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Performance evaluation of constructed wetland system treating domestic wastewater

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ABSTRACT

India is likely to be water scarce in future therefore rain water harvesting, water conservation, water pollution control, recycling and reuse of treated wastewater is necessary. Various methods have been developed to treat wastewater. Among them, constructed wetland systems (CWS) have gained importance as natural alternative to other physicochemical treatment methods for treating domestic wastewater. In the present study, performance of a two stage constructed wetland system treating domestic wastewater was evaluated. The study involved use of three locally available materials as wetland substrate as well as artificial aeration and addition of microbial consortium of *Pseudomonas aeruginosa* and *Bacillus sp.* in two stage CWS. The two stage CWS consisting of unplanted CWS followed by a planted CWS were used in the study. The gravel, sugarcane bagasse and rice-husk were the main media in unplanted CWS. The *Ranunculus sceleratus, Veronica anagallis-aquatica* and *Eichhornia crassipes* macrophytes were used in planted CWS. The systems were operated in batch mode with and without recirculation. The domestic wastewater with COD 224 – 352 mg/L, BOD 140 – 220 mg/L, TN 8.7 – 11.9 mg/L, TP 1 – 1.7 mg/L and bacterial count 2.80×10^{10} – 8.0×10^{10} CFU/100 mL was treated in CWS. The rice-husk followed by macrophyte species reduced the total nitrogen to zero whereas gravel and sugarcane bagasse followed by the plants reduced total nitrogen to a very low value of 0.6 – 1.1 mg/L at an overall detention time of 6 days. There was no significant removal of total phosphorus in unplanted CWS. Simultaneous removals of COD (50 – 100%), BOD (42 – 100%), TN (79 – 100%), TP (86 – 100%) and bacterial count (> 99%) were observed. Overall, *Veronica anagallis-aquatica* was more

effective than *Eichhornia crassipes* and *Ranunculus sceleratus*. The results show that treated effluent from CWS was meeting standards for discharge in the environment.

Keywords: Constructed Wetland System, Macrophytes, *Eichhornia crassipes, Ranunculus sceleratus, Veronica anagallis-aquatica.*

1. INTRODUCTION

Water is essential for all form of life. India is likely to be water scarce in future therefore rain water harvesting, water conservation, water pollution control, recycling and reuse of treated wastewater is necessary. Constructed wetland system (CWS) considered as an eco-friendly technology in treating a small and large volume of wastewater having varying contamination level (Licht and Isebrands, 2005). CWS require simple construction, low maintenance and is cost effective (Brix and Arias, 2005; Vymazal *et al.*, 2006; Ong *et al.*, 2009; Zhao *et al.*, 2013). CWS are used to treat wide range of wastewater like domestic wastewater (Morsy *et al.*, 2007; Tee *et al.* 2009), industrial wastewater (Vrhovsek *et al.*, 1996; Saeed and Sun, 2013; Kafle and Kim, 2013; Rossmann, 2013), agriculture wastewater (Babtunde *et al.*, 2011; Minghui *et al.*, 2011), landfill leachate (Bulc, 2006), storm water and acid mine drainage (Nyquist and Greger, 2009). This technology is thus gaining importance and considered as a natural alternative to various conventional methods (Licht and Isebrands, 2005). US Fish and Wildlife Service, defined the wetland as the transition area between terrestrial and aquatic system where water plays an important role in determining characteristics of soil and related biological communities i.e. plants and microorganisms (Sundaravadivel and Vigneswaran, 2009). The first experiment in the field of CWS was undertaken by a German scientist, Dr. Kathe Seidel, in early 1950s aimed at investigating the capabilities of wastewater treatment by bulrush (*Schoenoplectus lacustris*) grown in artificial environment (Vymazal, 2005). CWS involves vegetation, substrate and the microbial community which perform the physical, chemical and biological action to treat wastewater (Puigagut *et al.*, 2008; Saeed and Sun, 2013; Meng *et al.*, 2014). Most studies on CWS used only mineral substrates i.e. sand and gravel as growing media because these are believed to be a satisfactory substrate for both hydraulic conditions and removal of pollutants (Stottmeister *et al.*, 2003; Wiebner, 2005; Healy *et al.*, 2007). However, systems using sand and/or gravel may have clogging problems. The other types of mineral substrates, such as slag and charcoal are helpful in reatining phosphorus because of high adsorption capacity (Korkusuz *et al.*, 2005). Furthermore, few studies have used mixed media of mineral and organic substrates such as peat (Naylor *et al.*, 2003). Some CWS were based only on organic substrate, agriculture by-product such as sugarcane bagasse (Saeed, 2013) and rice husk (Tee, 2009). Organic substrates enhance plant settlement and growth due to organic and nutrient contents (Naylor *et al.*, 2003). More recently, baffled wetlands demonstrated high removal efficiency, due to effective use of aerobic-anaerobic regions created within matrices (Tee, 2012). So far, very few studies have focused on the use of organic substrate and externally added microbial consortium in wetland to treat wastewater. In the present study, performance of a two stage constructed wetland system treating domestic wastewater was evaluated. The study involved use of three locally available materials as wetland substrate as well as artificial aeration and addition of microbial consortium of *Pseudomonas aeruginosa* and *Bacillus sp.* in two stage CWS..

2. MATERIALS AND METHODS

Domestic wastewater

The domestic wastewater influent to oxidation pond at NIT Kurukshetra, was collected and used for present study. The characteristics of domestic wastewater used are summaraized in Table 1.

Table 1 Characteristics of Domestic Wastewater Used in Present Study

Parameter	Units	Values		
		Range	Mean Value	Standard Deviation
pH	-	6.60 – 7.12	6.95	0.12
Electrical Conductivity	µS/cm	675 – 820	750.8	40.2
Total Solids	mg/L	680 – 1056	811.7	99.2
COD	mg/L	224 – 352	287.2	35.4
BOD	mg/L	140 – 220	183.9	22.8
Total Nitrogen	mg/L	8.67 – 11.92	11.15	0.70

Total Phosphorus	μg/L	1004.8 – 1672.9	1275.8	158.5
Bacterial Colony	CFU/100 mL	2.80 – 8.0 x 10^{10}	5.54 x 10^{10}	1.46 x 10^{10}

Laboratory Scale Constructed Wetland System

Three laboratory-scale CWS of the same configurations, namely system S1, S2, and S3 were fabricated and installed at wastewater disposal site at NIT Kurukshetra (Figure 1). Each system consisted of two stage sequential treatment involving unplanted vertical flow - constructed wetland system (VF-CWS) followed by planted CWS. The three unplanted VF-CWS, namely A, B, C were made of PVC pipe having diameter 0.23 m and height 0.35 m. Gravels (10 - 12 mm size) were filled in all unplanted VF- CWS i.e. in A, B and C upto 10 cm from the bottom for drainage. Three locally available materials, gravel (12 to 16 mm size), organic sugarcane bagasse (retain on 6 mm sieve) and rice husk (retain on 2.36 mm sieve), were used as the main media in the unplanted VF- CWS. A 10 cm gravel layer was provided above the drainage layer in A of system S1, 20 cm sugarcane bagasse layer was provided above the drainage layer in B of system S2 and 20 cm ricehusk layer was provided above the drainage layer in C of system S3. Diffused air (air flow rate 1.2 to 1.3 L/min) was provided at the bottom to maintain aerobic condition. Each unplanted VF-CWS was followed by two planted CWS, namely A1, A2, B1, B2, C1, C2. The height and diameter of each planted CWS were 0.3 m and 0.15 m, respectively. In planted wetland, the layer of main media (gravels of size 10 to 12 mm) was 0.25 m deep. Three types of locally available macrophytes, *Ranunculus sceleratus, Veronica anagallis-aquatica* and *Eichhornia crassipes* were used in Phase I and Phase II of present study. The *Ranunculus sceleratus* and *Veronica anagallis-aquatica*, were planted into the wetlands for Phase I of the present study. The *Ranunculus sceleratus* and *Veronica anagallis-aquatica* were collected from oxidation pond at NIT kurukshetra and were planted into A1, B1, C1 and A2, B2, C2, respectively. The *Eichhornia crassipes and Veronica anagallis-aquatica*, were planted into the wetlands for Phase II of present study. The *Eichhornia crassipes* were collected from a pond at Dayalpur village, Kurukshetra and were planted into A1, B1 and C1 whereas *Veronica anagallis-aquatica* were collected from oxidation pond at NIT kurukshetra and were planted into A2, B2 and C2. After plantation all wetlands were water-logged for 1 week for allowing the establishment of the macrophytes.

Bacterial Strain

Bacterial strains *Pseudomonas aeruginosa* and *Bacillus sp*. were procured from Department of Microbiology, Kurukshetra University, Kurukshetra for the present study.

Culture Media

Nutrient broth, a nonselective media was used as culturing media for cultivation of bacterial strains. Nutrient agar was used as a growing media for microorganism for spread plate method.

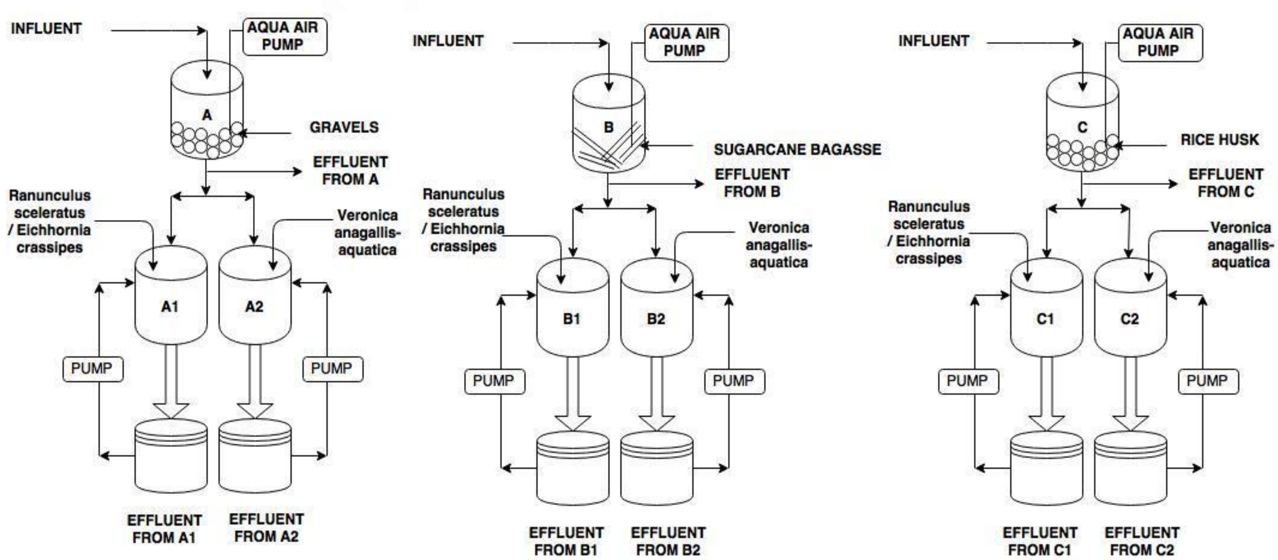

Figure 1 Schematic Diagram of Laboratory Scale Constructed Wetland System

Constructed Wetland System Operation

After the establishment of the macrophytes, the three unplanted CWS were fed with domestic wastewater from March 8, 2015 to June 2, 2015. Domestic wastewater was dosed manually into the first stage unplanted wetlands A, B, and C. The wastewater was detained and aerated for 6, 12, 24, 36, 48, 60 and 72 hrs in unplanted wetlands A, B and C. The effluents of the first stage unplanted wetland were transferred to the respective second stage planted CWS, i.e. from A to A1 and A2, B to B1 and B2 and C to C1 and C2 by gravity and again detained for 6, 12, 24, 36, 48, 60 and 72 hrs. The effluent from the second stage was continuously recirculated through planted second stage CWS. The detention time of each stage was equal and half of overall detention time.

Wastewater Sampling and Analysis

During present study, wastewater samples were collected after desire interval from each CWS. Each sample was analyzed for chemical oxygen demand (COD), Biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP) and bacterial plate count. The COD and BOD of samples were measured as per Standard Methods (APHA, 2005). TN and TP of samples were measured using continuous flow auto analyzer. For bacterial plate count, samples were diluted to 10^4 in a 0.85% saline solution using micropipette and then 100 μL sample was spreaded using glass rod on the three agar petri dishes. The petri dishes were incubated at 35 °C for 48 hrs. After incubation, the numbers of colonies formed were counted using a colony counter. Average value of number of colonies formed on three petri dishes were calculated and reported as a total bacterial count of the given samples. Bacterial streaking and straining are performed in order to differentiate effluent bacterial cells and to check their morphology (APHA, 2005). The observations related to type, color, pigment and size of colony were also recorded.

3. RESULTS AND DISCUSSIONS

The performance of CWS were evaluated based on BOD, COD, TN, TP and bacterial removal. The results of BOD, COD, TN, TP and bacterial removal are summarized in Table 2 and Table 3. The systems S1, S2 and S3 have shown satisfactory removal of BOD, COD, TN and microorganisms. Removal was depended strongly on the types of substrate and macrophyte used. There was low TP in domestic wastewater and it was easily uptaken by the macrophytes and adsobed by substrate thus it reduced to a very very low level. The microorganisms reduced more than 99% in all three CWS S1, S2 and S3.

BOD in the influent ranged 140 – 220 mg/L (Table 1). The maximum BOD removal was 79%, 83% and 85% in unplanted CWS A, B and C, respectively (Table 2). The BOD removal was 84 – 95, 82 – 100, 81 – 96% by *Ranunculus sceleratus, Veronica anagallis-aquatica, Eichhornia crassipes,* respectively. All three types of planted CWS with first stage unplanted system with rice-husk as a substrate shows comparatively higher BOD removal. The CWS with rice-husk as a substrate in first stage and *Veronica anagallis-aquatica* macrophyte in planted second stage CWS removed 100% BOD at an overall detention time of 6 days.

Average COD of the domestic wastewater was 287.2 mg/L (Table 1). The maximum COD removal were 73, 81 and 85% in unplanted CWS A, B and C, respectively (Table 2). The COD removal was 85% in two stage CWS B-B1, 88% in A-A1, A-A2, B-B2, 89% in C-C1 and 100% in C-C2 at 6 day over all detention time. The *Veronica anagallis-aquatica* has shown higher removal as compared to *Ranunculus sceleratus* and *Eichhornia crassipes* (Table 2). Ricehusk as a substrate in all the cases (whether before or after introducing bacterial consortium or whether recirculating flow in planted CWS or no recirculating flow) shown highest removal efficiency up to 100% at the overall 6 day detention time. It may be due to the high surface area available for the growth of microorganisms.

Total nitrogen mainly removed by microbial nitrification/denitrification process in the rhizosphere.TN in the influent ranged 8.67 – 11.9 mg/L (Table 1). The system B, containing sugarcane bagasse as a substrate media, have shown poor TN removal during cycle 1 which may be due to low pH thus inhibited nitrification – denitrification. Artificial aeration provided in system A, B and C enhanced nitrification and thus effectively reduces total nitrogen (Table 2). Ricehusk seems better option as a substrate when compare with other two substrate media i.e. gravel and sugarcane bagasse as it give 79% and 86% removal during Phase I and Phase II, respectively at 6 day overall detention time. The macrophytes used in the study are very effective in nitrogen removal, as removal efficiency was very high i.e. 79 – 93% during Cycle 1 of Phase I, 90 – 100% during Cycle 2 – 3 of Phase I and 93 – 100% during Cycle 1 – 3 of Phase II (Table 2). Rice-husk followed by macrophyte species i.e. *Ranunculus sceleratus* or E*ichhornia crassipes* or *Veronica anagallis-aquatica* reduced the total nitrogen to zero whereas gravel and sugarcane bagasse followed by the *Ranunculus sceleratus* or E*ichhornia crassipes* or *Veronica anagallis-aquatica* reduced total nitrogen upto 100%.

Phosphorus removal in CWS is resulted from adsorption, plant absorption, complexation, and precipitation. Small fraction of TP is removed by macrophyte rhizosphere in CWS. TP in the influent ranged 1004.8 – 1672.9 μg/L which is less than the prescribe limit for disposal (Table 1). There was no significant removal of TP in system A, B and C. The system A showed maximum TP removal i.e. 37% (DT 1.5 days) and 23% (DT 3 days) during the Cycle1 of Phase I due to retaintion of phosphorus on the substrate media or by oxidation of organic phosphorus by microbial communities. There was no phosphorus removal in system A and C after Cycle 2 which may be due to the inability of substrate media in retaining phosphorus. No improvement in phosphorus removal was observed with artificial aeration and externally added bacterial consortium. However, low phosphorus in domestic wastewater was easily adsorbed and utlized by macrophytes in planted CWS and removed it completely at the overall detention time of 6 days. The two stage system involving three type of macrophytes have shown total phosphorus removal ranging from 86 to 100%.

Table 2 BOD, COD, TN and TP Removal in Constructed Wetland System

Parameters	DT of Each stage (Days)	CWS Without Adding Bacterial Consortium Cycle 1 of Phase I									CWS After Adding Bacterial Consortium Cycle 2-3 of Phase I									CWS After Adding Bacterial Consortium Cycle 1-3 of Phase II								
		A	A-A1	A-A2	B	B-B1	B-B2	C	C-C1	C-C2	A	A-A1	A-A2	B	B-B1	B-B2	C	C-C1	C-C2	A	A-A1	A-A2	B	B-B1	B-B2	C	C-C1	C-C2
BOD Removal (%)	0.25	18	45	36	-14	14	9	27	45	55	37	58	55	18	53	53	32	61	61	46	64	69	51	61	69	46	72	72
	0.50	20	50	40	-25	25	10	35	55	55	45	66	66	34	68	66	45	66	66	45	66	72	51	68	70	51	74	75
	1.00	22	56	33	-17	28	11	33	56	56	57	70	73	43	73	68	59	68	68	51	69	73	63	69	75	65	76	78
	1.50	45	64	59	5	36	23	59	73	77	64	78	81	47	78	72	64	75	75	63	76	78	67	78	80	65	80	80
	2.00	44	66	72	-11	44	22	56	72	78	69	88	84	59	84	84	72	88	84	66	83	85	70	81	83	68	85	89
	2.50	65	75	75	10	55	40	60	80	80	69	92	90	64	85	85	69	92	92	75	90	92	81	88	92	81	93	98
	3.00	63	79	89	5	58	42	68	84	89	79	95	89	68	84	89	79	95	95	78	93	93	83	93	93	85	96	100
COD Removal (%)	0.25	18	45	45	-14	18	18	27	45	55	29	41	41	-6	0	12	35	41	47	45	55	58	48	58	61	48	68	68
	0.50	20	50	60	-25	10	20	30	50	50	47	58	58	-16	21	32	47	58	58	48	59	67	52	67	67	56	67	74
	1.00	22	56	56	-22	11	22	33	56	56	50	61	67	-11	28	28	50	61	61	52	60	72	60	76	76	64	76	80
	1.50	45	64	73	0	36	45	55	64	73	47	60	67	0	20	33	47	67	67	68	75	79	68	79	79	68	89	89
	2.00	44	67	78	-11	33	33	56	67	78	65	71	71	6	35	41	59	71	71	63	75	88	67	83	83	71	88	88
	2.50	60	70	80	-10	40	50	60	70	80	65	82	82	24	47	53	65	82	82	68	84	88	68	84	88	76	88	96
	3.00	60	80	90	-10	50	60	70	80	90	67	78	89	11	53	61	67	78	89	73	88	88	81	85	88	85	88	100
TN Removal (%)	0.25	0	64	63	-33	13	15	0	66	67	23	76	85	23	70	74	27	84	85	23	79	82	16	80	84	16	83	84
	0.50	-9	62	63	-45	6	10	5	63	70	29	84	89	26	82	83	31	87	88	34	83	81	25	82	89	25	83	86
	1.00	4	69	71	-29	42	44	19	74	75	39	87	92	41	86	86	37	90	89	33	91	92	32	89	92	32	91	92
	1.50	25	73	76	-24	47	49	39	84	85	53	91	95	54	89	88	53	92	94	47	92	93	47	92	95	47	94	96
	2.00	38	75	78	8	61	62	39	83	85	72	96	97	72	97	96	72	98	98	55	92	96	67	92	98	67	98	99
	2.50	49	76	80	10	64	64	52	90	90	72	90	92	71	90	90	75	99	98	69	90	93	80	98	98	80	99	100
	3.00	59	87	88	18	80	79	56	91	93	73	90	98	72	93	90	79	100	99	78	93	95	86	98	100	86	100	100
TP Removal (%)	0.25	12	87	91	-31	74	62	11	90	90	-6	78	95	-20	94	97	11	92	97	-3	83	97	-3	93	98	-3	79	95
	0.50	15	93	94	-19	76	73	19	93	92	-2	87	98	-16	97	99	-5	94	97	7	87	99	-15	89	98	0	86	96
	1.00	18	91	94	-67	71	61	23	95	94	16	92	99	-2	98	99	0	94	98	18	90	99	10	93	98	14	91	98
	1.50	37	93	94	0	92	89	30	96	96	-2	96	100	-16	100	100	10	96	98	-8	91	98	-6	92	99	-9	89	97
	2.00	4	96	95	-23	92	90	15	96	96	-4	94	99	-12	100	100	19	97	99	-8	92	100	-8	95	100	-13	87	98
	2.50	17	98	98	-12	96	93	22	98	98	-7	96	100	-16	99	99	-5	97	100	12	92	99	12	95	99	9	93	97
	3.00	23	98	99	17	98	96	34	99	99	-5	97	100	9	100	100	25	99	100	-12	92	100	-10	95	100	1	86	99

The Microorganisms in a wastewater comprise both heterotrophs and autotrophs. Total bacteria in the influent ranged 2.80 x 10^{10} – 8.0 x 10^{10} CFU/100 mL (Table 1). In Unplanted CWS, high bacterial removal was observed; maximum removal in system A, B and C were 97.72% (DT 2.5 day), 89.65% (DT 1.5 day) and 95.52% (DT 1.5 day), respectively (Table 3). The system B which contain sugarcane bagasse as a supporting media provided substrate and surface to enhance bacterial growth at a high rate till sugar fraction was depleted, resulted in very less removal. Organic and inorganic fraction depleted with time due to bacterial utilization. The oxygen required during respiration process was supplied by artificial aeration to maintain favourable growth condition for bacteria. When most fraction of organic matter depleted then autotrophic bacteria shows their dominance. In planted CWS, macrophyte rhizosphere provides oxygen for respiration and space for the growth of microorganisms. Thus bacteria retained within the rhizosphere in CWS, thus maximum bacterial removal was observed. The removal were 99.57, 99.79, 99.26, 99.47, 99.13 and 99.63% in A-A1, A-A2, B-B1, B-B2, C-C1 and C-C2, respectively at 6 day overall detention time (Table 3). It was observed that there were three types of bacterial genera present in the effluent i.e. Micrococcus, Diplobacillus, Streptobacillus (based on colony morphology and gram strain test). Streptobacillus gram positive and Micrococcus gram positive showed their dominance in the influent and effluent wastewater.

Table 3 Result of of Bacterial Removal in a Unplanted and Planted CWS

DT of Each Stage (Days)	Bacterial Removal (%)								
	A	A-A1	A-A2	B	B-B1	B-B2	C	C-C1	C-C2
0.25	85.80	-	94.81	70.92	-	90.08	72.92	-	95.50
0.50	92.30	95.67	95.60	56.95	78.40	93.74	91.75	96.15	97.87
1.00	93.58	97.19	97.49	89.65	70.67	76.79	95.52	91.45	97.11
1.50	95.17	92.98	91.71	76.52	86.54	81.93	94.48	83.08	95.74
2.00	91.93	94.14	95.77	82.50	46.39	75.28	90.31	90.89	84.32
2.50	97.72	95.74	97.10	79.66	92.78	97.33	85.80	95.97	98.41
3.00	94.68	99.57	99.79	71.08	99.26	99.47	91.44	99.31	99.63

4. CONCLUSION

In the study, it was found that artificial aeration and externally added bacterial consortium of *Pseudomonas aeruginosa* and *Bacillus sp*. enhanced the unplanted wetland capacity to remove COD, BOD and TN. Rice-husk as a substarte have shown better removal efficiency. Macrophye plays an important role in degradation, adsorption of pollutants and uptake of nutrients present in the domestic wastewater. The CWS have shown satisfactory removal of COD, BOD, TN and microorganisms. There was low TP in domestic wastewater and it was easily uptaken and adsorbed by the macrophytes. The microorganisms were removed more than 99% in all three CWS and it resulted in high quality effluent, which can be directly discharged into water stream or can be used for irrgation purpose.

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