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Phytoremediation of dairy effluent by constructed wetland technology

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Abstract Constructed wetlands are artificial wastewater treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants and which rely upon natural microbial, biological, physical and chemical process to treat wastewater and are gaining acceptance in the recent years as a viable option for the treatment of industrial effluents and removal of toxic components. In this study, an attempt was made to compare the efficiency of aquatic macrophytes like *Typha* sp., *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Azolla* sp. and *Lemna* sp. to treat the effluents from dairy factory, under laboratory conditions in constructed wetlands. The biological oxygen demand and chemical oxygen demand of dairy effluent were reduced up to 65.4–83.07% and 70.4–85.3%, respectively, after treatment with constructed wetland technology.

Keywords Biological oxygen demand · Chemical oxygen demand · Dairy effluent · Constructed wetlands · Phytoremediation · Macrophytes

1 Introduction

Constructed wetlands are artificial wastewater treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants and which rely upon natural microbial, biological, physical and chemical process to treat wastewater. The treatment systems of constructed wetlands are based on ecological systems found in natural wetlands. Continuous flooding and concentrations of total suspended solids, biochemical oxygen demand and other wastewater constituents affect wetland ecology in constructed wetlands. For the design and construction of treatment wetlands and the processes by which constructed wetlands can remove pollutants, it is important to have a basic understanding of how natural wetlands work. Wetlands are generally characterized by the presence of three basic parameters such as soils, hydrology and vegetation. Constructed wetlands can treat contaminants such as total suspended solids (TSS), biochemical oxygen demand (BOD5), organic compounds and inorganic constituents to meet regulatory targets. Although the same wetlands can achieve multiple goals of contaminant removal, the mechanisms vary. Understanding the mechanisms and processes controlling contaminant removal increases the probability of success of the wetland application. Numerous approaches have been taken to reduce water consumption, but in the long run it seems only possible to recycle wastewater into high quality water (Schröder et al. 2007).

Phytoremediation is defined as the use of plants as well as microorganisms of the rhizosphere to remove or render harmless pollutants from contaminated sites (Lasat 2002; Singh and Laban 2003). The most applicable technology using phytoremediation strategy is constructed wetland technology (CWs). Besides water quality improvement and energy savings, CWs have other features related to the environmental protection such as promoting biodiversity, providing habitat for wetland organisms and wildlife (e.g. birds and reptiles in large systems), serving climatic (e.g. less CO_2 production, (Dixon et al. 2003); hydrological functions, heavy metal bioaccumulation and biomethylation (Azaizeh et al. 2003).

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Alicia et al. (1994) reported that the roots of some aquatic plants could retain both coarse and fine particulate organic materials present in water bodies supporting their growth. Plants sustain large microbial population in the rhizosphere by rhizo-deposition, root cap cells, which protect the root from abrasion, may be lost to the soil at a rate of 10,000 cells per plant. In addition, root cells excrete mucigel, a gelatinous substance that is a lubricant for root penetration through the soil during growth, and microbes in the root zone can help to solubilize insoluble nutrients and recycle organically bound nutritive elements (Schnoor et al. 1995; Jones et al. 2004; Kirk et al. 2005).

In the present study, effluents from Kerala Co-operative Milk Marketing Federation, Thiruvananthapuram, India, popularly called milma was treated using constructed wetlands. The waste generation processes of major significance in the dairy industry include washing, cleaning of all pipelines, pumps, equipments, tanks, filling machines, milk cans, bottles and floor, start-up, products change, overhead shutdown, pasteurizers and loss in filling operations. The waste generated includes milk solids, detergents, sensitizers and lubricants generated in packaging and distribution operation. The wastewater also contains portions of spoiled milk. The dairy effluent cannot be added to a water body without harm since they use up too much of oxygen in the water.

The main aim of the study was to compare the efficiency of aquatic macrophytes like *Typha* sp., *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Azolla* sp. and *Lemna* sp. to treat the effluents from dairy factory, under laboratory conditions in constructed wetlands.

2 Materials and methods

2.1 Experimental setup

Approximately 10 l of raw effluent from factories was brought to the laboratory in plastic containers, and the experiments were set up in plastic crates. These crates were filled with wetland soil. The plants used for the study was an emergent wetland plant *Typha* sp. and floating wetland macrophytes like *Pistia* sp., *Azolla* sp., *Lemna* sp, *Salvinia* sp. and *Eichhornia* sp. The experimental plants were initially subject to stabilization in tanks containing well water for 1 month for acclimatization.

Ten litres of the effluent were prepared (one without dilution and the other with 50% dilution) and then transferred to plastic tubs. For each experimental set, two controls were maintained with 10 l of well water and 10 l of raw effluent, respectively. The setup was same for emergent and floating plants.

For treatments, the plants which maintained in the stock tanks were collected, cleaned and introduced in the experimental tanks. Six constructed wetland systems of same dimension (18 × 18 × 24 cm) were used for each plant. Approximately 250 g (wet weight) of each experimental plant is used for the study, each occupying half of crates. The number of plants varies according to species; for example, in case of *Typha* sp., only five plants were used but in *Eichhornia* sp. more than ten plants were used. Duplicate of each experimental setup was maintained. So a total of 48 constructed wetlands setup were used in this experiment. A volume of 500 ml each of water and effluent from the respective treatment sets were collected periodically for analysing the changes in its physico-chemical characteristics subsequently with an interval of 5 days up to 15 days. Thus, the analyses of water samples were carried out at four stages of treatment. The setup was same for all the treatments.

2.1.1 Design of the containers

The sizes of the containers were 18 × 18 × 24 cm. The base of the tank was filled with gravel (3 cm) and wetland soil (5 cm) up to 8 cm in height. Water/Effluent level in the tank was up to 15 cm height.

2.2 Estimation of physico-chemical parameters of the effluents

The effluent samples collected from the treatment sets were subjected to physico-chemical analysis following standard methods. Major parameters analysed include pH, turbidity, conductivity, total solids, TDS, TSS, sodium, potassium, nitrate-nitrogen, BOD5 and COD (APHA 1995).

2.3 Experimental plants

Typha is a genus of about 11 species of monocotyledonous flowering plants in the monogeneric family, *Typha*ceae. Cattails are wetland plants, typically 1–7 m tall, with spongy, strap-like leaves and starchy, creeping stems (rhizomes). *Typha* sp. plants are monoecious, wind-pollinated and bear unisexual flowers developing in dense, complex.

Water hyacinth (*Eichhornia crassipus*) belongs to the family Pontederiaceae. Leaves are axillary, appearing to develop in rossets, with long or short petioles. *Eichhornia sp.* reproduces mainly by vegetative reproduction by means of slender runners called stolons. It is normally free floating, buoyed by bladder like inflated petioles. The leaf blades are somewhat kidney shaped or rounded.

Salvinia, the sole genus in the family Salviniaceae, is a floating fern. The upper side of the floating leaf, which appears to face the stem axis, is morphologically abaxial. These are small, floating aquatics with creeping stems, branched and bearing hairs but no true roots.

Pistia is a genus of aquatic plant in the family Araceae. It floats on the surface of the water, and its roots hanging submerged beneath floating leaves. The leaves can be up to 14 cm long and have no stem. They are light green, with parallel veins, wavy margins and are covered in short hairs which form basket-like structures which trap air bubbles, increasing the plant's buoyancy. The flowers are dioecious and are hidden in the middle of the plant among the leaves. The plant can also undergo asexual reproduction.

Azolla is a genus of seven species of aquatic ferns, the only genus in the family Azollaceae. *Azolla* sp. floats on the surface of water by means of numerous, small, closely overlapping scale-like leaves, with their roots hanging in the water. They form a symbiotic relationship with the blue-green algae *Anabaena azollae*, which fixes atmospheric nitrogen, giving the plant access to the essential nutrient.

Lemna is a genus of free-floating aquatic plants from the duckweed family. The duckweeds have been classified as a separate family, the Lemnaceae, but some researchers consider the duckweeds members of the Araceae. The plants grow mainly by vegetative reproduction.

2.4 Statistical analysis

For testing statistical significance, Student's *t*-test was used. Independent sample *t* test was used for finding the mean difference of each parameter of the control effluents with those of the final value.

3 Results and discussion

3.1 Treatment of dairy effluent with *Pistia* sp.

A decrease in pH was observed when dairy effluent was treated with *Pistia* sp. The pH decreased steadily from 8.05 to 7.46 in case of undiluted effluent and from 7.89 to 7.64 in diluted effluent. In well water control, a slight positive change was observed but in dairy control, a slight negative change was observed. However, EC showed not much variation with dilution. In well water and effluent controls, the same trend was observed.

Significant reduction was observed in turbidity after 15 days of treatment in both diluted and undiluted effluents. But in undiluted effluent (66.97%), the reduction was more than the diluted effluent (65.43%). In case of TDS, there was a significant reduction ($p < 0.01$). In well water control also, TS, TDS and TSS were found to decrease with time. Among the various nutrients present in TTP *viz*., potassium, sodium and nitrate-nitrogen, sodium content was comparatively high (342.2 mg/l). However, the concentration of these nutrients reduced with dilution and also with retention time in the treatment system. Potassium content reduced significantly ($p < 0.05$). Salinity showed only a slight decrease with retention time (from 0.755 to 0.528 mg/l) in the undiluted effluent.

BOD5 and COD showed drastic changes when the effluent was treated by this system. In undiluted effluent treatment, BOD5 reduced significantly ($p < 0.01$) by 75.38% from initial level after 15 days. When the effluent was diluted, BOD5 reduction was (84.61%) more than undiluted effluent. However, in dairy control, the reduction was only 1.24%. COD of undiluted effluent also showed significant reduction (74.52%). The diluted effluent showed 87.5% reduction, which was statistically significant at 0.01 levels (Table 1).

3.2 Constructed wetlands with *Eichhornia* sp.

When treated with *Eichhornia* sp.-based CWs, the pH of dairy effluent was found to decrease from 8.05 to 7.54 in case of undiluted effluent and from 7.89 to 7.71 in diluted effluent. In well water control, a slight positive change was observed but in dairy control, a slight negative change was observed. However, EC showed much variation with dilution. In case of well water control, a positive change was observed, and with effluent control, a negative change was observed.

Turbidity was found to decrease in undiluted effluent (69.74%), but after dilution, turbidity also decreased (59.78%) during the treatment period. Total solids showed a pronounced reduction in both diluted and undiluted effluents ($p < 0.05$) in the *Eichhornia* sp.-based CWs. Among the different nutrients like potassium, sodium ($p < 0.05$) and nitrate, sodium showed the highest reduction (77.45%). A drastic reduction was observed in case of BOD5 (83.08%) and COD (82.53%) in undiluted effluent. The effluent control, in both BOD5 and COD did not show much variation. In case of diluted effluent, 79.49 and 80.48% reduction was observed with BOD5 and COD, respectively (Table 2).

3.3 Constructed wetlands with *Lemna* sp.

On treatment with *Lemna* sp.-based CWs, the pH of undiluted effluent and diluted effluent decreased slightly. But in the dairy control, pH was decreased at 0.49% only. The pH of well water control showed a slight increase (0.66%). The conductivity of undiluted, diluted and effluent control was found to decrease on 15th day and it was high in the case of undiluted effluent (48.52%). The EC of well water control increased (5.56%) slightly. Turbidity

Table 1 Variation in physico-chemical characteristics of dairy effluent treated with *Pistia* sp

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
pH	Initial	8.05	7.57	7.89	8.05
	5 days	8.02	7.41	7.82	7.67
	10 days	8.02	7.38	7.71	7.56
	15 days	8.01	7.62	7.64	7.46
	%Increase/decrease	−0.49	+0.66	−3.27	−7.33
Conductivity (μS cm^{-1})	Initial	1.01	1.44	0.89	1.01
	5 days	0.98	1.46	0.81	0.8
	10 days	0.97	1.49	0.73	0.62
	15 days	0.97	1.52	0.58	0.44
	%Increase/decrease	−3.9	+5.5	−34.83	−56.43
Turbidity (NTU)	Initial	542	4	353	542
	5 days	534	9	245	475
	10 days	523	6	175	312
	15 days	512	5	122	179
	%Increase/decrease	−5.53	+25	−65.43*	−66.97*
Total solids (mg/l)	Initial	1,986	18	876	1986
	5 days	1,982	23	656	1,086
	10 days	1,974	22	422	776
	15 days	1,964	21	323	465
	%Increase/decrease	−1.1	+16.6	−63.13*	−76.59*
TSS (mg/l)	Initial	6.44	0.94	3.24	6.44
	5 days	6.42	1.12	3.12	4.2
	10 days	6.42	1.42	2.56	3.4
	15 days	6.41	1.87	1.98	2.18
	%Increase/decrease	−0.47	+98.9**	−38.89	−66.14*
TDS (mg/l)	Initial	1,377.56	17.06	872.76	1,377.56
	5 days	1,313.58	16.88	652.8	666
	10 days	1,289.58	20.59	419.44	436
	15 days	1,161.59	19.14	321.02	247
	%Increase/decrease	−15.68	+12.19	−63.22	−82.07**
Potassium (mg/l)	Initial	17.4	11.8	6.2	17.4
	5 days	17.4	10.24	2.8	10.6
	10 days	17.3	9.86	1.4	6.6
	15 days	17.3	9.62	1.2	4.4
	%Increase/decrease	−0.57	−18.47	−80.64*(*)	−74.71*
Sodium (mg/l)	Initial	342.2	2.1	232.4	342.2
	5 days	342.1	1.4	104.8	265.4
	10 days	340.4	1.3	88.4	120.6
	15 days	338.2	1.2	27.1	107.5
	%Increase/decrease	−1.69	−42.86	−88.34**	−68.59*
NNO_3 (mg/l)	Initial	4.12	0.23	3.26	4.12
	5 days	4.10	0.21	3.21	4.98
	10 days	4.10	0.14	3.12	4.62
	15 days	4.07	0.09	2.98	4.34
	%Increase/decrease	−1.22	−60.87*	−8.59	+5.33

Table 1 continued

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
BOD5 (mg/l)	Initial	1,300	2.1	780	1300
	5 days	1,300	2.2	380	590
	10 days	1,298	1.8	240	410
	15 days	1,284	1.2	120	320
	%Increase/decrease	−1.24	−42.86	−84.61**	−75.38**
COD (mg/l)	Initial	2,920	2.8	1,670	2,920
	5 days	2,912	2.4	1,124	1,898
	10 days	2,912	1.8	524	812
	15 days	1,904	1.8	208	744
	%Increase/decrease	−34.79	−35.71	−87.5**	−74.52*

* Significance at 5% level

** Significance at 1% level

showed a decreasing trend in undiluted effluent, i.e., 542–179 NTU (66.97%). However, the well water control value increased from 4 to 5 NTU. TS ($p < 0.05$) and TDS also showed a decreasing trend towards the last day of treatment. TDS of undiluted effluent showed a high level of decrease (59.37%) from the initial. Contrastingly, the well water control value increased from 17.06 to 19.14 mg/l.

The nutrients in the effluent were observed to have a prominent decrease after 15 days of treatment. The sodium and potassium concentration in diluted effluent showed maximum decrease (83.65 and 70.97%, respectively). The change in potassium concentration in undiluted effluent was significant at 0.05 levels. BOD5 and COD showed drastic changes when the effluent was treated with *Lemna* sp.-based system. In undiluted and diluted effluent, BOD5 reduced by 68.31% ($p < 0.05$) and 80% ($p < 0.01$) from initial level after 15 days. However, in dairy control, the reduction was only 1.23%. COD in undiluted effluent was reduced by 72.12% from initial level after 15 days. In well water control, the decrease was only 35.71% (Table 3).

3.4 Constructed wetlands with *Typha* sp.

The pH of the undiluted effluent before treatment was 8.05. It decreased at a regular interval to 7.32 after 15 days of treatment. In case of diluted effluent, the percentage decrease was 3.17. Contrastingly, the pH of well water control was found to increase (0.66%). The conductivity of undiluted, diluted effluent and dairy control decreased during the treatment process. Turbidity showed a decreasing trend both in undiluted and diluted effluent after 15 days of treatment, and it was more in diluted effluent (72.24%). The TS of the undiluted effluent was 1,986 mg/l, which then decreased considerably to 322 mg/l after 15 days of treatment ($p < 0.01$). In diluted effluent, the initial TS were 876 mg/l and decreased to 204 mg/l after 15 days of treatment and the reduction was 76.71%. TSS was observed to increase in both undiluted and diluted effluents. In case of well water control, TSS increased to 98.94% but the effluent control showed a slight decrease. TDS of the undiluted effluent was 1,377.56 mg/l, which then decreased to 314.86 mg/l after 15 days of treatment. The nutrients, potassium, sodium and nitrate-nitrogen decreased considerably.

BOD5 of the undiluted effluent decreased after 15 days of treatment from 1,300 to 260 mg/l ($p < 0.01$). In diluted effluent, the percentage decrease was 87.69. In case of COD, the undiluted effluent has a value of 2,920 mg/l, which then decreased considerably to 424 mg/l. In diluted effluent, the COD decreased to 88.86%. COD of both controls also decreased slightly (Table 4).

3.5 Constructed wetlands with *Salvinia* sp.

On treatment with *Salvinia* sp.-based CWs, the pH of dairy effluent was found to decrease from 8.35 to 7.42 and from 7.89 to 7.62 in undiluted and diluted effluent, respectively, after 15 days of retention period. However, in well water control, the pH was found to increase slightly. The conductivity of undiluted, diluted effluent and dairy control decreased during the course of treatment. The reduction was high in diluted effluent (45.17%).

Turbidity was found to decrease in undiluted effluent and diluted effluent. Total solids showed a pronounced reduction in both diluted and undiluted ($p < 0.05$) effluent in the *Salvinia* sp.-based CWs. TDS also showed a drastic decrease as the retention time increased. In case of TSS, the values of all treatments except in dairy control were found to increase. Different nutrients like potassium ($p < 0.05$), sodium ($p < 0.01$) and nitrate showed a marked reduction in concentration in both diluted and undiluted effluents. BOD5 and COD values also reduced significantly. The BOD5 values of undiluted effluent showed a marked

Table 2 Variation in physico-chemical characteristics of dairy effluent treated with *Eichhornia* sp

Parameters analysed	Retention time	Milma control	Well water control (l)	Diluted effluent	Undiluted effluent
pH	Initial	8.05	7.57	7.89	8.05
	5 days	8.02	7.41	7.81	7.88
	10 days	8.02	7.38	7.76	7.56
	15 days	8.01	7.62	7.71	7.54
	%Increase/decrease	0.49	+3.4	−1.85	−6.33
Conductivity (μS cm^{-1})	Initial	1.01	1.44	0.89	1.01
	5 days	0.98	1.46	0.77	0.87
	10 days	0.97	1.49	0.74	0.62
	15 days	0.97	1.52	0.65	0.54
	%Increase/decrease	−3.9	+5.56	−26.97	−46.53
Turbidity (NTU)	Initial	542	4	353	542
	5 days	534	9	265	486
	10 days	523	6	202	324
	15 days	512	5	142	164
	%Increase/decrease	−5.53	+25	−59.78	−69.74*
Total solids (mg/l)	Initial	1,986	18	876	1,986
	5 days	1,982	23	724	1,244
	10 days	1,974	22	421	784
	15 days	1,964	21	388	516
	%Increase/decrease	−1.11	+16.67	−55.71	−74.02*
TSS (mg/l)	Initial	6.44	0.94	3.24	6.44
	5 days	6.42	1.12	2.84	4.22
	10 days	6.42	1.42	2.11	5.88
	15 days	6.41	1.87	1.86	6.54
	%Increase/decrease	−0.47	+98.94**	−42.59	+1.56
TDS (mg/l)	Initial	1,377.56	17.06	872.76	1,377.56
	5 days	1,313.58	16.88	721.16	1,239.78
	10 days	1,289.58	20.59	418.89	778.12
	15 days	1,161.59	19.14	386.14	509.46
	%Increase/decrease	−15.68	+12.19	−55.75	−63.02*
Potassium (mg/l)	Initial	17.4	11.8	6.2	17.4
	5 days	17.4	10.24	4.6	16.8
	10 days	17.3	9.86	4.2	12.3
	15 days	17.3	9.62	3.6	11.2
	%Increase/decrease	−0.57	−18.47	−41.93	−35.63
Sodium (mg/l)	Initial	342.2	2.1	232.4	342.2
	5 days	342.1	1.4	123	245
	10 days	340.4	1.3	96.4	183.4
	15 days	338.2	1.2	52.4	120.6
	%Increase/decrease	−1.17	−42.85	−77.45**	−64.75*
NNO_3 (mg/l)	Initial	4.12	0.23	3.26	4.12
	5 days	4.10	0.21	3.11	3.96
	10 days	4.10	0.14	3.02	3.61
	15 days	4.07	0.09	2.62	3.22
	%Increase/decrease	−1.21	−60.87*	−19.63	−21.84

Table 2 continued

Parameters analysed	Retention time	Milma control	Well water control (l)	Diluted effluent	Undiluted effluent
BOD5 (mg/l)	Initial	1,300	2.1	780	1,300
	5 days	1,300	2.2	420	880
	10 days	1,298	1.8	310	540
	15 days	1,284	1.2	160	220
	%Increase/decrease	−1.23	−42.86	−79.49**	−83.07**
COD (mg/l)	Initial	2,920	2.8	1,670	2,920
	5 days	2,912	2.4	984	1,754
	10 days	2,912	1.8	648	1,124
	15 days	1,904	1.8	326	510
	%Increase/decrease	−34.79	−35.71	−80.48**	−82.53**

* Significance at 5% level

** Significance at 1% level

reduction, i.e., from 1,300 to 290 mg/l (77.69%) and from 780 to 96 mg/l in undiluted and diluted effluents, respectively. BOD5 reduction was high in diluted effluent (87.69%), and COD reduction was also high in diluted effluent (81.67%). The COD values of undiluted effluent also showed a marked reduction, i.e., from 2,920 to 822 mg/l (Table 5).

3.6 Constructed wetlands with *Azolla* sp.

Effluent treatment using *Azolla* sp.-based CWs showed that the pH of dairy effluent decreased to acidic range, i.e., from 8.05 to 6.8 in undiluted effluent after 15 days of retention period. However, in dairy control, pH was found to decrease slightly. But in well water control, pH slightly increased. EC in all the experimental samples were found to increase with increase in retention period and it was high in the case of undiluted effluent (10.89%).

Turbidity was found to decrease in undiluted effluent and in diluted effluent. The reduction in turbidity was high with undiluted effluent (77.49%). In well water, the turbidity was found to increase slightly (25%). Total solids showed a pronounced reduction in both diluted and undiluted effluent ($p < 0.05$) in the *Azolla* sp.-based CWs. TSS showed a positive change in undiluted, diluted and effluent control. Among the different nutrients like potassium ($p < 0.05$), sodium ($p < 0.01$) and nitrate-nitrogen, sodium showed the highest reduction (85.54%) in diluted effluent. The percentage reduction was more with diluted effluent for sodium and potassium. BOD5 values of undiluted effluent showed a marked reduction from 1,300 to 220 mg/l (83.07%) and were statistically significant at 0.01 levels. BOD5 reduction was high in diluted effluent (87.43%), and COD reduction was also high in diluted effluent (89.10%). COD values of undiluted effluent also showed a marked reduction, i.e., from 2,920 to 598 mg/l (Table 6).

3.7 Discussion

Performance criteria for contaminant removal in wetlands may be based on the contaminant concentration in the wetland outflow or on the total or per cent mass removal of the contaminant. It is important that the selected criteria accurately reflect the actual performance of the wetland relative to the objectives and intended uses of the wetland treatment system. In the present study, an attempt has been made to have a comparative assessment of the efficiency of aquatic weeds like *Typha* sp., *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Azolla* sp. and *Lemna* sp. to treat the effluents from dairy effluent under laboratory conditions. The effluent samples collected from the treatment set were analysed periodically with a view to find out the changes in its physico-chemical properties brought by the growth of the respective weeds. The physico-chemical properties of effluent samples analysed include the changes in pH, turbidity, conductivity, total solids, TDS, TSS, sodium, potassium, nitrate-nitrogen, salinity, BOD5, COD and heavy metals. The percentage change (increase/decrease) in the physico-chemical characteristics of control and effluent samples treated with aquatic macrophytes in retention time of 15 days were also calculated.

pH seems to be the most important parameter in the biosorptive process: it affects the solution chemistry of the metals, the activity of the functional groups in the biomass and the competition of metallic ions (Galun 1987). The pH of the water samples from the control and treatment sets of *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Typha* sp., *Azolla* sp., *Lemna* sp. were brought to the neutral range after treatment with the respective weeds. The pH of raw effluents used for the present study was found to be alkaline. The pH was reduced from alkaline to nearly neutral by treatment with aquatic macrophytes. Abioye (2005) and Mahmood et al. (2005) earlier reported similar results. It can be

Table 3 Variation in physico-chemical characteristics of dairy effluent treated with *Lemna* sp

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
pH	Initial	8.05	7.57	7.89	8.05
	5 days	8.02	7.41	7.71	7.72
	10 days	8.02	7.38	7.59	7.61
	15 days	8.01	7.62	7.46	7.56
	%Increase/decrease	−0.49	+0.66	−5.44	−6.08
Conductivity (μS cm^{-1})	Initial	1.01	1.44	0.897	1.002
	5 days	0.98	1.46	0.82	0.86
	10 days	0.97	1.49	0.73	0.78
	15 days	0.97	1.52	0.634	0.52
	%Increase/decrease	−3.96	+5.56	−28.76	−48.52
Turbidity (NTU)	Initial	542	4	353	542
	5 days	534	9	245	475
	10 days	523	6	175	312
	15 days	512	5	122	179
	%Increase/decrease	−5.53	+25	−65.44*	−66.97*
Total solids (mg/l)	Initial	1,986	18	876	1,986
	5 days	1,982	23	776	1,236
	10 days	1,974	22	564	864
	15 days	1,964	21	422	562
	%Increase/decrease	−1.11	+16.7	−51.82	−71.70*
TSS (mg/l)	Initial	6.44	0.94	3.24	6.44
	5 days	6.42	1.12	3.16	4.8
	10 days	6.42	1.42	2.71	3.8
	15 days	6.41	1.87	2.02	2.3
	%Increase/decrease	−0.47	+98.93	−37.65	−64.29*
TDS (mg/l)	Initial	1,377.56	17.06	872.76	1,377.56
	5 days	1,313.58	16.88	772.84	1,231.2
	10 days	1,289.58	20.59	561.29	860.2
	15 days	1,161.59	19.14	419.98	559.7
	%Increase/decrease	−15.67	+12.19	−51.87	−59.37
Potassium (mg/l)	Initial	17.4	11.8	6.2	17.4
	5 days	17.4	10.24	3.4	12.6
	10 days	17.3	9.86	2.5	8.4
	15 days	17.3	9.62	1.8	6.7
	%Increase/decrease	−0.57	−18.47	−70.97*	−61.49*
Sodium (mg/l)	Initial	342.2	2.1	232.4	342.2
	5 days	342.1	1.4	124.8	284.4
	10 days	340.4	1.3	96.4	160
	15 days	338.2	1.2	38	126
	%Increase/decrease	−1.17	−42.85	−83.65**	−63.18*
NNO_3 (mg/l)	Initial	4.12	0.23	3.26	4.12
	5 days	4.10	0.21	3.24	3.86
	10 days	4.10	0.14	3.16	3.64
	15 days	4.07	0.09	3.02	3.28
	%Increase/decrease	−1.21	−60.87*	−7.36	−20.38

Table 3 continued

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
BOD5 (mg/l)	Initial	1,300	2.1	780	1,300
	5 days	1,300	2.2	420	628
	10 days	1,298	1.8	260	480
	15 days	1,284	1.2	156	412
	%Increase/decrease	−1.23	−42.86	−80	−68.31*
COD (mg/l)	Initial	2,920	2.8	1,670	2,920
	5 days	2,912	2.4	1,214	1,968
	10 days	2,912	1.8	768	1,216
	15 days	1,904	1.8	524	814
	%Increase/decrease	−34.79	−35.71	−68.62*	−72.12*

* Significance at 5% level

** Significance at 1% level

interpreted that the reduction in pH may due to absorption of nutrients and other salts by plants or by simultaneous release of H+ ions with the uptake of metal ions (Mahmood et al. 2005; Maheswari and Murugesan 2009).

The conductivity was reduced considerably except with *Azolla* sp.-based CWs. The maximum reduction in conductivity (56.43%) was observed with *Pistia sp.*-based CWs in the undiluted effluent. Trivedi and Gudekar (1987) noticed a reduction of 65.31% in conductivity of settled waste treated with *Eichhornia crassipes* after 4 days of treatment. The diluted effluent of dairy effluent also showed decrease in conductivity except with *Azolla* sp.-based CWs. Mahmood et al. (2005) on working with *Eichhornia* sp.-based CWs reported 55.71% reduction in conductivity after 12 days of treatment period.

Phytoremediation generally reduced turbidity (Neralla et al. 2007). In this study also, a very high reduction in turbidity was noticed with all the experimental plants. Among the effluents, turbidity of undiluted dairy effluent showed maximum reduction, i.e., up to 77.49% in undiluted effluent with *Azolla* sp.-based CWs. The turbidity of undiluted effluent was reduced more than that of the diluted effluent in dairy effluent. Alicia et al. (1994) reported that the roots of some aquatic plants can retain both coarse and fine particulate organic materials present in water bodies supporting their growth. This was mainly achieved through the electrical charges associated with the root hairs, which reacts with the opposite charges on colloidal particles. The experimental plants have extensive root system which traps the colloidal particles and other dust particles in their roots. Thus, the effluent becomes clearer in terms of turbidity. The reduction in total solids of effluent samples treated by the aquatic macrophytes in the present study could be attributed to this reason. Gudekar and Trivedi (1989) reported 59.54% reduction in turbidity in treatment of engineering industry waste with water hyacinth.

The total solids of all the effluents were significantly reduced with all the plants after the treatment period. The maximum reduction in undiluted effluent was in dairy effluent with *Typha* sp. (83.79%). In case of diluted effluent also, the maximum reduction was in dairy effluent with *Typha* sp. (76.71%). The Ghaly et al. (2004) reported 54.7–91.0% reduction in total solids in aquaculture waste treated with aquatic macrophytes in 12 days. The reduction in TS was due to the retaining of coarse and fine particulate organic materials present in water bodies supporting their growth by the root system (Alicia et al. 1994).

Wetlands are capable of achieving a high efficiency of suspended solids removal from the water column. Suspended matter in the water may contain a number of types of contaminants, such as nutrients, heavy metals and organic compounds. These contaminants may themselves be in particulate form or they may be physically or chemically bound to the particulate matter. Thus, in cases where the bulk of the contaminant load is associated with particulate matter, physical settling of suspended solids can result in efficient removal of the contaminants from the water or wastewater stream. Total suspended solids in the effluents were reduced in almost all the cases after the retention time of 15 days. Dilution of the effluent with well water also decreased the total suspended solids considerably. A good reduction (90%) of total suspended solids by constructed wetland plants with a retention time of 7 days was reported by Amelia (2001).

In dairy effluent, a high reduction in suspended solids was recorded in undiluted effluent. *Pistia* sp. and *Lemna* sp.-based CWs removed TSS significantly in undiluted effluent. According to IWA report (2000), in CW systems using floating macrophytes, the average overall efficiency for total suspended solids removal was 86.1%. The removal percentages of TSS in the present study agree with the study of (Ghaly et al. 2004; Haris 2007).

Table 4 Variation in physico-chemical characteristics of dairy effluent treated with *Typha* sp

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
pH	Initial	8.05	7.57	7.89	8.05
	5 days	8.02	7.41	7.81	7.71
	10 days	8.02	7.38	7.74	7.56
	15 days	8.01	7.62	7.64	7.32
	%Increase/decrease	−0.49	+0.66	−3.17	−9.07
Conductivity (μS cm^{-1})	Initial	1.01	1.44	0.897	1.002
	5 days	0.98	1.46	0.83	0.86
	10 days	0.97	1.49	0.72	0.52
	15 days	0.97	1.52	0.62	0.45
	%Increase/decrease	−3.96	+5.56	−30.34	−55.45
Turbidity (NTU)	Initial	542	4	353	542
	5 days	534	9	226	489
	10 days	523	6	162	364
	15 days	512	5	98	162
	%Increase/decrease	−5.54	+25	−72.24*	−70.11*
Total solids (mg/l)	Initial	1,986	18	876	1,986
	5 days	1,982	23	568	1,020
	10 days	1,974	22	342	642
	15 days	1,964	21	204	322
	%Increase/decrease	−1.11	+16.67	−76.71**	−83.79**
TSS (mg/l)	Initial	6.44	0.94	3.24	6.44
	5 days	6.42	1.12	3.34	6.28
	10 days	6.42	1.42	3.14	6.52
	15 days	6.41	1.87	4.12	7.14
	%Increase/decrease	−0.46	+98.94	+27.16	+10.87
TDS (mg/l)	Initial	1,377.56	17.06	872.76	1,377.56
	5 days	1,313.58	16.88	564.66	1,013.72
	10 days	1,289.58	20.59	338.86	635.48
	15 days	1,161.59	19.14	199.88	314.86
	%Increase/decrease	−15.68	+12.19	−77.10**	−77.14**
Potassium (mg/l)	Initial	17.4	11.8	6.2	17.4
	5 days	17.4	10.24	3.2	12.4
	10 days	17.3	9.86	2.1	6.6
	15 days	17.3	9.62	0.98	3.2
	%Increase/decrease	−0.57	−18.47	−84.19**	−81.61**
Sodium (mg/l)	Initial	342.2	2.1	232.4	342.2
	5 days	342.1	1.4	112.5	245.6
	10 days	340.4	1.3	74.2	110.3
	15 days	338.2	1.2	33.1	96.4
	%Increase/decrease	−1.16	−42.86	−85.76**	−71.83*
NNO_3 (mg/l)	Initial	4.12	0.23	3.26	4.12
	5 days	4.10	0.21	2.54	3.21
	10 days	4.10	0.14	1.56	2.54
	15 days	4.07	0.09	1.03	1.21
	%Increase/decrease	−1.21	−60.86	−68.40*	−70.63*

Table 4 continued

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
BOD5 (mg/l)	Initial	1,300	2.1	780	1,300
	5 days	1,300	2.2	360	680
	10 days	1,298	1.8	180	320
	15 days	1,284	1.2	96	260
	%Increase/decrease	−1.23	−42.86	−87.69**	−80**
COD (mg/l)	Initial	2,920	2.8	1,670	2,920
	5 days	2,912	2.4	746	1,234
	10 days	2,912	1.8	435	714
	15 days	1,904	1.8	186	424
	%Increase/decrease	−34.79	−35.71	−88.86**	−85.48**

* Significance at 5% level

** Significance at 1% level

Total dissolved solids measurements are often used to express the degree of contamination or amount of impurities in water and wastewater. A wide variety of inorganic ions and organic compounds, many of which may not be considered as contaminants, contribute to the sum total of dissolved solids. A number of these are biologically utilized or chemically reactive in wetlands. However, TDS often includes relatively high concentrations of unreactive, dissolved compounds, which are not removed in wetlands. In the present study, a high amount of total dissolved solids were present in dairy effluent (1,377.56 mg/l) and upon dilution, it was reduced to 872.76 mg/l. *Pistia* sp.-based CWs removed the highest (82.07%) amount of total dissolved solids from undiluted effluent and *Typha* sp. removed maximum from diluted effluent (77.10%). Khosravi et al. (2005) reported the importance of TDS uptake by *Azolla filiculoides* for their growth in wetlands. Groudev et al. (2001) observed reduction of total dissolved solids from 2,620 to 1,230 mg/l in treatment of acid mine drainage from a uranium deposit by means of a natural wetland. However, a slight removal of TDS was observed by Wirojanagud et al. (2002) in pulp and paper industrial wastewater.

The nutrients, potassium, sodium and nitrate-nitrogen content of the control and effluent dilutions from *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Typha* sp., *Azolla* sp. and *Lemna* sp. treatment sets were found to be decreasing as the treatment days increased. Trivedi and Gudekar (1987) noticed a reduction of 56% of sodium and 99.39% potassium, respectively, with 100 and 25% concentration of textile industry waste treated with *Eichhornia crassipes* after 4 days of treatment.

Sodium content of the effluents was found to be decreasing with increase in retention time. In dairy effluent, high amount of sodium was present in undiluted effluent and upon dilution, the concentration was reduced. Aquatic macrophytes were more efficient in removal of sodium from diluted effluent. Among the treatment plants, *Azolla* sp. removed highest amount of sodium from undiluted dairy effluent (77.56%). In case of diluted effluent, *Salvinia* sp. removed the maximum sodium from dairy effluent (90.36%). In short, floating macrophytes were the efficient candidates for sodium removal. Water hyacinth (*Eichhornia crassipes)* is a floating macrophyte whose appetite for nutrients and explosive growth rate has been put to use in cleaning up municipal and agriculture wastewater (Gupta 1980).

Nitrogen in wastewater exists in many forms. Each of the nitrogen forms is interconvertible and they were components of the nitrogen cycle. Nitrate-nitrogen was the maximum in dairy effluent among the various effluents. The concentration of nitrate-nitrogen decreased in all effluents upon dilution. In dairy effluent, maximum utilization of nitrate-nitrogen was in *Typha* sp.-based CWs. Tegegne et al. (2008) noticed significant difference in the concentration of nitrate-nitrogen when the effluents from various industries were treated with wetlands. Simon and Silhol (1987) and Ghaly et al. (2004) observed 82.9 to 98.1% decrease in nitrate-nitrogen of aquaculture waste water using wetlands.

The BOD5 of the effluents ranged from 120 to 1,200 mg/l. Organic matter contains approximately 45–50% carbon, which is utilized by a wide array of microorganisms as a source of energy. A large number of these microorganisms consume oxygen to break down organic carbon to carbon dioxide, a process that provides energy for growth. Therefore, the release of excessive amounts of organic carbon to surface waters can result in a significant depletion of O_2 and subsequent mortality of fish and other O_2-dependent aquatic or marine organisms. Marked reduction in BOD5 was noticed with water samples from various treatment sets. Different effluent samples

Table 5 Variation in physico-chemical characteristics of dairy effluent treated with *Salvinia* sp

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
pH	Initial	8.05	7.57	7.89	8.05
	5 days	8.02	7.41	7.84	7.67
	10 days	8.02	7.38	7.71	7.54
	15 days	8.01	7.62	7.62	7.42
	%Increase/decrease	−0.49	+0.66	−3.42	−7.83
Conductivity (μS cm^{-1})	Initial	1.01	1.44	0.897	1.002
	5 days	0.98	1.46	0.845	0.964
	10 days	0.97	1.49	0.734	0.784
	15 days	0.97	1.52	0.488	0.622
	%Increase/decrease	−3.96	+5.56	−45.17	−38.42
Turbidity (NTU)	Initial	542	4	353	542
	5 days	534	9	234	482
	10 days	523	6	184	322
	15 days	512	5	136	194
	%Increase/decrease	−5.53	+25	−61.47*	−64.21*
Total solids (mg/l)	Initial	1,986	18	876	1,986
	5 days	1,982	23	742	1,216
	10 days	1,974	22	512	856
	15 days	1,964	21	362	514
	%Increase/decrease	−1.11	+16.67	−58.67	−74.12*
TSS (mg/l)	Initial	6.44	0.94	3.24	6.44
	5 days	6.42	1.12	3.12	6.12
	10 days	6.42	1.42	3.56	5.84
	15 days	6.41	1.87	3.68	6.54
	%Increase/decrease	−0.46	+98.94**	+13.58	+1.55
TDS (mg/l)	Initial	1,377.56	17.06	872.76	1,377.56
	5 days	1,313.58	16.88	738.88	1,209.88
	10 days	1,289.58	20.59	508.44	850.16
	15 days	1,161.59	19.14	358.32	507.6
	%Increase/decrease	−15.68	+12.19	−58.94	−63.15*
Potassium (mg/l)	Initial	17.4	11.8	6.2	17.4
	5 days	17.4	10.24	3.8	12.6
	10 days	17.3	9.86	2.4	8.4
	15 days	17.3	9.62	2.1	6.4
	%Increase/decrease	−0.57	−18.47	−66.12*	−63.21*
Sodium (mg/l)	Initial	342.2	2.1	232.4	342.2
	5 days	342.1	1.4	121.4	241.3
	10 days	340.4	1.3	96.2	141.2
	15 days	338.2	1.2	22.4	111.9
	%Increase/decrease	−1.17	−42.86	−90.36**	−67.29*
NNO_3 (mg/l)	Initial	4.12	0.23	3.26	4.12
	5 days	4.10	0.21	3.21	4.98
	10 days	4.10	0.14	3.12	4.62
	15 days	4.07	0.09	2.98	4.34
	%Increase/decrease	−1.21	−60.87	−8.59	+5.34

Table 5 continued

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
BOD5 (mg/l)	Initial	1,300	2.1	780	1,300
	5 days	1,300	2.2	340	630
	10 days	1,298	1.8	180	440
	15 days	1,284	1.2	96	290
	%Increase/decrease	−1.23	−42.85	−87.69**	−77.69**
COD (mg/l)	Initial	2,920	2.8	1,670	2,920
	5 days	2,912	2.4	1,136	1,788
	10 days	2,912	1.8	664	1,212
	15 days	1,904	1.8	306	822
	%Increase/decrease	−34.79	−35.71	−81.67**	−71.85*

* Significance at 5% level

** Significance at 1% level

from *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Typha* sp., *Azolla* sp. and *Lemna* sp. showed marked reduction in BOD5. The maximum reduction in BOD5 in undiluted effluent was with *Azolla* sp. and *Eichhornia* sp.-based CWs (83.07%) followed by *Typha* sp.-based CWs (80%). In case of diluted effluent, the maximum reduction was with *Salvinia* sp. and *Typha* sp.-based CWs followed by *Azolla* sp.-based CWs. Sinha and Sinha as early as in 1969 reported a reduction of 93.7% BOD5 with digested sugar factory effluent after 7 days of treatment and 100% reduction with septic tank effluent after 3 days of treatment with *Eichhornia crassipes*. Santos et al. (1987) also reported reduction of 90.7% BOD5 in 5 days with a high organic load stabilization pond using water hyacinth. Tegegne et al. (2008) and Kirzhner et al. (2008) noticed significance decrease in the concentration of BOD5 when the effluents from various industries were treated with constructed wetlands.

Recent studies by Adeola et al. (2009) reported significant reductions in the biochemical oxygen demand throughout the system with levels decreasing by up to 76.7% across the constructed wetland cells. Gudekar and Trivedi (1989) reported 63.41% reduction in BOD5 with 4 days treatment and 89.13% reduction in BOD5 with 2 days treatment using effluent from engineering industry waste. Sharma and Sharma (1994) noticed a reduction of 70% COD and 72% BOD5 after 10 days of treatment with paper mill effluent. Kirzhner et al. (2008) working in phytoremediation reported that the BOD5 of industrial effluents was removed by 65–70% after 4 days of retention period by floating macrophytes.

Effluent samples after treatment from *Eichhornia* sp., *Salvinia* sp., *Pistia* sp., *Typha* sp., *Azolla* sp. and *Lemna* sp. showed marked reduction in chemical oxygen demand. The maximum reduction in undiluted effluent was with *Typha* sp.-based CWs (85.48%) followed by *Eichhornia* sp.-based CWs (82.53%). In case of diluted effluent, the maximum reduction was with *Azolla* sp.-based CWs followed by *Typha* sp.-based CWs after treatment period of 15 days.

Zimmels et al. (2006) noticed 360% reduction in COD in a pilot study with *Eichhornia crassipes* and *Pistia stratiotes* for treatment of urban sewage in Israel. Zhang et al. (2007) reported that the efficiency of COD removal varied a lot for various species to different contaminants. In case of undiluted effluent, *Typha* sp.-based CWs removed maximum amount of COD followed by *Azolla* sp.-based CWs. Treatment of textile dye using anaerobic baffled reactor by wetland plants removed 70–90% COD (Bell and Buckley 2003; Haris 2007). Tegegne et al. (2008) noticed significant difference (56.0–91.5%) in the concentration of COD when the effluents from various industries were treated with wetlands.

The reduction in BOD5 and COD can be attributed to many reasons. Aquatic plants have the unique feature of transporting oxygen from the aerial plant portions to the submerged parts of the plant, and the oxygen transported by aquatic plants significantly increase the sub-canopy oxygen content of the water (Hartman and Eldowney 1993). Reddy and DeBusk (1987) reported that oxygen transfer by aquatic plants into the root zone plays a significant role in supporting the growth of aerobic bacteria in the root zone and subsequent degradation of waste water carbon. Moreover, the higher suspended solids in the effluent samples may help in enhanced microbial activity as additional substrate on the roots of aquatic plants. The reduction in COD and BOD5 can result in an increase in dissolved oxygen concentration of wastewater (Mahmood et al. 2005). In case of milma effluent, which had high BOD5 and COD, compared with other effluents used for this study, it was effectively remediated by the emergent plant. *Eichhornia* sp., *Azolla* sp. and *Pistia* sp.

Table 6 Variation in physico-chemical characteristics of dairy effluent treated with *Azolla* sp

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
pH	Initial	8.05	7.57	7.89	8.05
	5 days	8.02	7.41	7.86	7.41
	10 days	8.02	7.38	7.64	7.12
	15 days	8.01	7.62	7.58	6.8
	%Increase/decrease	−0.49	+0.66	−3.92	−15.53
Conductivity (μS cm^{-1})	Initial	1.01	1.44	0.897	1.002
	5 days	0.98	1.46	0.84	0.98
	10 days	0.97	1.49	0.94	1.02
	15 days	0.97	1.52	0.96	1.12
	%Increase/decrease	−3.96	+5.56	+7.86	+10.89
Turbidity (NTU)	Initial	542	4	353	542
	5 days	534	9	224	384
	10 days	523	6	164	264
	15 days	512	5	98	122
	%Increase/decrease	−5.53	+25	−72.24*	−77.49**
Total solids (mg/l)	Initial	1,986	18	876	1,986
	5 days	1,982	23	716	1,322
	10 days	1,974	22	548	984
	15 days	1,964	21	368	588
	%Increase/decrease	−1.11	+16.67	−57.99	−70.39*
TSS (mg/l)	Initial	6.44	0.94	3.24	6.44
	5 days	6.42	1.12	3.18	5.88
	10 days	6.42	1.42	3.96	6.24
	15 days	6.41	1.87	4.1	6.58
	%Increase/decrease	−0.47	+98.93**	+26.54	+2.17
TDS (mg/l)	Initial	1,377.56	17.06	872.76	1,377.56
	5 days	1,313.58	16.88	712.82	1,316.12
	10 days	1,289.58	20.59	544.04	977.76
	15 days	1,161.59	19.14	363.9	581.42
	%Increase/decrease	−15.67	+12.19	−58.30	−57.79
Potassium (mg/l)	Initial	17.4	11.8	6.2	17.4
	5 days	17.4	10.24	3.6	12.4
	10 days	17.3	9.86	2.4	10.4
	15 days	17.3	9.62	1.8	6.5
	%Increase/decrease	−0.57	−18.47	−70.97*	−62.64*
Sodium (mg/l)	Initial	342.2	2.1	232.4	342.2
	5 days	342.1	1.4	136.2	246.2
	10 days	340.4	1.3	74.6	103.4
	15 days	338.2	1.2	33.6	76.8
	%Increase/decrease	−1.17	−42.86	−85.54**	−77.56**
NNO_3 (mg/l)	Initial	4.12	0.23	3.26	4.12
	5 days	4.10	0.21	3.24	3.98
	10 days	4.10	0.14	3.11	3.62
	15 days	4.07	0.09	2.74	3.34
	%Increase/decrease	−1.21	−60.87*	−15.95	−18.93

Table 6 continued

Parameters analysed	Retention time	Milma control	Well water control	Diluted effluent	Undiluted effluent
BOD5 (mg/l)	Initial	1,300	2.1	780	1,300
	5 days	1,300	2.2	440	680
	10 days	1,298	1.8	186	320
	15 days	1,284	1.2	98	220
	%Increase/decrease	−1.23	−42.86	−87.43**	−83.07*
COD (mg/l)	Initial	2,920	2.8	1,670	2,920
	5 days	2,912	2.4	865	1,216
	10 days	2,912	1.8	364	724
	15 days	1,904	1.8	182	598
	%Increase/decrease	−34.79	−35.71	−89.10**	−79.52*

* Significance at 5% level

** Significance at 1% level

Table 7 Comparison of efficiency of tested plant species in removing the pollutants after 15 days from undiluted effluent

Parameters	Dairy effluent	*Pistia*	*Eichhornia*	*Lemna*	*Typha*	*Salvinia*	*Azolla*
pH	8.05	7.46	7.54	7.56	7.32	7.42	6.8
Conductivity (μS cm^{-1})	1.002	0.44	0.54	0.52	0.45	0.622	1.12
Turbidity (NTU)	542	179	164	179	162	194	122
Total solids (mg/l)	1,986	465	516	562	322	514	588
Total suspended solids (mg/l)	6.44	2.18	6.54	2.3	7.14	6.54	6.58
Total dissolved solids (mg/l)	1,377.56	247	509.46	559.7	314.86	507.6	581.42
Potassium (mg/l)	17.4	4.4	11.2	6.7	3.2	6.4	6.5
Sodium (mg/l)	342.2	107.5	120.6	126	96.4	111.9	76.8
NNO_3 (mg/l)	4.12	4.34	3.22	3.28	1.21	822	3.34
BOD5 (mg/l)	1,300	320	220	412	260	290	220
COD (mg/l)	2,920	744	510	814	424	434	598

was also helpful in removing the pollutants from the milma effluent.

From this study, the emergent plant *Typha* sp.-based constructed wetland has proved as a promising technology for dairy effluent. Its rooted nature has favoured increased rhizosphere activity, thereby enhancing nutrient and metal uptake. Among the floating plants, *Eichhornia* sp. and *Salvinia* sp. were found to be more effective. The extensive root system and flourished biomass growth might have favoured this. Comparison of efficiency of tested plant species in removing the pollutants after 15 days from dairy effluent were shown in Table 7. From this study, it is clear that for the treatment of dairy effluents, constructed wetland technology with *Typha sp*. is the best option.

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