part of the project [14].

India's wastewater treatment market is positively expanding with PPP opportunities. More than 25 wastewater PPP contracts are at various stages of tendering, with at least six expected to be awarded this year, according to global water intelligence data. Under a contract awarded to Hyderabad-based Sai Enviro Engineers last year by the Greater Visakapatnam Municipal Corporation (GVMC), Sai will construct a 63,000 m^3/d WWTP under a 25-year DBFOT contract, and will take responsibility for identifying and billing industrial customers for the sale of treated effluent. For every cubic meter of sewage received, Sai will pay GVMC a royalty of INR 2.25 ($0.05), which will be subject to a 5% escalation clause every year. Sai is scheduled to start payments to the utility in 2014 once the construction work is complete [15].

6.2.2. Improvement in the technical understanding of STPs personnel

Proper training program needs to be planned and implemented at every level including engineering-level staff/officers, managers/supervisors, chemists, operators, and cleaning staff [9].

6.2.3. Legislation and framing of manpower performance evaluation regulations

Suitable legislation should be enacted for the creation of separate cadre of managers and technocrats for environmental protection services including wastewater treatment, disposal, and reuse. Subsequently, stringent regulations should be created for the accountability of manpower thus created specifically. Procedures should be laid down for daily record keeping of regular monitoring data, technical evaluation and recording of its minutes, feedback to superior technical, managerial, and administrative staff. As of now, the chief executive are mostly drawn from administrative cadre who are often posted for a brief tenure within which they are unable to comprehend, organize, and implement any meaningful initiative [8].

6.2.4. Imperative requisite of operation and maintenance manual

Operation and maintenance manual is an essential prerequisite to uphold the good operating conditions at STPs' site and achieve desired results. The purpose of O&M manual is to provide STPs' operators with the proper understanding of recommended operating techniques and procedures, and the references necessary to efficiently operate and maintain their facilities. (Giordano and Petta, EMwater Learning Course). Operation and maintenance manual should spell out the procedure of reporting and recording of all the data/parameters including the quality of wastewater in various units of the plants in a user-friendly manner. Furthermore, the manual should offer the methods to troubleshoot the problems associated with electrical and mechanical facilities. The recommended operational guidelines should be followed strictly. The operation and maintenance manual should be available to each staff and shall be maintained at the treatment plant at all times.

6.2.5. Proper record keeping

It is important to prepare daily status report preferably using information and communication technology so as to record occurrence of problems in respect of running, functioning, repair, maintenance, etc. of all the equipment, units, facilities, etc. installed at each STP, so that the problems, if any, can be solved as and when applicable. This will also serve as feedback for future planning and execution as well as tool for monitoring the performance of STPs at a higher level [9].

6.2.6. Financial support

In case of construction of STPs with central funding under NRCP by Ministry of Environment and Forests (MoEF), the operation and maintenance cost is to be borne by the respective state governments. This arrangement is the main stumbling block in the functioning of these facilities and provisions required to be created for uninterrupted availability of funds. If the amount for operation and maintenance of STPs cannot be provided on regular basis by the state governments, the matter needs to be looked into at the highest level, whether further new works should be taken up under the program [9]. Separate provision of funds for operation and maintenance should be earmarked and sufficient autonomy be given to the staff for remedial measures and smooth functioning of STPs.

The innovative program like PRODES initiated by the Brazilian federal government to finance wastewater treatment plants while providing financial incentives to properly operate and maintain the plants can be good idea in order to improve the water quality status of surface water bodies. The program, known under its Brazilian acronym as PRODES (*Programa Despoluição de Bacias Hidrográficas* or Basin Restoration Program), was introduced in 2001. Under it, the federal government pays utilities (mostly public state or municipal water and sanitation companies) for treating wastewater based on certified outputs. Up to half the investment costs for wastewater treatment plants are eligible to be reimbursed over three to seven years, provided that the quality of the wastewater discharged meets the norms. If the norms are not met in one trimester, a warning is issued. If they are not met in the following trimester, the payment is suspended. If the norms are still not met in the next trimester, the service provider is excluded from the program. This provides strong incentives to properly operate and maintain plants. In short, the program does not fund promises, but results. Between 2001 and 2007, PRODES leveraged investments of US$ 290 m with subsidies and subsidy commitments of US$ 94 m, financing 41 wastewater treatment plants in 32 cities serving 2 million people. The program had a portfolio of 52 other projects to be financed serving 5.7 million people [16].

6.2.7. Avoid frequent transfer of STPs' personnel

The operation and maintenance staff/engineers should be deputed at a plant for sufficient number of years and their experience and knowhow transferred to their successors in a planned and systematic manner.

6.2.8. Stringent regulations for outsource agencies

In case of operation and maintenance is outsourced on contract basis through private agencies, the agreement should be such that the same contractor may continue after initial period of one year, subject to its satisfactory performance. As a matter of fact, operation and maintenance of an STP should be included in the main construction contract for a period of at least 5–10 years. The proposed arrangement is found to be giving good results in case of some of the STPs, namely at Chennai, Panji, and Nasik where this practice has been adopted [9].

6.2.9. Training of STPs' personnel

Two 5-d basic training courses on "Operation and Maintenance of Sewerage Works" for junior- and senior-level engineers was organized by Department of Civil Engineering and Continuing Education Center of IIT Roorkee in December, 2010. The main objective of the training program was to impart basic knowledge and essential skills in daily O&M of the STPs, including troubleshooting of Electrical, Civil, and Mechanical facilities. The medium of instruction was Hindi/English language.

The core part of the course was related to the basic understanding of different modes of sewage treatment (aerobic, anaerobic, and facultative), field visits, and exercises on pumping station, oxidation pond, ASP, and UASB process plants operating nearby Roorkee city. Emphasis was placed on the use of on-site water quality monitoring for process control, and basics of electrical and mechanical facilities of STPs.

Totally, 33 participants nominated by the UP Jal Nigam, Haryana PWD, Delhi Jal Board, Uttarakhand Pay Jal Sansadhan Vikas Evam Nirman Nigam, Punjab Water Supply and Sewerage Board, and Rajasthan Water Supply and Sewerage Board have attended the course. The lectures were delivered by several wastewater treatment experts mainly from IIT Roorkee, Aligarh Muslim University, Private Consultants & Engineers (Sapient Consultant, Ahmadabad and Chavare Engineering, Mumbai), Central Pollution Control Board, Delhi, etc. Laboratory and field visit exercises were supported by research fellows/scholars and Lab & Field staff.

The training was divided into 22 curriculums involving opening and closing sessions, lectures, field exercises, and a laboratory exercise. On the first day prior to the commencement of the training, the opening session involves an examination on the O&M of STP based on a question paper consisting of 60 multiple choice questions. The main objective of this examination is to assess the ability of participants in the field of sewerage works. Participants obtained average marks of 26 out of 60 which amounted to 43% (range: 3–28 ± 7). Thereafter, the lectures/practical/field visits were started.

The final test similar to the first was conducted on the last day in order to check the enhancement of knowledge of the participants during the 5 d of intensive training. The participants did well in the exam as the average obtained marks increased to 41 out of 60 which amounted to 68% (range: 12–40 ± 6). In addition, the feedback on the overall training was collected from the trainee. Prize is distributed to the outstanding participant based on the highest marks obtained from the post-evaluation examination.

Therefore, on the backdrop of above experience/ training of operation and maintenance staff should be planned and implemented properly. Training aspects may include the following:

(1) Assessment of Trainees and Training Institutions. Certify O&M training institutions.
(2) Multi-tier Training courses.
    (a) Managerial/Engineering Staff.
        (i) Module advanced course: 3-d training module on overview of sewage works and management for senior level engineers.
        (ii) Intermediate Course: 5-d training for middle level engineers.
        (iii) Basic course: 5-d training of junior level engineers covering Principles of treatment, water quality analysis, operation and maintenance, troubleshooting, field visits.
    (b) Operators.
        (i) Basic course: 5-d training of operators on details of STP and related facilities.
        (ii) Intermediate course: 3-d training module on operation and maintenance, and troubleshooting.

6.2.10. Pollution charges: raise revenues and recover costs

Water taxes or pollution charges are an important complement to technical, regulatory, and institutional tools to achieve a sustainable and efficient management of wastewater. The main objectives are to raise revenue to help finance wastewater services, to provide incentives to use water efficiently and carefully, to provide disincentives for the anti-social release of polluted wastewater, to make the polluter pay for the environmental damage done, and to raise awareness on the environmental and societal costs of water use and wastewater discharge [17].

The most common economic tool used in wastewater management is the "polluter pays principle" which includes the pricing of wastewater services and imposing of charges for wastewater discharge into the environment [17]. Pollution charges are often collected by local or national governments on the discharge of water into the environment, i.e. mostly into surface waters. They are usually imposed on operators of treatment plants and industrial dischargers. The charges are generally calculated based on actual quantities and/or pollution loads of the effluent. For treatment plants, the pollution charge is often calculated based on the number of inhabitants served by the plant. Further on, charges are calculated based on specific chemical, biological, and biochemical parameters determining the pollution load, such as content of phosphorus, nitrogen, biological oxygen demand, and heavy metals. Pollution charges are, therefore, of special interests for industries who discharge wastewater of high pollution loads into sewer systems or directly into nature. High pollution charges will encourage reduction in effluents produced or in-house treatment by industry [17].

6.2.10.1. Fees for wastewater services/user charges. Fees or user charges are directly charged to users of wastewater services upon connection to and discharge of wastewater into the sewerage system. For households, volume of discharged wastewater is directly related to the consumption of potable water. Consequently, the fee is usually collected as a surcharge on the water consumption bill. Different regulations could be considered if large amounts of potable water are used for other purposes like irrigating the garden [17].

6.2.10.2. Awareness raising and economic efficiency. Economic tools can also be introduced in order to raise awareness on the relationship between water use and resulting environmental and/or social impacts. In order to attain economic efficiency, prices for wastewater discharge would have to reflect to consumers all the financial, environmental, and other costs that their decision to use water (and produce wastewater) imposes on the rest of the system and the economy [17].

Realizing the loss of credibility of municipal authorities in India the situation is so grim that the serving populations do not rely on the performance of these agencies and therefore any legislative initiative regarding user charges render the political class unpopular.

6.2.10.3. Other points.

(1) Planned/preventive inspection and maintenance.
(2) Multiplicity of organizations should be reduced to minimize fragmented responsibilities.
(3) Inter- and intra-departmental coordination of state/central organizations/agencies.
(4) Promotion of by-laws and regulations to make them effective.
(5) Creation of customer complaints and redressal systems.
(6) Improvement in credibility of urban local bodies (ULBs)/implementation agencies. Devolution of functions to ULBs as per 12th schedule of Section 74 of Indian Constitution is implemented.
(7) Introduction of adequate user charge/sewage cess to contained wastewater generation rates and proper mechanism shall be required for revenue collection.
(8) Community engagement ensured.
(9) PPP and Public Sector Partnership need to be extended.

As mentioned in Section 6.2, the requisite changes need a holistic approach for abatement of pollution in general and water or river pollution out of sewage treatment in particular. The phenomenon of water pollution in Europe and USA is almost under strict surveillance through regulations, but the scenario is grim and uncertain in India, in view of social, political, and legal infirmities and legislative inadequacies. In Indian context with respect to its constitution, the issue of water resource management is in the Union list but all other actions which contribute to rivers belong to concurrent list, therefore a unified national policy with some hard decisions has to be taken jointly by the respective states and central government and their regulatory authorities on stringent legislations, policies, and maintenance of standards as suggested in this paper in the near future.

Just to substantiate our point, the Japanese policy deserves citation. The policy of enactment of law for the installation of onsite wastewater treatment in Japan called Johkasou paid rich dividends as it has reduced load on central municipal waste treatment facilities and also reduced sludge by 35% resulting in an observed growth yield of only 0.18. It is a combination of "Jouka" means purification and "Sou" means tub or tank. The success of Johkasou owe to the provision of a national subsidy and bond issuance to home owners, which increased from 100 million yen in 1987 to 21 billion yen in 2000. The discrepancy out of multiplicity of agency particularly absence of incentives to the O&M staff could only be addressed by the proper legislative initiatives as suggested above. Unfortunately, the ground reality is that people on punishment postings are deployed of water and wastewater treatment facilities.

The implementation of the O&M requirements and design for good O&M discussed in Section 6 lies with the creation of stringent policies by virtue of legislation in our federal structure, which is already discussed at many places in the paper. In addition, authors would like to suggest that proper fund allocation for O&M, water quality analysis, well-furnished laboratory, availability of diesel for power generating sets during power cuts, beautification and esthetics, and also interconnection of various unit processes can also significantly improve the O&M.

7. Conclusion

The present efforts revealed that the treatment of sewage and operation and maintenance of sewerage facilities have not received the appropriate attention by the wastewater treatment authorities/central and state government/environmental protection agencies. This outlook worsened the water environment situation in the country and ultimately led to depletion of surface water resources. Therefore, in order to reduce the pollution load and restore the water quality of rivers, build-up of sewerage infrastructure, appropriate operation and maintenance of STPs in order to utilize the their full capacity, skilled manpower at STP site, operation and maintenance-related documents/manual and reuse of treated effluent for potable and non-potables purposes are the major issues that required the top priority by water and wastewater treatment authorities. In Indian context with respect to its constitution, the issue of water resource management is in the Union list but all other actions which contribute to rivers belong to concurrent list; therefore, a unified national policy with some hard decisions has to be taken jointly by the respective states and central government and their regulatory authorities on stringent legislations, policies, and maintenance of standards.

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