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Phytoremediation efficiency of water hyacinth (*E. crassipes*), canna (*C. indica*) and duckweed (*L. minor*) plants in treatment of sewage water

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Abstract

Due to the continuous increase in industrialisation and urbanization, wastewater has been released regularly into the environment in excess amount, causing noteworthy impacts on human and wild life. Management and eco-friendly treatment of the waste water whether industrial and domestic is the challenge of this century. In the present study an attempt has been made to treat the waste water using three aquatic macrophytes viz. water hyacinth (*Eichhornia crassipes*), canna (*Cana indica*) and duckweed (*Lemna minor*) for assessing the potential of these plants in the treatment of sewage collected from drain located nearby Graphic Era University, Dehradun using phytoremediation technology on the basis of different physicochemical parameters such as pH, EC, DO, ORP, Salinity, TDS, BOD, COD, Hardness and Temperature. The study was divided into seven consecutive assessment periods of five days interval each. Highest removal was observed in the experiment containing canna in each parameters which suggest that in the present study canna (*C. indica*) was found most efficient plant in comparison to *E. crassipes* and *L. minor.* The capability of these plants in the treatment of wastewater was established from the study. For efficient water purification, it is recommended to remove the aquatic macrophytes from water bodies. If the harvesting of these aquatic macrophytes will not be performed properly, the vast majority of the nutrients that have been absorbed and stored into the plant tissue will released again into the water bodies due to decomposition of these macrophytes.

Key words: Harvesting, *Eichhornia crassipes, IWMI, O and M problem, sullage.*

Introduction

On one hand the need of water is growing day by day while on the other hand scarcity of water resources is continuously growing in the world. The International Water Management Institute (IWMI) predicts that by 2025, one person in three will live in conditions of absolute water scarcity only in India. Approximately 61754 MLD sewage, was generated during 2015 in the country. Out of this sewage only 38% was treated (22963 MLD) and about 62% (38791 MLD) of the total sewage was released directly into the environment. Primary treatment facilities are available only in Twenty seven cities and forty-nine have primary and secondary treatment facilities. The level of treatment available in cities with existing treatment plant varies from 2.5% to 89% of the sewage generated (Source: ENVIS centre on Hygiene, Sanitation, Sewage Treatment Systems and Technology).

Status on Sewage Generation in Metropolitan Cities, Class-I Cities and Class-II Towns: The data indicate that due to population explosion, huge volume of sewage is being produced in metropolitan cities. Discharge of untreated sewage both in surface and ground waters is the most important water polluting source in India (Bhutiani *et al.*, 2016). There is a large gap between per day sewage generation and treatment capacity (Out of 100 only 32%) in India. Even the existing treatment facilities are facing operation and maintenance problem (O and M) due to absence of skill and poor economic conditions (nearly 39% plants are not conforming to the general standards prescribed under the Environmental (Protection) Rules for discharge into streams as per the CPCB's survey report). Auxiliary power back-up facility is required at all the intermediate (IPS) and main pumping

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stations (MPS) of all the STPs. Approximately 81% of the water supplied to the 299 class I returned as sewage (16,662 MLD). The reuse of wastewater is a valuable economical source of water in developing countries like India (Bhutiani and Ahamad, 2018). Due to high capital and maintenance costs, with no economic return, the available technologies are unaffordable. In India only in 4% (only 232 out of 4700 towns / cities), have the sewerage system, and that too only partial. Most of the untreated waste water is, therefore, discharged directly into river bodies or other water surface or underground water bodies. Sue lack of awareness and treatment facilities most of the sewage and sullage generated in rural areas discharged directly in to the open water bodies such as pond, which caused the problem of eutrophication in these water bodies due to excess of nitrate and phosphates. Thus in developing countries like India simple, easy to use and cost-effective technology of waste water purification is on high demand. One of the treatment technologies meeting all these parameters is 'Phytoremediation' for purification of waste water.

Phytoremediation is the biological treatment of wastewater (Roongtanakiat *et al.*, 2007), based on the concept of using plants and microbiological processes to remove contaminants from the nature. Phytoremediation techniques relies on specific planting arrangements of plants, constructed wetlands (CW), floating-plant systems and numerous other configurations (Cunningham *et al.*, 1995). Different removal mechanisms like sedimentation, filtration, chemical precipitation, adsorption, microbial interactions and uptake of vegetation are involved in in this technology (Hammer, 1989). Nowadays due to low cost and low energy requirement for sewage treatment phytoremediation has become popular among all treatment technologies (Sooknah and Wilkie, 2004; Padmapriya and Murugesan, 2012; Kumar and Chopra, 2016, Kumar *et al.*, 2016). Selection of an appropriate plant having high removal capacities both for organic and inorganic pollutants is the most important factor in implementing the phytoremediation for waste water treatment (Roongtanakiat *et al.*, 2007, Stefani *et al.*, 2011).The uptake and accumulation of pollutants vary from plant to plant and also from specie to species within a genus (Singh *et al.*, 2003). The economic success of phytoremediation largely depends on photosynthetic activity and growth rate of plants (Xia and Ma, 2006) and with low to moderate amount of pollution (Jamuna and Noorjahan, 2006). Aquatic macrophytes treatment systems for waste-water are the need of developing countries, because they are cheaper to construct and a little skill is required to operate (Mahmood *et al.*, 2005) and they remove the pollutant by absorbing nutrients with their effective root system (Dhote and Dixit, 2007; Schulz *et al.*, 2003). The most common aquatic macrophytes among the floating-leaved, being employed in wastewater treatment are water hyacinth, *Canna*, water lettuce and *Lemna* (John *et al.*, 2008; Maine *et al.*, 2004; Mishra *et al.*, 2008).

***Eichhornia crassipes*:** Water hyacinth (*E. crassipes*) is a productive free floating aquatic weed (Wolverton and McDonald, 1979) is perennial macrophytes has a very fast growth rate (Reddy and Sutton, 1984; APIRIS 2005; Patil *et al.*, 2011; Dhote and Dixit, 2009). Water hyacinth is considered as an unpleasant weed and attracted the whole world attention due to its fast growth leading to serious problems in navigation, irrigation, and power generation (Dar *et al.*, 2011; Villamagna, 2009). About 60-70% of the total biomass is represented by the leaves of the plant and the leaf turnover rate can range from 60-70% per month. Water hyacinth has been successfully applied not only in removing organics and metals but also act as a bio indicator for assessment of metal pollution. It is seen that water hyacinth has a tremendous capacity of absorbing metals like copper, cadmium, zinc, iron, mercury, arsenic and lead. There is shortage of water throughout the world. Therefore, there is a need for recycling of waste water i.e., the use of reclaimed waste water whenever possible. *E. crassipes* is an aquatic plant having good feasibility of phytoremediation of wastewaters containing metallic and other kind of chemical pollutants (Kumar *et al.*, 2017a, b).

***C. indica* (Wild Cana Lily):** In Maharashtra *C. indica* is commonly known as, 'Kardali'. Macrophytes *C. indica* is a perennial herb with tuberous root. These macrophytes commonly grow naturally near open streams, near houses and along riverbanks. The plant prefers a sheltered situation. It also grows perfectly in direct sunlight, and

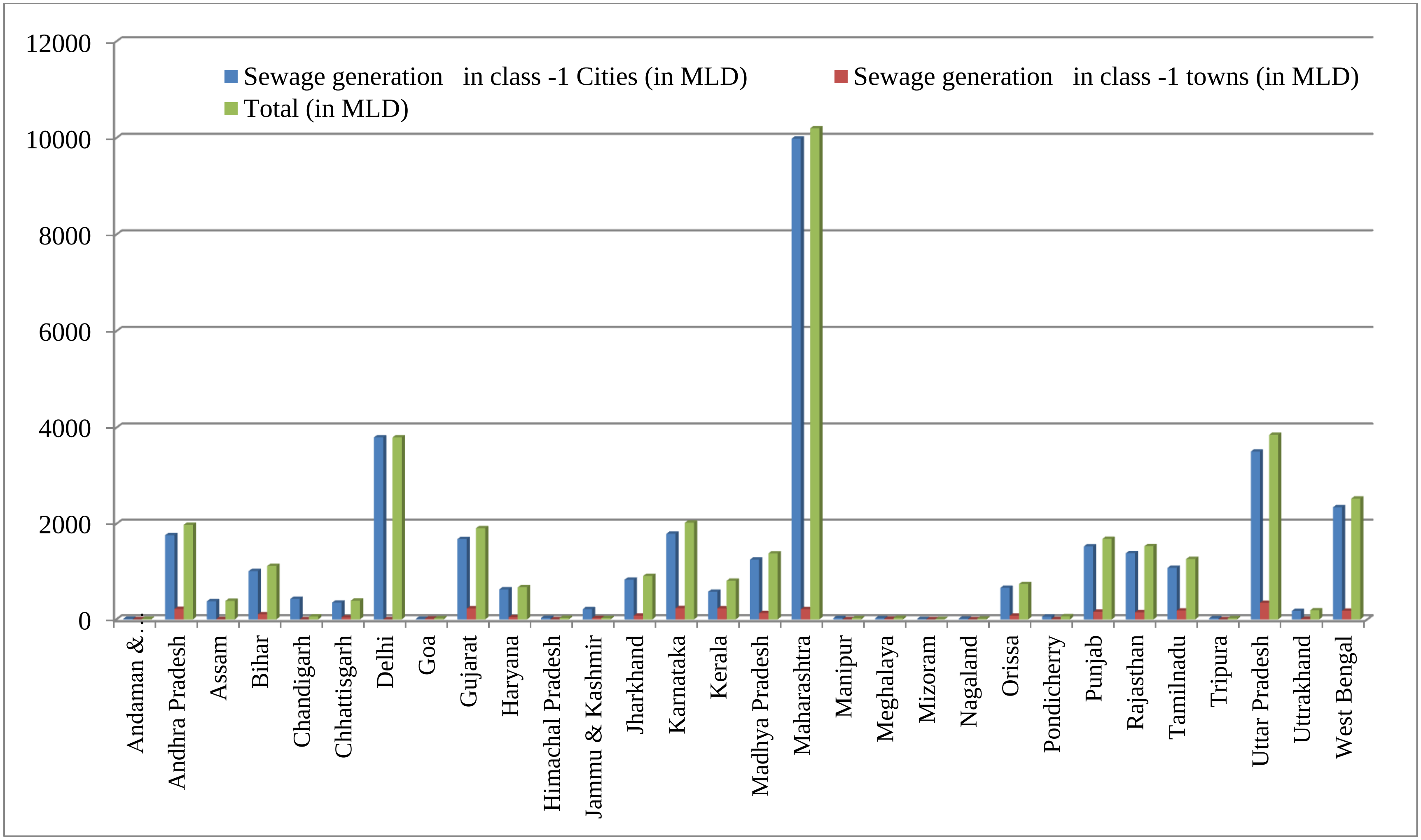

Fig 1. State-wise sewage generation of Class-I Cities and Class-II Towns

Source: ***http://www.cpcb.nic.in/upload/NewItems/NewItem_153_Foreword.pdf***

prefers medium depth levels of water. *Cana* indica grows in the soils of varied range of pH ranging from a pH of 5 to 8.5. It is adapted to a wide variety of soil type such as chalk, clay, clay loam, loam, loamy sand, peat, sandy clay, sandy clay loam and sandy loam soils. It has a clump forming growth form, and has an ultimate height of 2m / 6.6ft and spread of 0.5m / 1.6ft.

***Lemna minor* (Duck weed):** *L. minor* commonly grows in motionless or slow-flowing, nutrient-enriched waters through-out tropical and temperate zones. Suitable growth conditions for *L. minor* include temperatures range of 6-33°C, a wide pH range with optimal growth between pH 5.5 and 7.5 (Mkandawire and Dudel, 2005a, 2005b). *L. minor* are the dominant primary producer in Lemnatae type of macrophytic communities, a quartz "mono-specific" plant association (Landolt, 1980, 1982, 1986; Les *et al.*, 2002). Their advance but simple anatomical and physiological structure has scientific and engineering significance. These properties allow easy handling, and manipulating under laboratory conditions. *Lemna* is a small free-floating and fast growth aquatic plant has great ability to reduce the BOD, COD, suspended solids, bacterial and other pathogens from waste water. Reduction of BOD, COD in effluents varies from 80-90% at the retention time of 7-8 days. Of these, applications of duckweed in wastewater treatment was found to be very effective in the removal of nutrients, soluble salts, organic matter, heavy metals and in eliminating suspended solids, algal abundance and total and fecal coliform densities (Nieder *et al.*, 2004; Selvarathi and Ramasubramanian, 2010). The main aim of this study was to explore the phytoremediation potential of E.*crassipes*, *C.indica* and *L.minor* in treatment of sewage waste water.

This followed the underlying objectives:-

1. To assess phytoremediation potential *of E. crassipes, C. indica and L. minor* in treatment of sewage waste water.
2. To investigate effect of phytoremediation on physico-chemical characteristics of sewage waste water.

Materials and Methods

Collection of wastewater: Wastewater samples were collected from sewage drain located nearby Graphic Era University, Dehradun. These wastewater samples were distributed in 4 plastic tubs. 3 plants namely, *Eichhornia*, *Canna* and *Lemna* were chosen for the current study. All the physicochemical parameters were analyzed using standard methods described by APHA, 2012: Trivedy and Goel, 1986 and Khanna and Bhutiani, 2008.

Collection of Macrophytes: *E. crassipes* and *L.minor* was collected from Gang Nahar Canal, Roorkee whereas *C.indica* was collected from sewage drain of Graphic Era university campus. All three macrophytes were collected on the same day and brought to laboratory for experimental setup. Before starting the experiment, plants was thoroughly washed with tap water followed by distill water and finally roots were rinsed with acetone to avoid any contamination.

Experimental Setup: Plastic tubs, of round shape, 5 litre capacity were selected for starting experiment. Tubs were properly washed and dried with tissue. 5 litres of waste water was filled in all tubs. Tub 1 was fixed as a control and it was without any plant. *E. crassipes* was grown in tub 2, *C. indica* plant was grown in tub 3 and *L. minor* was put in tub 4 (Fig 3). Samples were taken after every 3 days separately from all four tubs and were analyzed for pH, EC, DO, ORP, salinity, TDS, BOD, COD and temperature. This assessment was carried out for 30 days at a regular interval of 3 days. Along with this microbial CFU count was carried out in laboratory of Biotechnology at Graphic Era University before and after the final treatment. Furthermore, genera of gram negative rods were identified in waste water.

Salinity and TDS of the wastewater sample was measured using Multipara meter system of model no. SensION+ MM 150. Each time before taking the reading, calibration of the instrument was done. The measurements were taken at regular intervals of 3 days. Rest of the parameters was analyzed using titrimetry and spectrophotometry technique.

Results and Discussion

Physico-chemical characteristics of waste water

Before starting the experiments, physic-chemical analysis of waste water was carried out in the laboratory. Waste water was analyzed for pH, temperature, electrical conductivity (EC), oxidation-redox potential (ORP), dissolved oxygen

Fig 2. Experimental set up for treatment of sewage waste water by *E.crassipes, C.indica, L. minor* along with control.

(DO), biochemical oxidation demand (BOD_5), chemical oxidation demand (COD), salinity, total dissolve solids (TDS), hardness (as $CaCO_3$) (Table 5.1)

pH: During assessment period a decrease was observed in pH in control experiment as well as in all the three treatments i.e. *Eichhornia crassipes, Canna indica and Lemna minor*. In control experiment pH was decreased from 7.69±0.02 to 7.32±0.03 from initial to final assessment (Table 2). Maximum decrease of 0.05 unit was recorded between 21st to 24th and 24th to 27th day of assessment period whereas minimum decrease of 0.01 unit was recorded between 1st to 3rd, 15th to 18^{th,} and 27th to 30th day of assessment period. A total of 0.37 unit decrease in pH was observed during entire assessment period (Fig 3).

In the experiment containing *Eichhornia crassipes*, pH was changed from 7.6±0.03 to 7.16±0.02 throughout assessment period. Maximum decrease of 0.08 unit was recorded between 15th to 18th day of treatment, whereas minimum decrease of 0.03 unit was observed between 27th to 30th day of assessment. Entire *Eichhornia* treatment resulted into a decrease of 0.44 unit in wastewater pH. *Canna* treatment showed a change in wastewater pH from 7.6±0.03 to 7.16±0.01 during experimental period. Maximum decrease of 0.07 unit was recorded between 12th to 15th day of treatment, however minimum decrease of 0.01 unit was observed between 27th to 30th day of assessment. Overall, *Canna* treatment showed a pH decrease of 0.49 unit which was maximum among all treatments. Microbial degradation in the waste water results into conversion of organic matter into acids which decreases pH of waste water. This is confirmed in all treatments. Results show that maximum microbial degradation occurred in *Canna* treatment. *Lemna* treatment also resulted into similar pattern of pH decrease from initial to final day of treatment. pH changed from 7.6±0.03 to 7.16±0.02 during assessment period. This change was very close to *Canna* treatment. *Lemna* treatment showed a maximum decrease of 0.09 unit

Table 1. Physico-chemical characteristics of sewage waste water

SN	Parameter	Unit	Value
1.	pH	-	7.69
2.	Electrical Conductivity (EC)	µS/cm	1534.0
3.	Oxidation-Redox potential (ORP)	mV	-69.1
4.	Total dissolved solids (TDS)	mg/L	983.0
5.	Salinity	mg/L	785.0
6.	Biochemical oxygen demand (BOD_5)	mg/L	252.0
7.	Chemical oxygen demand (COD)	mg/L	345.0
8.	Dissolved oxygen (DO)	mg/L	2.2
9.	Hardness (as $CaCo_3$)	mg/L	230.0
10.	Temperature	^{0}C	23.5

between 12th to 15th day of assessment while minimum decrease of 0.01 unit was recorded between 15th to 18th and 27th to 30th day of assessment period. Among all three treatments *Canna* treatment showed maximum decrease in pH followed by *Lemna*, *Eichhornia* and control treatment. Similar findings were observed by Mahmood *et al.*, 2005.

Electrical Conductivity (EC): During assessment period, EC was changed from 1534.0±7.0 to 1482.0±4.0 µS/cm in control; 1529.0±6.0 to 958.0±3.0 µS/cm in *Eichhornia*; 1534.0±7.0 to 750.0±2.0 µS/cm in *Canna* and 1545.0±5.0 to 811.0±5.3 µS/cm in *Lemna* treatment (Fig 4 and Table 2). In control, EC showed a maximum decrease of 9.0 µS/cm between 24th to 27thday of treatment, whereas minimum decrease of 2.0 µS/cm was found between 1st to 3rd and 15th to 18th day of treatment. However *Eichhornia* treatment showed great fluctuations in the pattern of decrease in EC value during assessment period. Maximum decrease of 218.0 µS/cm was observed between 9th to 12th day of assessment period and minimum decrease of 9.0 µS/cm was recorded between 1st to 3rd and 27th to 30th day of treatment. *Eichhornia* plant could not survive after 18th day of treatment which resulted into less decrease in EC afterwards compared to previous days of treatment. An average of 19.0 µS/cm/day EC reduction was observed during 30 days of treatment. More or less similar results were observed by Borgs *et al.*, 2008.

In *Canna* treatment, Maximum decrease of 131.0 µS/cm was observed in EC between 9th to 12thday of treatment while minimum EC reduction of 15.0 µS/cm was observed between 24th to 27th day of treatment. *Canna* treatment showed an average decrease of 26.13 µS/cm/day in EC during assessment period. *Lemna* treatment also exhibited similar trend of EC decrease during treatment period. Maximum decrease of 111.0 µS/cm in EC was recorded between 18th to 21stday of treatment. Minimum EC reduction of 51.0 0 µS/cm was found between 27th to 30th day of treatment. Average EC decrease of 24.46 µS/cm/day was observed in *Lemna* treatment. Among all three treatments *Canna* showed maximum reduction in EC followed by *Lemna*, *Eichhornia* and Control. EC reduction occurs as result of nutrient uptake of macrophytes and it suggests that *Canna* has highest nutrient uptake potential among *Eichhornia and Lemna*.

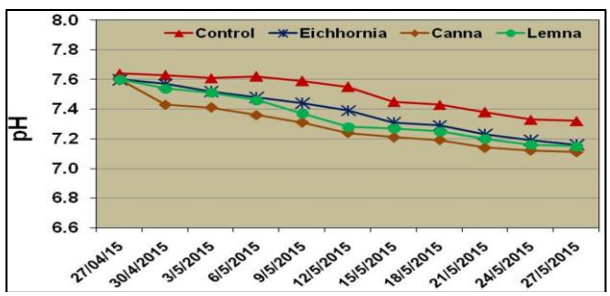

Fig 3. Change in pH of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

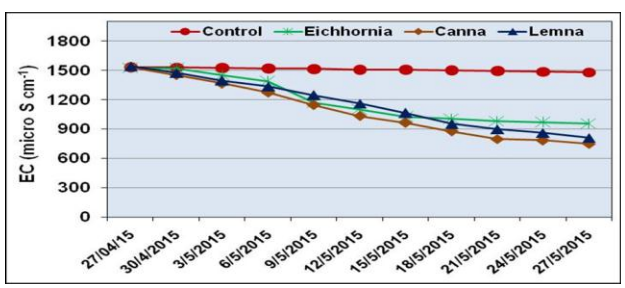

Fig 4. Change in EC of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

Oxidation-Redox potential (ORP): During assessment period, ORP was changed from -68.3±-3.3 to -48.2±-2.5 mV in control, -68.7±-4.3 to -31.9±-2.8 mV in *Eichhornia*, -72.5±-4.2 to -12.8±-2.1 mV in *Canna* and -77.2±5.4 to -16.3±-2.5 mV in *Lemna* (Fig 5 and Table 2). Average ORP change of -0.67, -1.23, -1.99 and -2.03 mV/day was observed in control, *Eichhornia*, *Canna* and *Lemna* treatment during study period respectively. In control treatment, maximum ORP change of -5.8 mV was observed between 21st to 24th day of treatment, whereas, minimum change of -0.3 mV was recorded between 6th to 9th day of assessment. In *Eichhornia* treatment, maximum change of -9.8 mV was observed between 15th to 18th day of study period whereas minimum ORP change -0.6 mV in this treatment was observed between 12th to 15th day of assessment.

In *Canna* treatment, ORP change between two consecutive assessment periods fluctuated between -1.2 to -16.8 mV. Highest ORP change was observed between 1st to 3rd day of treatment while lowest ORP change of -1.2 mV was found between 18th to 21st and 24th to 27th day of treatment. ORP change was observed in all treatments due to oxidation of organic matter by microbial action. Highest ORP change in *Canna* treatment reflects maximum microbial action in this treatment in terms of degradation of organic waste present in waste water.

Total dissolved solids (TDS): TDS concentration was decreased from 983.0±10.0 to 856.0±6.0 mg/L in control, 978.0±12 to 342.0±6.0 mg/L in *Eichhornia*, 967.0±11 to 243.0±4.0 in *Canna* and 961.0±8.0 to 298.0±5.0 mg/L in *Lemna* treatment during treatment period (Table 2). Highest TDS removal was achieved by *Canna* while control treatment showed lowest TDS removal during assessment period. Average TDS removal per day was observed as 4.2, 21.2, 24.1 and 22.1% in control, *Eichhornia*, *Canna* and *Lemna* (Fig 6). Except control treatment, rest three treatments showed more or less similar TDS removal efficiency during treatment period.

Control treatment showed 1.0 to 65.0 mg/L of TDS removal between two consecutive assessment periods. Highest TDS removal was observed between 3rd to 6th day of treatment however lowest removal was recorded between 21st to 24th day of assessment. *Eichhornia* treatment provided higher fluctuations in TDS removal between two consecutive treatment periods compared to control treatment. Maximum TDS removal of 174.0 mg/L was observed between 9th to 12th day of treatment whereas minimum removal of 2.0 mg/L was recorded between 27th to 30th day. After 15th day of treatment TDS removal rate dropped down significantly due of death of *Eichhornia crassipes* experimental pot. This reveals that macrophytes contribute significantly in TDS removal from wastewater. More or less similar results were observed by Borgs *et al.*, 2008.

In *Canna* treatment, TDS removal rate showed more compromising results compared to other treatments. TDS removal rate fluctuated between 31 to 150 mg/L between two consecutive treatment periods. Maximum TDS removal of 150.0 mg/L was recorded between 3rd to 6th day of treatment while minimum removal was observed between 27th to 30th day of assessment. *Lemna* treatment showed more consistent results in terms of TDS removal between two consecutive assessment periods. TDS removal fluctuated between 14.0 to 79.0 mg/L between two consecutive assessment periods. From initial day of treatment upto 18th day of treatment TDS removal consistently remained between 70.0 to 70.9 mg/L in consecutive assessment periods. Highest TDS removal was achieved in 3 consecutive assessment periods i.e. between 1st to 3rd day, 3rd to 6th day and 15th to 18th day of treatment. Lowest TDS removal of 14.0 mg/L was recorded between 27th to 30th day of treatment. Total dissolved solids are measure of all dissolved solutes in waste water. As plants grow in waste water it absorb dissolved salts from the waste water through its root system which results into decrease in TDS concentration with time (Greongerg *et al.,* 1995). Maximum TDS reduction was observed in *Canna* treatment which shows the efficient potential of *Canna indica* in absorption of salts from waste water.

Salinity: Salinity is the amount of all the dissolved salts present in the in the wastewater. Salinity concentration showed a change from 797.0±9.0 to 723.0±4.0 mg/L in control, 757.0±8.0 to 284.0±3.0 mg/L in *Eichhornia*, 745.0±11.0 to 146.0±5.0 mg/L in *Canna* and 735.0±8.0 to 184.0±3.0 mg/L in *Lemna* treatment (Fig 7 and Table 2). Average salinity removal per day was recorded as 2.5, 15.8, 20.0 and 18.4% in control, *Eichhornia*, *Canna* and

Lemna treatment respectively. *Canna* and *Lemna* showed more or less similar removal of salinity during treatment period. In control treatment, highest salinity removal of 13.0 mg/L was achieved between 3rd to 6th day of treatment whereas lowest salinity removal was recorded between 21st to 27th day of treatment. *Eichhornia* treatment showed a high range of fluctuations in salinity removals between consecutive assessment periods; as high as 185.0 mg/L removal was observed between 9th to 12th day of treatment and as low as 3.0 mg L^{-1} between 21st to 24th and 27th to 30th day of treatment. *Canna* treatment showed highest removal of salinity among all treatments and provided removal fluctuations between 19.0 to 109.0 mg/L removal between consecutive assessment periods. Maximum removal was achieved between 6th to 9th day of treatment whereas minimum removal was recorded between 27th to 30th day of treatment period. *Lemna* treatment also provided compromising results for salinity and was close to *Canna* treatment. Furthermore, removal efficiency was more consistent in *Lemna* treatment and fluctuated between 14.0 to 91.0 mg/L between two consecutive assessments. Higher removals were achieved between 6th to 18th day of treatment.

Plants absorb dissolved salts from the waste water through at their root zone which leads to decrease in salinity in waste water. Absorbed salts are used by plants as macronutrients. Maximum salinity reduction was observed in *Canna* treatment which shows that *Canna indica* has high capability in absorption of salts from waste water.

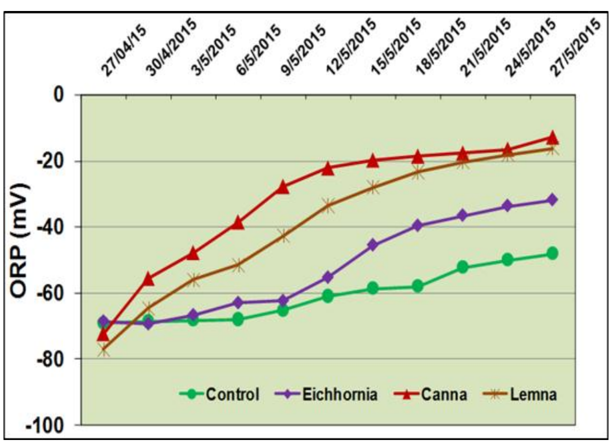

Fig 5. Change in ORP of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

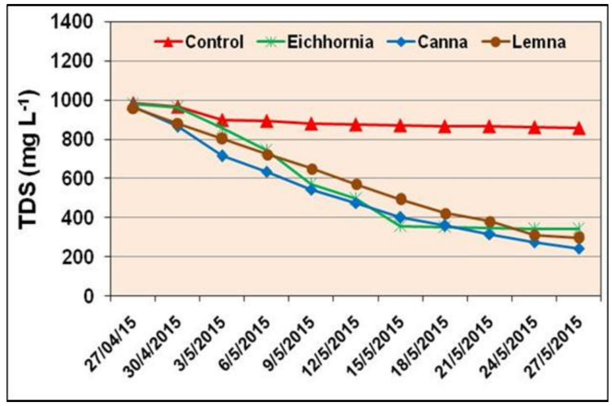

Fig 6. Change in TDS of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

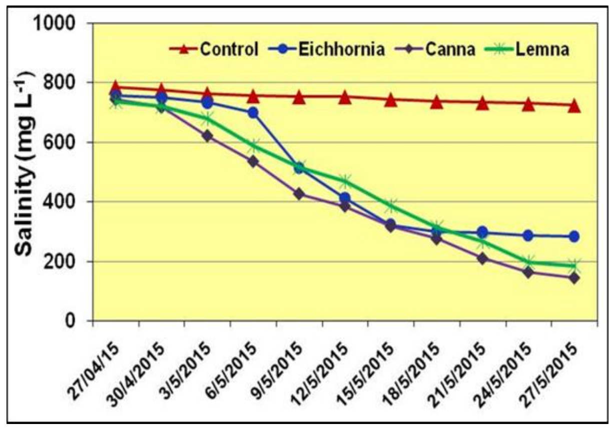

Fig 7. Change in Salinity of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

Biochemical Oxygen Demand (BOD): BOD value in control, *Eichhornia*, *Canna* and *Lemna* treatment showed a decrease from 252.0±8.0 to 218.0±6.5 mg/L, 251.0.0±5.9 to 150.0±8.2 mg/L, 246.0±6.7 to 65.0±2.5 mg/L and 251.0±4.6 to 79.0±3.3 mg/L respectively (Fig 8 and Table 2). A more or less similar trend in COD reduction was observed by Deshmukh *et al.*, 2013. Furthermore, Average BOD removal per day during assessment period was found as 1.3, 3.4, 6.0 and 5.7 mg/L. Highest BOD removal was achieved by *Canna* followed by *Lemna*, *Eichhornia* and control. Control treatment showed maximum BOD removal of 7.0 mg/L between 1st to 3rd day of treatment and a minimum removal of 1.0 mg/L between both 24th to 27th and 27th to 30th day of treatment. *Eichhornia* treatment showed varied removal rate among different assessment periods; maximum of 28 mg/L between 1st to 3rd day of treatment and minimum of 2.0 mg L^{-1}between 12th to 15th and 15th to 18th day of treatments. *Eichhornia crassipes* could not survive after 15th day of treatment therefore it adversely affected the BOD removal efficiency and resulted into a significant drop in BOD afterwards till the end day of treatment. In *Canna* treatment, BOD removal showed more fascinating results compared to *Eichhornia*, *Lemna* and control treatments. Removal rate fluctuated between 9.0 to 52.0 mg/L between two consecutive assessment periods. Higher BOD removal was observed during initial treatment periods (upto 12th day of treatment). Maximum BOD removal of 52 mg/L was recorded in first three days of treatment whereas minimum BOD removal of 9.0 mg/L was achieved between 18th to 21stday of treatment. Among all three macrophytes selected for the treatment *Canna* plant showed highest tolerance to pollution stress in terms of its growth and new leaves.

Biochemical Oxygen demand (BOD) is amount of oxygen required by microorganisms for degrading organic waste present in waste water. It reflects amount of pollution present in waste water. Higher BOD results into depletion of oxygen from wastewater and causes anaerobic conditions in wastewater. Microorganisms secrete enzymes which degrade organic matter into simpler nutrients which are further absorbed by macrophytes growing in waste water. Thus microorganisms assist in converting complex organic compounds into simpler ones to be absorbed by macrophytes.

Maximum BOD reduction in *Canna* treatment reflects the higher microbial degradation in this treatment resulting into break down of organic matter into simpler nutrients. *Lemna* treatment also showed satisfactory results with respect to BOD removal during treatment period. BOD removal rate fluctuated between 9.0 to 35.0 mg/L between consecutive assessment periods. Like *Canna* treatment, higher removal rates were observed in first three assessment periods (from 1st to 9th day of treatment) and reached 34.0% of BOD removal upto this period. Similar results were recorded by Oron *et al.* (1988), who mentioned that the duckweed contribution for the removal of organic material is due to their ability to direct use of simple organic compounds.

Chemical Oxygen Demand (COD): Chemical oxygen demand is amount of oxygen required to oxidize the organic and inorganic pollution present in waste water. In control treatment COD value was decreased from 350.0±12.0 to 306.0±8.0 mg/L throughout the assessment period (Fig 9 and Table 2). COD removal rate was observed as 11.3%. Average COD removal was recorded as 1.5 mg/L/day. COD removal fluctuated between 1.0 to 7.0 mg/L between different assessment periods. Maximum removal was recorded between 6th to 9thday of treatment while minimum removal was observed between 27th to 30th day of treatment. On the other hand, *Eichhornia* treatment showed a decrease in COD from 342.0±7.9 to 191.0±4.5 mg/L during treatment. Total COD removal in this treatment was observed as 44.2% (Table 5.3) and average COD removal was recorded as 5.0 mg/L/day during assessment period. Maximum COD removal of 30.0 mg/L was observed between 1st to 3rd day of assessment period followed by 3rd to 6th and 21st to 24th days (19 mg/L) of treatments.

In *Canna* treatment, COD value dropped from 345.0±11.0 to 102.0±5.4 mg/L during whole treatment period. *Canna* treatment recorded highest COD removal rate among all treatments and provided 70.4% of COD removal during treatment. Average COD removal was achieved as 8.1 mg/L/day which were maximum among all three treatments. COD removal ranged from 19.0-44.0 mg/L between successive assessment periods. Highest removal (44.0 mg/L) was achieved on first three days of treatment whereas lowest COD removal (19.0 mg/L) was observed between 6th to 9th and 12th to 15th day of treatment. A more or less similar trend in COD reduction was observed by Deshmukh *et al.,* 2013. Presence of plants in wastewater can deplete dissolved CO_2 during the period of high photosynthetic activity. This photo-synthetic activity increases the dissolved oxygen of water, thus creating aerobic conditions in wastewater which favour the aerobic bacterial activity to reduce the BOD and COD (Reddy, 1983).

Dissolved Oxygen (DO): Dissolved oxygen showed a change of 2.20±0.13 to 0.5±0.01 mg/L in control, 2.20±0.15 to 1.10±0.05 mg/L in *Eichhornia*, 2.25±0.07 to 1.58±0.04 mg/L in *Canna* and 2.21±0.07 to 1.45±0.03 mg/L in *Lemna* treatment (Fig 10 and Table 2). Total drop of DO was recorded as 77.3, 50.0, 29.8 and 34.4% in control, *Eichhornia, Canna* and *Lemna* treatment respectively during treatment period (Table 5.3). Maximum DO drop was observed in control followed by *Eichhornia*, *Lemna* and *Canna*. Average daily decrease in DO was observed as 0.1, 0.04, 0.02 and 0.03 mg/L /day control, *Eichhornia*, *Canna* and *Lemna* respectively.

Dissolved oxygen is utilized by microorganisms during degradation of organic waste from waste water. Continuous decrease in DO level during experimental period suggests that microbial degradation was prominent during experimental period. However DO decrease was lower in macrophyte treatment. This confirms that macrophytes were enriching atmospheric oxygen in the waste water by photosynthesis process. *Canna* and *Lemna* plants showed higher photosynthetic activity which contributed to low decrease in DO level in these treatments. The results favours the findings of Mangas-Ramirez and Elias-Gutierrez, 2004 and Perna and Burrows, 2005 but are opposites to Darr *et al.*, 2011 and Shah *et al.*, 2010.

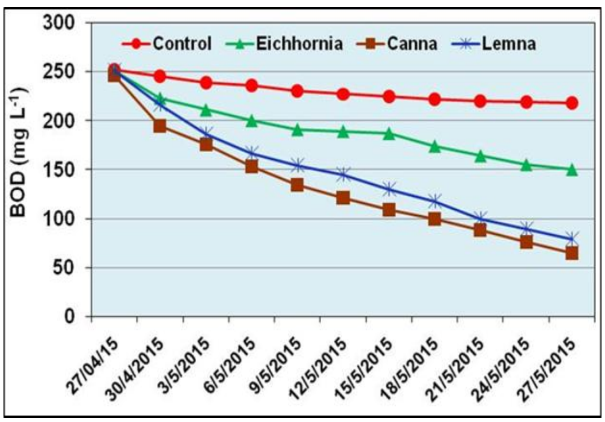

Fig 8. Change in BOD of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

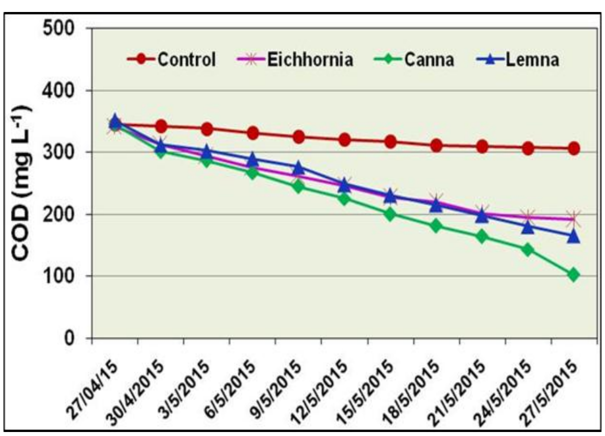

Fig 9. Change in COD of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

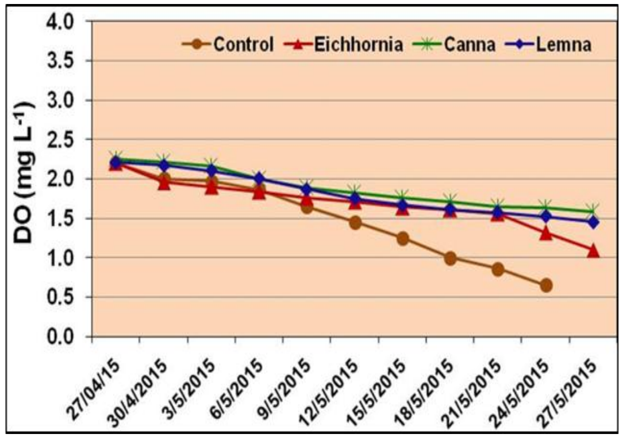

Fig 10. Change in DO of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

Hardness (as $CaCO_3$)

Hardness showed a decrease in all treatments during treatment period as; 230.0±8.5 to 183.0±4.8 mg/L in control; 232.0±5.6 to 134.0±7.6 mg/L in *Eichhornia*, 230.0±8.2 to 125.0±2.5 mg/L in *Canna* and 236.0±4.8 to 137.0±3.1 mg/L in *Lemna* treatment (Fig 12 and Table 2).

Average hardness removal was observed as; 1.8 mg/L/day in control, 2.27 mg/L in *Eichhornia*, 3.50 mg/L in *Canna* and 3.30 mg/L in *Lemna* treatment. Removal range between successive assessment periods varied from 1.0 to 10.0 mg/L in control, -1.0 to 20.0 mg/L in *Eichhornia*, 2.0 to 25.0 mg/L in *Canna* and 4.0 to 19.0 mg/L in *Lemna* treatment. Hardness removal mechanism is associated with uptake of Ca and Mg salts by plants through roots. Similar trend of hardness removal was also observed by Fonseka and Amarasinghe, 2016 and Shah *et al.*, 2010.

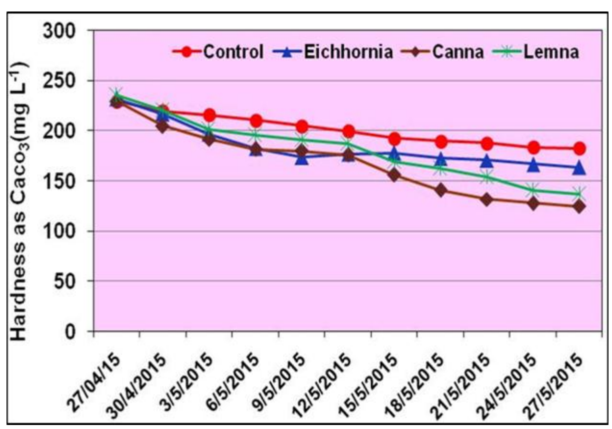

Fig 11. Change in TH of sewage during the treatment process by *Eichhornia, Canna* and *Lemna.*

Table 2. Showing changes in the physico-chemical properties of sewage before and after the treatment with *Eichhornia, Canna* and *Lemna.*

		pH	EC (µ s/cm)	ORP (mV)	DO (mg/l)	temp. (^{0}C)	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	Hardness (mg/l)	Salinity (mg/l)
27/4/15	Control	7.64	1534	-69.1	2.20	21.8	983	252	345	230	785
	Eichhornia	7.60	1529	-68.7	2.20	24.6	978	251	342	232	757
	Canna	7.60	1534	-72.5	2.25	24.6	967	246	345	230	745
	Lemna	7.60	1545	-77.2	2.21	24.6	961	251	351	236	735
30/4/15	Control	7.63	1532	-68.7	2.00	23.1	965	245	342	220	776
	Eichhornia	7.57	1520	-69.5	1.96	23.4	961	223	312	217	750
	Canna	7.43	1454	-55.7	2.21	23.0	865	194	301	205	719
	Lemna	7.54	1476	-64.7	2.17	26.3	882	216	312	221	720
3/5/15	Control	7.61	1528	-68.3	1.97	26.0	900	239	338	216	763
	Eichhornia	7.52	1453	-66.8	1.90	24.4	856	211	293	197	734
	Canna	7.41	1367	-47.9	2.16	26.1	715	176	286	192	623
	Lemna	7.51	1398	-56.1	2.10	23.0	803	186	302	202	678
6/5/15	Control	7.62	1521	-68.0	1.86	26.0	893	236	331	211	755
	Eichhornia	7.48	1387	-63.1	1.84	26.4	743	200	275	183	700
	Canna	7.36	1276	-38.6	2.00	26.6	634	153	267	182	537
	Lemna	7.46	1338	-51.6	2.00	25.5	725	166	289	196	587
9/5/15	Control	7.59	1518	-65.3	1.65	26.4	882	230	325	205	752
	Eichhornia	7.44	1169	-62.5	1.76	26.4	569	191	261	174	515
	Canna	7.31	1145	-27.8	1.89	26.1	543	134	244	180	428
	Lemna	7.37	1246	-42.8	1.87	26.0	650	154	276	191	516
12/5/15	Control	7.55	1511	-61.0	1.45	26.9	875	227	320	200	752
	Eichhornia	7.39	1100	-55.4	1.71	26.9	496	189	245	177	412
	Canna	7.24	1032	-22.2	1.82	26.9	474	121	225	176	387
	Lemna	7.28	1162	-33.7	1.75	25.6	572	145	248	187	467
15/5/15	Control	7.45	1509	-58.7	1.25	24.7	872	225	317	193	743
	Eichhornia	7.31	1025	-45.6	1.64	23.9	356	187	227	178	323
	Canna	7.21	965	-19.8	1.76	24.6	400	109	200	156	319
	Lemna	7.27	1065	-28.1	1.67	27.1	493	130	230	169	387
18/5/15	Control	7.43	1502	-58.1	1.00	25.4	867	222	311	190	736
	Eichhornia	7.29	1010	-39.7	1.61	25.5	351	174	219	173	301
	Canna	7.19	876	-18.6	1.71	25.1	359	100	181	141	277
	Lemna	7.25	954	-23.4	1.61	24.1	423	118	215	163	312
21/5/15	Control	7.38	1497	-52.3	0.86	28.1	866	220	309	188	732
	Eichhornia	7.23	985	-36.6	1.56	28.3	347	164	200	171	298
	Canna	7.14	800	-17.7	1.65	28.4	315	88	164	132	211
	Lemna	7.20	900	-20.5	1.57	25.5	382	100	198	154	267

Conclusion

Present study revealed that phytoremediation is an effective technology for treatment of sewage waste water. Among all three macrophytes, *Canna indica* showed maximum reductions in EC, TDS, BOD, COD, hardness and salinity. pH showed a decrease in all treatments with maximum decrease in *Cann*a treatment followed by *Lemna* and *Eichhornia*. After 15th day of treatment *Eichhorni*a plant could not survive in waste water which resulted into a drop in removal efficiency in *Eichhornia* treatment. This suggests that Macrophytes play an important role in absorbing contaminants from waste water through their roots. Further, following conclusions are taken out from the present study. Many factors such as temperature, pH, solar radiation, and salinity of the water influence plant growth and its phytoremediation performance. During the present study among all the three selected macrophytes *C. indica* was found most efficient in the treatment of sewage. The harvesting of macrophytes after maturation is necessary because if the plant died in the water body, the degradation of plants results in the leaching of absorbed nutrients into the water again.

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