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Efficiency evaluation of sewage treatment plants with different technologies in Delhi (India)

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Abstract Physical, chemical and microbiological efficiencies of Sewage Treatment Plants (STPs) located in Delhi's watershed in context of different treatment technologies employed in these plants have been determined. There were in all seventeen STPs treating domestic wastewater which were studied over a period of 12 months. These STPs were based on Conventional Activated sludge process (ASP), Extended aeration (Ex. Aeration), physical, chemical and biological removal treatment (BIOFORE) and oxidation pond treatment process. Results suggests that except "Mehrauli" STP which was based on Extended aeration process and "Oxidation pond", effluents from all other STPs exceeded FC standard of 10^3 MPN/100 ml for unrestricted irrigation criteria set by National river conservation directorate (NRCD). Actual integrated efficiency (IE_a) of each STP was evaluated and compared with the standard integrated efficiency (IE_s) based upon physical, biological and microbiological removal efficiencies depending upon influent sewage characteristics. The best results were obtained for STPs employing extended aeration, BIOFORE and oxidation pond treatment process thus can be safely used for irrigation purposes.

Keywords Wastewater treatment plants · Efficiency · Activated sludge process · Fecal coliform · Fecal streptococcus

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Introduction

River Yamuna, which drains an area of approximately 1483 km^2, is the main watercourse through Delhi. The river has instigated deterioration in its water quality through the course of time. To improve the quality of river water, government of Delhi in 1993, started Yamuna action plan (YAP 2006a), under which number of Sewage Treatment Plants (STPs), aerobic as well as anaerobic were upgraded and constructed.

Design of STPs was based upon TSS (Total suspended solids) and BOD_5 (Biochemical oxygen demand) removal, whereas the removal of Fecal Coliforms (FC) and pathogens was not considered. Based upon these parameters sixteen up-flow anaerobic sludge blanket reactors (UASBR) were constructed along river Yamuna. The cost of construction, operation and maintenance cost, low energy consumptions were the additional main advantage. But later it was realized that these plants produced very poor quality of effluent having high level of BOD_5, COD and FC values (Sato et al. 2006).

Simultaneously under same plan new STPs were constructed and the existing STPs were upgraded inside Delhi watershed to check the river water quality. These plants employed aerobic process for sewage treatment. The efficiency of these STPs in terms of indicator organism removal is still unknown.

FCs and enteric viruses are present in high concentrations in raw wastewater. For example, typical abundance of total and FC in raw sewage is 10^7–10^9 and 10^6–10^8 MPN/100 ml respectively, (Garcia-Amrisen and Servais 2006). Therefore effluent from STPs also carries high concentration of FC, Fecal Streptococcus (FS) including pathogens which are major cause of epidemic outbreaks in downstream population. It has been reported that the conventional treatment methods, which do not include disinfection, reduce FC levels by 1–3 orders of magnitude (Koivunen et al. 2003).

So far efficiency of STPs was based on physical and chemical removal, (Gray 1983; Andreadakis et al. 2003; Colmenarejo et al. 2006; Maeng et al. 2006) with scanty data available on biological removal. The increasing demography and growing population in Delhi city has led to water shortage, thus more and more reclaimed water is being used for irrigation purposes. Consequently, the National River Conservation Directorate (NRCD) of India's Ministry of Environment and Forests established effluent standard parameters with priority placed in order of (1) the removal of organic matter and suspended solids, (2) removal of pathogenic bacteria, and (3) removal of nutrients (Khan et al. 2001; Foundation for Greentech Environmental Systems 2004).

Therefore keeping in view the interest of public health, National river conservation directorate (NRCD 2005) has reviewed the water and wastewater standards with special reference to the levels of microbial load and made the standards in treated wastewater stricter. The revised microbial and BOD_5 discharge standards, when effluent is discharged to surface water body or is used for irrigation purposes are 10^3 MPN/100 ml and 30 mg/l respectively, 10^4 MPN/100 ml being maximum permissible limit for FC.

In present study efficiencies of STPs in Delhi watershed was evaluated based on the concept of integrated efficiency (IE). Physical, chemical and microbiological parameters were studied to determine integrated efficiency of each STP. This study will help in suggesting measures to improve the overall efficiency of STPs, and selection and implementation of tertiary treatment to effluent, so as to meet the effluent discharge and reuse criteria set by NRCD.

Materials and methods

Characteristics of Sewage Treatment Plants evaluated

Delhi watershed is divided into five major zones (Municipal Corporation Delhi). Depending upon the population, each zone is served by number of STPs (Table 1). Due to poor sewerage network and unavailability of raw sewage most of STPs are under utilized. Figure 1 presents the description of unit process of different treatment technologies employed by STPs in Delhi city. The details of actual sewage treated and Hydraulic Retention Time (HRT) for all STPs are presented in Table 2. The evaluation of STPs was carried out for a period of 12 months, i.e. from November 2005 to November 2006. Influent sewage samples and effluent samples were collected from all STPs. The influent sewage characteristics varied, depending upon the land use characteristics and the type of population served.

Sampling and analysis

Influent and effluent samples from STPs were preserved at 4°C during transportation to laboratory. They were immediately analyzed for FC, FS, COD (Total and Dissolved), BOD_5, pH and turbidity. All analyses were carried out following the standard methods (APHA 1998).

FC and FS were enumerated using most probable number method (MPN). For the enumeration of FC and FS, samples were suitably diluted using sterile deionized water before inoculation in appropriate

Table 1 Zone-wise distribution of sewage treatment plants

Zone	STPs	Population	Wastewater generated(MLD)	Design Treatment Capacity (MLD)
Shahadra	Yamuna Vihar Kondli	2,798,000	543.8	295.1
Rithala-Rohini	Narela Rithala Rohini	2,226,333	466.0	476.7
Okhla	Vasant Kunj I and II Mehrauli Okhla Sen nursing home Delhi Gate	3,499,642	850.8	701.9
Keshopur	Papankallan Nazafgarh Keshopur Nilothi	2,204,864	484.3	622
Coronation pillar	Coronation pillar I,II,III Oxidation pond Timarpur	1,029,400	201.8	208.8

medium. Enumeration of FC was carried out by direct inoculation technique, using A1 broth (Difco) as per Standard Methods. FS were recovered on Azide dextrose broth (HiMedia) at an incubation temperature of 35±0.5°C for 48 h. All positive tubes were subjected to the confirmation test by using Pfizer selective enterococcus Agar (HiMedia).

During the evaluation period, four influent and effluent samples were analyzed from each plant thus giving total 136 samples.

Results and discussion

Influent sewage characteristics

Table 3 lists the influent sewage characteristics of the STPs that were investigated during this study. COD varied from 172 mg/l at the “Nazafgarh”, to 672 mg/l at the “Delhi Gate”, BOD_5 from 120 mg/l at “Nazafgarh”, to 350 mg/l at “Delhi Gate” and turbidity from 50 NTU at “Coronation Pillar” to 521 NTU at “Vasant Kunj”. Maximum FC and FS levels were observed at “Kondli” (7.90 log order) and at “Delhi Gate” (7.14 log order) respectively. Minimum FC and FS levels were found at “Oxidation Pond” (5.54 log order) and at “Coronation Pillar” (4.10 log order) respectively.

At “Nazafgarh” STP because of irregular power supply wastewater stays in sump for longer time as a result low COD and BOD_5 values were observed in the influent samples due the development of anaerobic conditions. “Delhi Gate” STP receives wastewater through open drain from industrial areas, contributing to high COD value.

“Vasant Kunj I” and “Vasant Kunj II” STP receives domestic sewage from residential area therefore was observed to have high turbidity similar to raw domestic sewage, whereas “Coronation Pillar” receives industrial and septic, dark colored sewage contributing to low turbidity. “Kondli” STP located on Trans-Yamuna area, receives sewage through open drains from resettlement colonies and slums. Both resettlement colonies and slums are not served by sewerage system and as a result 3 million people defecate in open everyday thereby contributing to high levels of FC in storm drains (YAP 2006b).

FC/FS ratio less than 1 at “Papankallan”, “Delhi Gate”, “Sen Nursing Home” and “Oxidation pond” supports the fact these STPs receive large quantities of industrial as well as septic sewage from open storm drains that effects the survival of indicator organism. Fecal coliforms being gram negative bacteria are reported to have low survival time as compared to fecal streptococcus which has ability to survive under harsh environment thus responsible for low FC/FS ratio. Low FC and FS levels at coronation pillar receiving septic and stale sewage suggests that prolonged exposure of FC and FS to polluted effluents affected their survival by almost similar rate thereby maintaining the high FC/FS ratio.

Physical chemical and microbiological removal efficiency

Table 4 presents the effluent sewage characteristics of STPs with different treatment processes. Physical

Fig. 1 Unit process description and sampling collection points for STPs **a** conventional activated sludge process, **b** high rate aeration process, **c** Trickling filter process, **d** BIOFORE, **e** extended aeration process and **f** Oxidation pond

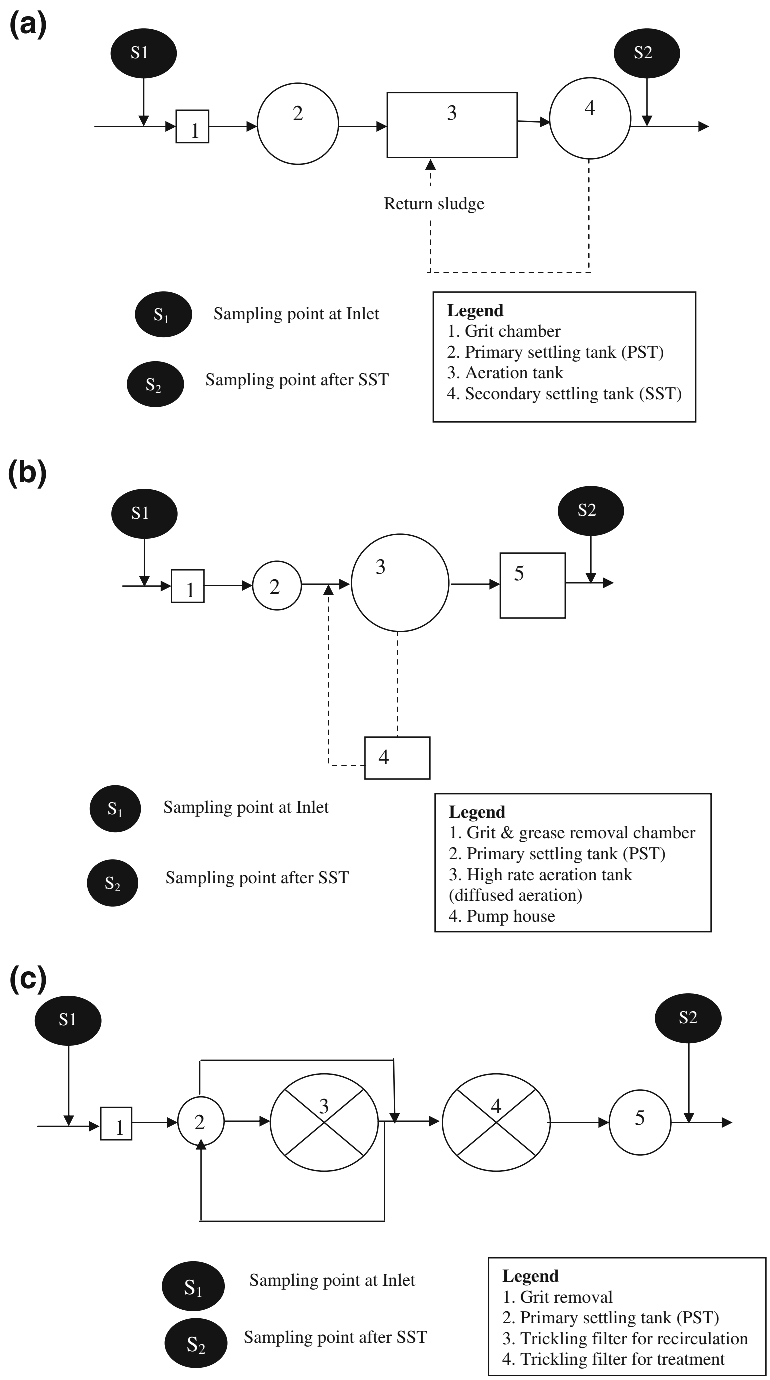
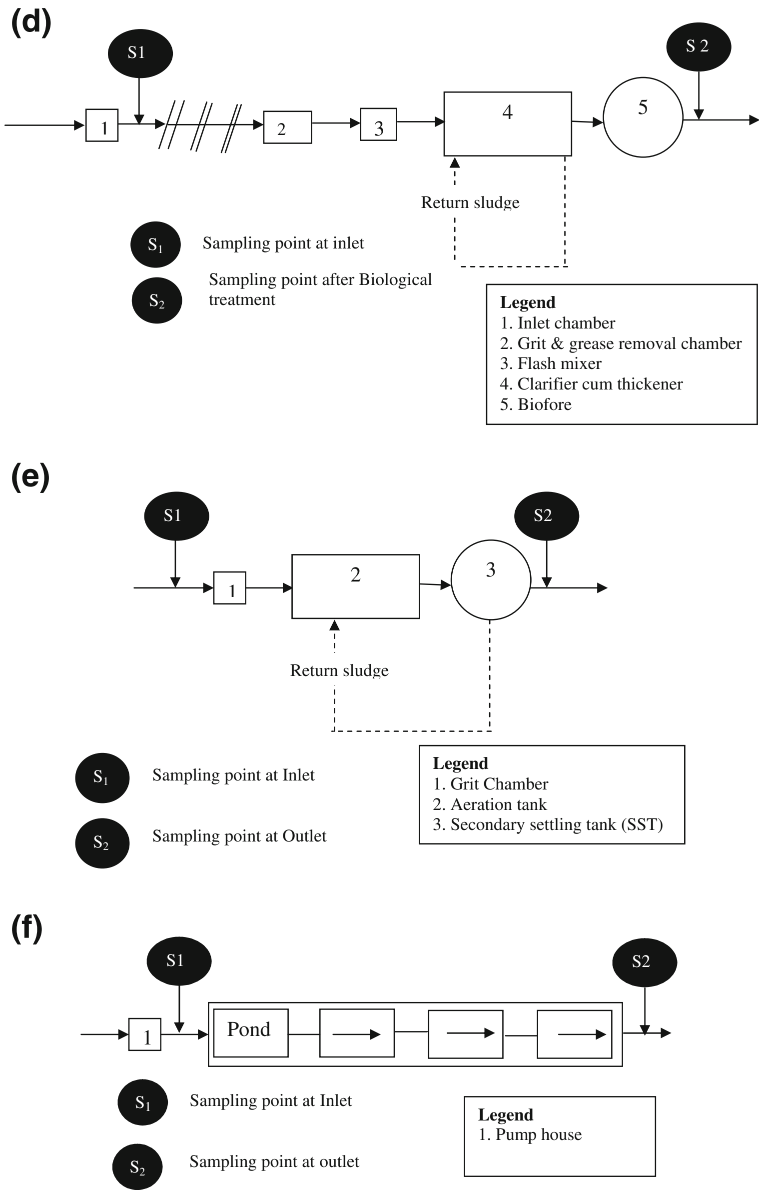


Fig. 1 (continued)



removal efficiency of an STP could be defined in terms of important physical parameter like turbidity. Turbidity less than two NTU has already been reported as a criterion for irrigation purposes (Maeng et al. 2006; USEPA 2004). Chemical removal efficiency of the STPs could be defined on the basis of major chemical, and biochemical parameters, i.e., COD and BOD_5. All STPs in Delhi are designed to produce effluents with BOD_5 below 30 mg/l and the efficiency of plants is generally measured in terms of removal of organic matter (CPHEEO 1993). Figures 2 and 3 present the physical and chemical characteristics of influent and effluent from different STPs.

Turbidity removal efficiencies of STPs based on Ex. aeration process ranged between 80% at “Nazafgarh” and 99% at “Vasant Kunj I”. STPs employing conventional ASP, turbidity removal efficiency ranged from 85% at “Keshopur” to 96% at “Kondli” (Table 5). STPs with BIOFORE technology, 97% turbidity removal of was observed at “Sen

Table 2 Sewage treatment plant characteristics

Sewage treatment plants	Technology	Source	Design treatment capacity (MLD)[a]	Utilization (%)	HRT (h)[b]
Kondli	ASP	Open storm drain	204.3	30.0	32.0
Yamuna Vihar	ASP	Open storm drain	90.8	30.0	32.0
Rithala I	ASP	Open storm drain + Sewerage system	181.6	57.5	16.7
Coronation pillar II & III	ASP	Open storm drain	136.2	50.0	19.2
Okhla	ASP	Sewerage system	635.6	75.0	12.8
Nilothi	ASP	Open storm drain	181.6	12.5	76.8
Keshopur	ASP	Open storm drain + Sewerage system	326.8	50.0	19.2
Papankallan	ASP	Open drain	90.8	45.0	21.3
Vasant Kunj I	Ex. Aeration	Sewerage system	13.6	66.7	36.6
Vasant Kunj II	Ex. Aeration	Sewerage system	9.9	54.5	44.7
Mehrauli	Ex. Aeration	Open storm drain	22.7	34.0	71.8
Nazafgarh	Ex. Aeration	Open storm drain	22.7	24.0	101.7
Delhi gate	BIOFORE	Open storm drain	9.9	100.0	8.0
Sen nursing home	BIOFORE	Open storm drain	9.9	100.0	8.0
Coronation pillar I	Trickling Filtration	Open storm drain	45.4	40.0	8.8
Rithala II	ASP + (High rate aeration process)	Open storm drain + Sewerage system	181.6	66.3	11.4
Oxidation pond Timarpur	Oxidation Pond	Open storm drain	27.2	33.3	433.9

[a] Million Liters per day

[b] Hours

Nursing home" whereas "Rithala II" STP based on high rate aeration process exhibited low turbidity removal of 54.14%. At "Oxidation Pond", turbidity removal of 98.12% was observed, which was lower as compared to the turbidity removal observed at "Vasant Kunj I" STP.

STPs based on Ex. aeration process, maximum and minimum BOD_5 removal efficiencies of 84% and 99% were observed at "Nazafgarh" and "Vasant Kunj I" respectively. For STPs employing conventional ASP, BOD_5 removal efficiencies varied from 77% at "Coronation Pillar II and III" to 95% at "Yamuna Vihar" respectively. STPs employing BIOFORE technology, high BOD_5 removal efficiencies were observed (Table 5). Greater removal could be attributed to the chemical treatment employed at "Delhi Gate" and "Sen Nursing home" (Fig. 3). At "Rithala II" STP lowest BOD_5 removal of 71% was observed. The "Oxidation Pond" STP exhibited good BOD_5 removal efficiency of 96%.

Microbiological standards for effluents from the STPs are recent phenomena. India is one of the World's first countries, which has stipulated microbiological standards for effluents from STPs. Microbiological quality is assessed on the basis of FC count from the effluents. Figure 4 shows the FC and FS levels in influent sewage and effluent from the different STPs evaluated.

Mehrauli" STP showed the highest FC (99.98%) and FS (99.92%) removal efficiencies. "Nilothi" STP based on conventional ASP also exhibited high FC and FS removal efficiency of 99.87 and 98.07% respectively as compared to other STPs based on same technology (Table 5). STPs based on BIOFORE technology exhibited microbial removal efficiency greater than 98% for both FC and FS. "Oxidation Pond" had removal efficiency greater than 99.9% for both FC and FS. Rithala II STP showed lowest FC removal efficiency of 82%.

Factors affecting quality of effluent produced from STPs

Factors such as aeration, percentage flow treated, protozoan predation etc. affects the overall efficiency of STPs. In the present study STPs based on

Table 3 Characteristics of raw sewage

STPs	pH	Turbidity (NTU)	BOD (mg/l)	COD (mg/l)	TKN (mg/l)	FC Log (MPN/100 ml)	FS Log (MPN/100 ml)
Kondli	6.8±0.2	426±175	250	300±132	64±69	7.90±0.56	6.62±0.29
Yamuna Vihar	6.7±0.1	231±53	225±49	285±95		6.72±0.83	6.05±0.57
Rithala I	7.1±0.2	308±190	329±94	464±168	46±1	6.00±0.15	4.20±0.18
Coronation pillar II and III	6.6±0.0	50±2	264	320±40	46±2	6.00±0.15	4.17±0.18
Okhla	7.3±0.1	281±41	250	356±49	51±5	6.91±0.39	6.44±0.205
Nilothi	6.9±0.1	419±99	230±77	363±65	34±1	7.00±0.69	6.33±0.19
Keshopur	6.9±0.2	337±30	307±131	496±138	67±11	7.18±0.37	6.81±0.32
Papankallan	7.0±0.1	401±75	316±127	505±145	56±5	6.32±0.65	6.35±0.15
Vasant Kunj I	7.2±0.1	646±160	450	632±107	54±7	7.20±0.27	7.05±0.57
Vasant Kunj II	7.2±0.1	646±160	450	632±107	54±7	7.20±0.27	7.05±0.57
Mehrauli	7.5±0.0	226±98	322±102	533±124	79±16	7.10±0.19	5.99±.309
Nazafgarh	7.3±0.2	120±56	119±32	172±49	44±16	6.35±0.39	5.70±0.51
Delhi gate	7.3±0.2	304±89	350	666±98	64±19	6.97±0.28	7.14±0.43
Sen nursing home	7.3±0.1	291±53	317	552±163	58±11	6.87±0.39	6.85±0.39
Coronation pillar I	6.6±0.0	50±2	264	320±40	46±2	6.00±0.15	4.17±0.18
Rithala II	7.1±0.2	308±190	329±94	464±168	46±1	6.00±0.15	4.20±0.18
Oxidation pond Timarpur	6.4±0.2	252±86	183±33	320±124	42±23	5.54±0.28	5.94±0.35

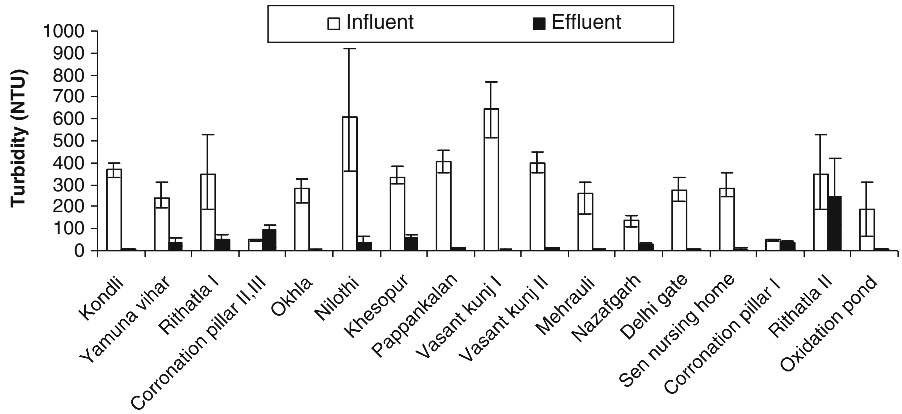
Ex. aeration, Oxidation pond and BIOFORE process were the overall best performers.

"Vasant Kunj I" STP receives domestic sewage form area completely served by sewerage system thereby making whole treatment process more efficient. High turbidity removal at "Vasant Kunj I" is attributed to good settling characteristics of flocs. Due to technical problems "Vasant Kunj II" STP was

Table 4 Characteristics of effluent

STPs	pH	Turbidity (NTU)	BOD (mg/l)	COD (mg/l)	TKN (mg/l)	FC Log (MPN/100 ml)	FS Log (MPN/100 ml)
Kondli	7.1±0.3	6±00	9	24±1	3±1	4.2±0.00	3.89±0.00
Yamuna Vihar	7.4±0.1	39±16	10	64±8		5.10±0.70	4.7±1.0
Rithala I	7.7±0.2	51±16	72±4	112±24	37±11	5.36±0.94	5.39±0.10
Coronation pillar II and III	6.8±0.0	91±31	40	48±6	20±10	4.52±0.23	2.65±0.91
Okhla	7.5±0.1	5±2	25	25±6	19±1	5.27±0.51	4.50±0.27
Nilothi	7.5±0.2	33±27	32±5	40±8	32±5	4.20±0.82	4.24±0.84
Keshopur	7.4±0.1	60±13	63±18	170±68	37±8	5.19±1.3	5.94±0.61
Papankallan	7.5±0.1	11±0	40±10	48±10	17±3	5.40±0.11	5.24±0.36
Vasant Kunj I	7.5±0.3	3±1	3±1	28±8	18±3	4.6±0.20	4.11±0.72
Vasant Kunj II	7.5±0.2	12±5	3±1	42±24	31±5	5.8±0.78	5.28±0.21
Mehrauli	7.5±0.0	3±1	5±1	32±20	8±2	3.02±0.5	2.92±0.202
Nazafgarh	8.3±0.3	31±2	37±7	72±19	25±7	3.88±0.72	3.41±1.25
Delhi gate	7.2±0.1	4±2	2	21±12	19±4	4.95±0.92	4.71±0.71
Sen nursing home	7.1±0.2	7±2	17	53±9	20±6	4.49±0.36	4.19±0.14
Coronation pillar I	7.2±0.2	14±10	18	40±5	22±8	4.85±0.01	2.61±0.20
Rithala II	7.1±0.1	226±50	90±18	146±20	33±10	5.64±1.42	5.53±0.76
Oxidation pond Timarpur	7.7±0.1	5±1	6±2	21±9	5±2	2.08±0.20	1.86±0.73

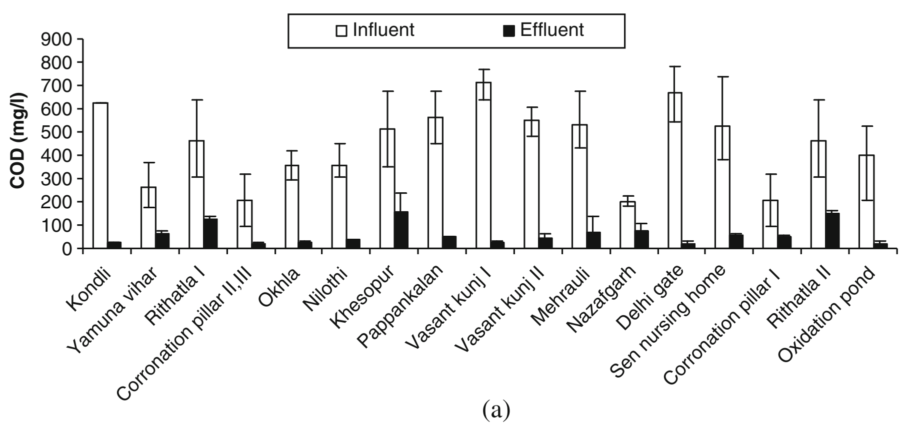
Fig. 2 Turbidity of influent sewage and effluent from different STPs



operated with diffuse aeration system (Aeration tank) as a result, low removal efficiencies was observed as compared to "Vasant Kunj I" and "Mehrauli" STP employing Ex. Aeration treatment technology (Table 5). Total 96% turbidity removal efficiency observed at "Kondli" STP was because of extended HRT. Low physical chemical and biological removal efficiency at "Nazafgarh" STP was observed due to improper aeration in the reactor, which produced poor quality flocs thereby resulting in high BOD_5 in the effluent.

In STPs employing BIOFORE technology, high turbidity and BOD_5 removal efficiencies were observed (Table 5). Greater removal could be attributed to the coagulation and flocculation employed at "Delhi Gate" and "Sen Nursing home" (Fig. 3). At "Rithala II" STP (based on high rate aeration process), problem of sludge bulking, and foam formation was quite frequent,

Fig. 3 Chemical quality of influent and effluent sewage from different STPs **a** COD, **b** BOD_5



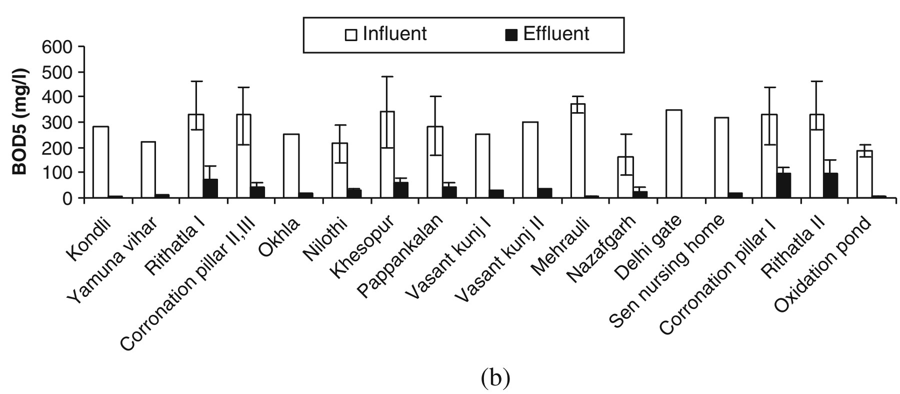


Table 5 Removal efficiencies (%) of different STPs

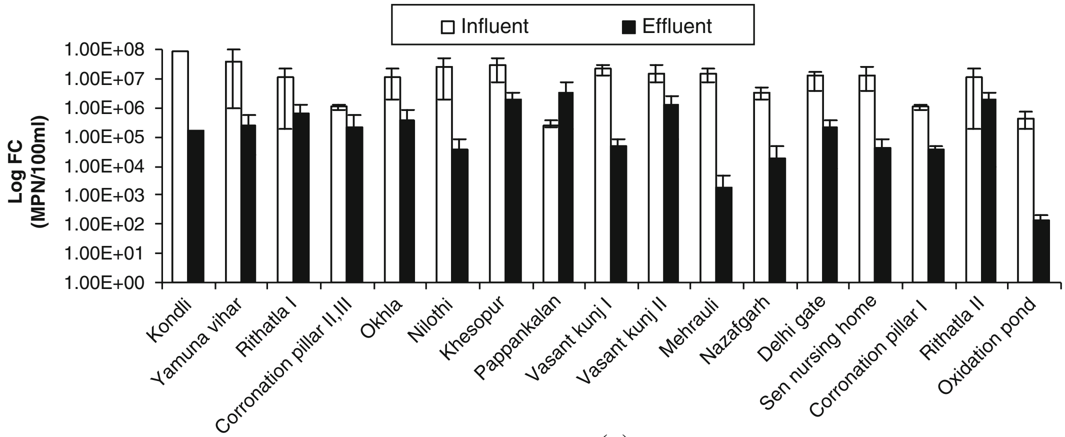
STPs	Removal (%)					
	FC (MPN/100 ml)	FS (MPN/100 ml)	BOD_5 (mg/l)	COD (mg/l)	TKN (mg/l)	Turbidity (NTU)
Kondli	99.82	96.10	93.57	92.00	94.63	96.06
Yamuna Vihar	99.83	99.75	95.45	72.45		92.55
Rithala I	94.43	97.70	78.79	73.28	21.08	85.23
Coronation pillar II and III	78.31	95.70	76.52	80.00	43.35	–
Okhla	96.75	98.83	92.00	92.88	63.04	95.16
Nilothi	99.87	98.07	85.12	88.81	78.13	92.66
Keshopur	95.70	90.42	81.47	69.79	48.28	85.03
Papankallan	91.94	88.77	85.96	91.43	70.99	93.14
Vasant Kunj I	99.79	99.94	99.11	96.64	68.55	99.49
Vasant Kunj II	91.78	95.57	92.23	88.00	34.48	96.22
Mehrauli	99.99	99.92	98.71	87.50	94.58	98.94
Nazafgarh	99.46	94.85	83.75	64.47	51.94	80.87
Delhi gate	98.35	99.72	99.43	96.80	69.19	98.75
Sen nursing home	99.69	99.86	95.00	89.80	88.89	97.22
Coronation pillar I	96.56	93.23	78.79	93.33	55.76	85.88
Rithala II	81.82	94.14	70.61	67.24	36.96	54.14
Oxidation pond Timarpur	99.97	99.98	96.47	92.31	86.35	98.12

therefore responsible for low turbidity and BOD_5 removal of 54% and 70% respectively. Algal growth in Oxidation ponds contributed to slightly high turbidity and BOD_5 value in effluents from oxidation ponds (Table 5). Coronation Pillar II and III" STP receives sewage through open drains from industrial area, thereby affecting the overall treatment process.

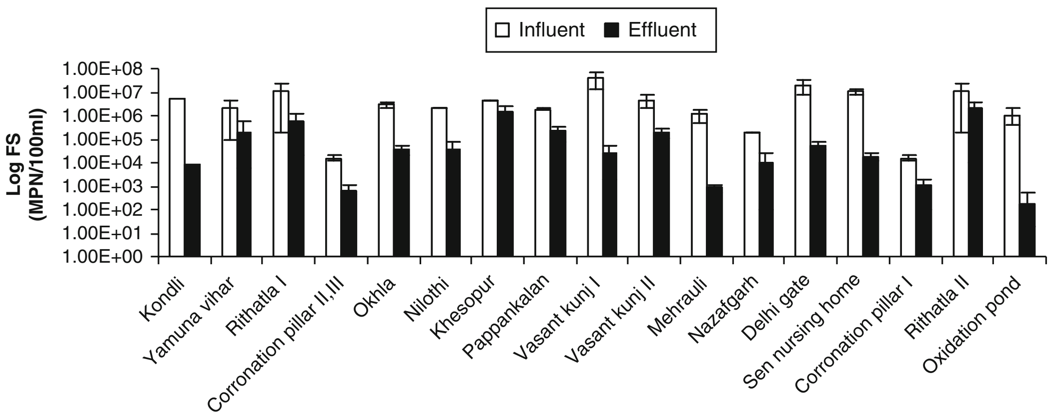
From Table 4 it is evident that effluent from "Mehrauli" and "Oxidation Pond" complies with FC standards of 10^3 MPN/100 ml. FC and FS count for all the STPs showed, that even after significant removal of organic load and turbidity, treated effluents had high levels of FC and FS. In STPs based on Ex. aeration process, the heterogeneous micro-organism are in endogenous phase having low F/M ratio, which imparts better settling characteristics to the flocs, thereby contributing high FC and FS removal (Table 4). Low F/M ratio also corresponds to high yield coefficient and generation time for ciliate protozoa and rotifers, thus making the system more efficient for FS and FC removal. Whereas in ASP, F/M ratio is high and micro-organisms are in logarithmic growth phase, as a result the flocs have poor settling characteristics imparting lower removal of indicator organisms. The removal mechanism in STP based on oxidation pond treatment process includes settlement of suspended solids, protozoan predation and inactivation due to solar radiation which is also linked with temperature FC and FS removal. It has also been reported that facultative ponds are very efficient in the removal of pathogens with removal rates for FC and FS >90% (Pommepuy et al. 1992).

"Delhi Gate" and "Sen Nursing Home" STPs (BIOFORE) based on attached growth treatment process also showed high FC and FS removal efficiencies as compared to "Coronation Pillar I", which receives septic sewage with low pH, thus affecting its performance. Gray (1983) reported that fixed film reactors are extremely effective in removal of indicator organism with normal removal efficiencies of >95%. Greater removal is achieved as the contact between indicator organism and adsorption sites in the biomass is increased. Once FC or FS have been adsorbed onto the film they are essentially removed and their subsequent ingestion by grazing organism may not be significant.

Extended HRT (76 h) at Nilothi was responsible for comparatively higher FC and FS removal as compared to other STPs with similar technology. "Coronation Pillar II and III" receives industrial and septic sewage with high sulfide levels (pH 6.6) which promote growth of foam forming bacteria such as



(a)



(b)

Fig. 4 Biological quality of influent and effluent sewage from different STPs, **a** FC, **b** FS

Beggiatoa and *Thiothrix* spp. thus responsible for higher turbidity and low indicator organism removal (Table 3). Whereas in case of 'Rithala II" STP based on high rate aeration system, inefficient aeration by diffusers results in low DO (Dissolved Oxygen), which in turn promotes growth of foam forming bacteria such as *H. hydrossis*, *M. parvicella* and *S. natans*, thus responsible for high turbidity of 226.12 NTU and low FC and FS removal (Table 4) (Leslie Grady et al. 1999).

Thus the study indicates that considerable numbers of microbes were free in water and could not be removed by settling process, or that micro-organisms were liberated from settling sludge in the final clarifier. Therefore an additional tertiary treatment step is needed to remove micro-organisms efficiently. Techniques such as tertiary filtration, as a final step of wastewater treatment, could not only improve the microbiological quality of wastewater, but also other qualities of effluent water (Koivunen et al. 2003).

Determination of integrated efficiencies of STPs evaluated

From the above results, it is clear that STPs exhibit different physical, chemical and microbiological efficiencies depending upon characteristics of influent sewage, HRT, percentage of capacity utilization etc. therefore there is a need to define one common parameter which could determine the overall efficiency of plant in terms of physical, biochemical and

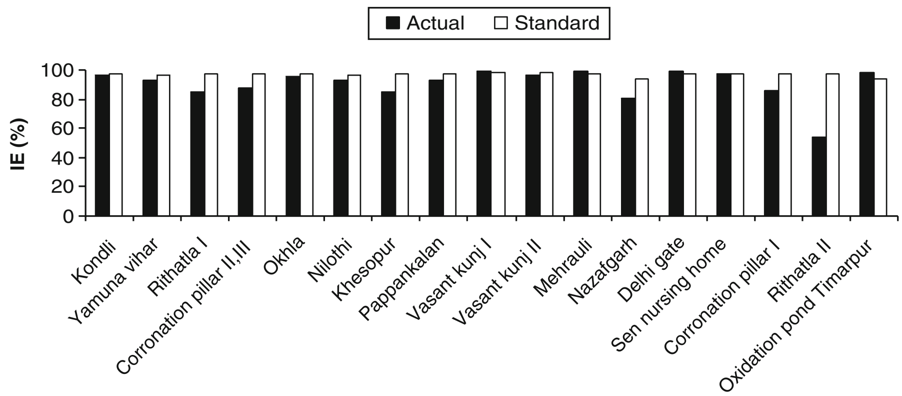


Fig. 5 Standard and actual integrated efficiency of all STPs evaluated

microbiological removal efficiencies. The parameter will also help in making decision for efficient reuse of effluent.

Colmenarejo et al. (2006) determined the general efficiency indicator to compare overall performances of the different plants. General efficiency was an average TSS, COD, BOD_5 and ammonia removal efficiencies. In cases where wastewater is used for irrigation purposes, microbiological quality of reclaimed water is important along with the physical and chemical qualities, since presence of microbes directly affects the health of the farmers and the people consuming raw vegetables etc. For this, the actual and standard integrated efficiency (IE) for STPs was determined by taking into consideration turbidity, BOD_5 and FC removal. Calculations of actual and standard integrated efficiencies for each STP were based on effluent sewage characteristics

$$IE_a = \frac{1}{3}\left[E_{TUR} + E_{BOD_5} + E_{FC}\right] \quad (1)$$

Where IE_a is the actual integrated efficiency in (%), E_{TUR} is average efficiency of turbidity removal (%), E_{BOD5} is average efficiency of BOD_5 removal (%), E_{FC} is average efficiency of FC removal (%). Hence, in order to evaluate integrated efficiency -physical,

Table 6 Actual and standard integrated efficiencies (%) of different STPs

STPs	Actual integrated efficiency (IE_a)	Standard integrated efficiency (IE_s)
Kondli	96.06	97.09
Yamuna Vihar	92.55	96.60
Rithala I	85.23	97.65
Coronation pillar II and III	87.49	97.25
Okhla	95.16	96.98
Nilothi	92.66	96.86
Keshopur	85.03	97.53
Papankallan	93.14	97.64
Vasant Kunj I	99.49	98.33
Vasant Kunj II	96.22	98.32
Mehrauli	98.94	97.49
Nazafgarh	80.87	93.59
Delhi gate	98.75	97.76
Sen nursing home	97.22	97.55
Coronation pillar I	85.88	97.24
Rithala II	54.14	97.64
Oxidation pond Timarpur	98.12	94.07

chemical and biological removal efficiencies of STPs were determined.

The standard integrated efficiency (IE_s), and actual integrated efficiency (IE_a), based on the effluent discharge standards and actual effluent quality of the respective plants was evaluated and compared as shown in Fig. 5. The IE_a was found to be greater than IE_s for "Vasant Kunj I", "Delhi Gate" "Oxidation Pond" and "Mehrauli" with values greater than 98% in all cases. Effluent from these STPs is comparatively safer for agricultural use than from the other STPs (Table 6).

For Plants with extended aeration process, IE_a was in the range 96–99% except in the case of "Nazafgarh", where irregular power supply was the main reason for poor performance. For STPs with an activated sludge process, IE_a was in the range of 85–97%, "Kondli" having highest IE_a of 97%. IE_a value greater than 97% was also obtained for "Sen Nursing Home" STP with physical, chemical and biological treatment.

Therefore, from above results it can be concluded that tertiary treatment is required for effluent from STPs with IE_a value less than 98%, in case effluent is to be discharged to surface water or used for irrigation purposes.

Conclusions

From present study it was observed that STPs investigated were unable to produce effluent that complies with the discharge standard in terms FC removal except "Mehrauli" and "Oxidation pond". In order to improve the efficiencies of the STPs, the treatment systems must be properly operated and maintained, sources of raw sewage need to be identified, and existing facilities should be upgraded accordingly. As for proper operation and maintenance, there is a need for trained and experienced workers to analyze the treatment performance at defined time intervals. Sources of raw sewage need to be identified, and STPs should be utilized to full capacity so as to control the quality of final effluent.

From this evaluation it was further concluded that the Ex. aeration, oxidation pond and BIOFORE were more efficient and have more stable results than ASP. Extended HRT contributes towards high removal of FC and FS from the system. The results also showed that "Vasant Kunj I", "Delhi Gate", "Oxidation pond" and "Mehrauli" perform comparatively well, with actual integrated efficiency (IE_a) value greater than 98%. Effluent from these STPs is comparatively safer for agricultural use than from other STPs.

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