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Assessing the pollutant removal potential of native reeds in sewage and paper mill effluents

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Abstract

Reed plants are cost effective method of remediating the wastewater. To test the removal efficiency of pollutants from sewage and paper mill effluents, four different reed plant species, *Canna indica* (Indian Shot), *Colocassia esculenta* (Taro), *Typha domingensis* (Southern Cattail) and *Xanthosoma sagittifolium* (Tannia), were compared for their removal efficiency of pollutants from sewage and paper mill effluents. Because of the high cost and limited effects of present physico-chemical treatments in wastewater treatment plant, this reed bed system can act as a cheaper process, that are essential to remove the organic pollutants, thus make them suitable for agricultural and irrigation purposes. In this study, initially, the raw effluent of sewage and paper mill was characterized. The four reed plants were separately screened with both the effluents by adopting the treatments for the four reeds and seven days retention time as two factors with 2 replications in pots. Each day, the treated effluent was collected from the pot and analysed. Up to day 7, the screening was done with both the effluents. The result shows that the *Canna indica* and *Colocassia esculenta* could be the better option for pollutant removal from the sewage and paper mill effluent respectively. The removal efficiency was higher in *Canna indica* (60%) for sewage wastewater and *Colocassia esculenta* (65%) for paper mill effluent. This removal percentage shows that the tolerating nature of the plants to the wastewater. The efficiency of the removal of pollutant by reeds can be further improved by bioaugmentation process which aids the action of microbes in the rhizosphere of the reed plants which may be used in the reed bed system.

Keywords

paper mill effluent; pollutant removal; reeds; screening and removal efficiency; sewage wastewater

Introduction

Nowadays, various industrial and commercial activities generate enormous amounts of wastewater. The water supply is anticipated to decline in many parts of the world. The water consumption for agriculture alone is predicted to rise by 20% in 2050 worldwide and this increase would be much higher without any advancements in technology or legislative measures. Providing water for agriculture and food production is one of the most extensive demands on freshwater resources. Just 4% of the world's freshwater resources are found in India, despite the country housing almost 16% of the global population (1). Per capita domestic water demand in India is expected to rise between 46 and 62 m^3/person/year by 2025 and 2050, respectively, from an estimated 31 m^3/person/year in 2000. Because of the rise in the average household water demand, there is a significant increase in the coverage of water supplies in both urban and rural areas (2). India's average annual freshwater availability per person has declined dramatically since 1951, from 5177 m^3 to 1869 m^3 in 2001 and 1588 m^3 in 2010, due to a growing population and a rapid loss of water resources. The anticipated reduction in water resource loss was 1341 m^3 in 2025 and 1140 m^3 in 2050. Thus, increasing the effectiveness of water use and recycling wastewater is essential for managing water resources (3).

The pulp and paper industry ranked third in the world for intense water consumption in the production process after the metals and chemical industries and it plays an integral role in the global economy. India ranks 15thworldwide in paper production, contributing about 3.7 per cent of total production. There are about 759 pulp and paper mills in India, each with an installed capacity of 12.7 million tonnes and producing 10.9 million tonnes per annum. The Indian pulp and paper industry is highly water intensive, consuming 100-250 m^3 freshwater/ton of paper production and generating the corresponding wastewater of 75-225 m^3 wastewater/ ton of paper produced (4, 5). More than 80% of India's water use accounts for agriculture. However, growing demand from other uses, such as municipal and industrial, is leading to increased competition, especially near urban areas. Currently, water is polluted by anthropogenic and natural sources, so it is necessary to treat the wastewater to control water scarcity in future.

The limitation of water resources and sustainable use of alternative water sources have led to demand for the development. There are many technologies like the Active Sludge Process (ASP), Rotating Biological Contactor (RBC), Stabilization ponds (SP), Trickling Filter (TF) and oxidation ditch for wastewater treatment (6, 7). Similarly, a natural wastewater treatment process is called "constructed wetland technology" or "Reed Bed System". Technology for treating wastewater must be suitable and long-lasting. It must also be less expensive, simple to use and maintain and highly effective at eliminating heavy metals and organic debris. Natural therapeutic methods work better in developing nations. In warm regions especially, natural treatment solutions are thought to be among the finest available options (8). Among the several natural systems employed to treat municipal wastewater with macrophytes are constructed wetlands or reed bed system technology. Commercially constructed wetland systems can treat wastewater effectively through biological means. Compared to conventional methods, constructed wetland systems are more environmentally friendly when treating sewage and paper mill effluent. A constructed wetland system consists of the following main components: Basin, substrate, vegetation (Plant species) and inlet/ outlet arrangement system (9).

According to Ntengwe (10), nutrients in wastewater help microorganisms flourish by giving them an optimal environment, including food, moisture and temperature. These microbes assist in the breakdown of organic substances into stable end products in biological wastewater. Because their rhizomes provide the ideal environment for both bacterial and physiochemical processes, macrophytes, or plants, serve as vital to the Reed bed treatment system (11, 12). With this prelude, this study aimed to identify the pollutant removal efficacy of four different reeds on the mini scale for treating sewage and paper mill effluent. This proposed work strives to utilize the reed plants for the best use in the reed bed treatment system.

Materials and Methods

Study Site

This study collected raw sewage effluent from STP of TNAU and paper mill effluent from ITC Paper Ltd., Karamadai, Coimbatore. This study was done in Tamil Nadu Agricultural University (11.0122° N and 76.9354° E) in Coimbatore District, Tamil Nadu, India. This site usually experienced a maximum temperature of 38°C and a minimum of 19°C, with an average precipitation of 800 mm. The University is located along Lawley Road, 10 km from Coimbatore city. Samples were collected in 5 sampling containers with a capacity of 10 litres each. Sampling was done thrice and the average was considered the value of the initial characteristics.

Collection of native reeds

The native reed plants were obtained from lakes and sewage entering areas in the Coimbatore district and the irrigated areas of ITC Paper Mill Ltd. at Karamadai, Coimbatore. Botanical Survey of India (BSI), TNAU, Coimbatore verified and identified the reed as *Canna indica* (Indian Shot) near lakes, *Colocasia esculenta* (Taro) from paper mill areas, *Typha domingensis* (Southern Cattail) near the Selvampathy lake and *Xanthosoma sagittifolium* (Tannia) near the sides of the polluted sites.

Characterization of effluent

The sewage effluent from the TNAU Sewage treatment plant and paper mill effluent from ITC Private Limited were initially collected and characterized. The physical parameters like pH, EC, TDS, TSS and TS were analysed for both the samples. The chemical parameters include Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD carbonates, bicarbonates, calcium, magnesium, chloride, sulphate, potassium content, total nitrogen and total phosphorus (13). After the samples were collected, analysis was completed immediately and they were carefully preserved. For screening, the treated effluents were extracted and collected daily using a valve opening from the bottom of the pots. The effluents were kept in polyethene plastic bottles, carried to the lab the same day and kept cold and dark at 4°C till the experiment was conducted (14).

Characterization of substrates used for screening

The substrates used in this screening study were soil, sand and gravel. The physical and chemical properties of the substrates used were characterized by following the standard methods. The standard method determined the porosity of soil and sand (15). The soil mass was measured by weighing a balanced instrument and recorded in kg. The substrates' pH, electrical conductivity and redox potential are also characterized (13).

Plant biometric observation

Plant height was recorded in centimetres from the root's base to the primary leaf's tip. The root length of the plants was measured using a meter scale and was recorded in cm. The distance between the tip of the shoot and its junction with the root was measured using a meter scale and the mean was recorded as shoot length in cm. Plant biomass was measured using a weighing balance instrument and recorded in gm. These biometric parameters were measured and compared between the reeds during the initial and final stages of the screening experiment.

Screening of native reed plants

To identify the native reed plants suited to treat sewage and paper mill effluent, a pot culture experiment using a reed bed system was conducted at Tamil Nadu Agricultural University, Coimbatore. Evaluations were also conducted on the effectiveness of native reeds in treating sewage and paper mill effluent. After thoroughly washing, the reeds were set aside for a month to develop steadily. In this investigation, pots of the same size that have a feature to collect treated effluent samples from the bottom were employed. The planting medium comprised 8 cm of gravel, coarse sand and garden soil. The plants were layered in a sandwich pattern, with gravel at the bottom and coarse sand and garden soil on top. The reeds were evenly planted in the pots once their biomass was ascertained.

The parameters such as plant biomass, plant height, shoot height and root height were measured in native reeds, namely *Colocasia esculenta, Xanthosoma sagittifolium, Canna indica* and *Typha domingensis,* to determine the suitability for treating the sewage and paper mill effluents. The raw effluent of 7 litres was poured into each of the pots. The treated effluent from the pot culture experiment was collected for seven days with an interval of 24 hours and they were analyzed by following the standard analytical procedures mentioned earlier. The screening study setup is given in Fig. 1. The pollutant removal efficiency was calculated by influent concentration - (treated) effluent concentration / influent concentration × 100 (16).

$$\text{Efficiency of pollutant removal} = \frac{\text{Input - Output}}{\text{Input}} \times 100$$

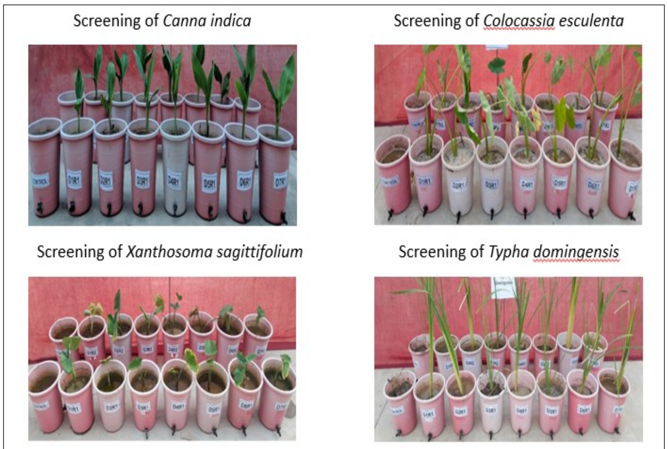

Fig. 1. Screening study setup with four reed plants.

Statistical analysis

Using a 95% confidence level, the nutrient removal performance was assessed using SPSS 21 (SPSS Inc., USA). The significance of the variation in the amount of pollutant removed between the four reeds groups of treatment conditions (planted and control systems) was ascertained using statistical analysis.

Results and Discussion

Physical characterization of sewage and paper mill effluent includes pH, EC, TDS, TSS and TS. Chemical characterization includes BOD, COD, carbonates, bicarbonates, calcium, magnesium, chlorides, sulphate, potassium content, total nitrogen and total phosphorus. pH of sewage and paper mill raw effluent were 7.84 and 7.20 respectively. The electrical conductivity of both the samples were 2.41 and 3.03 dSm^{-1}. This pH and EC were widely used to determine the acidic or alkaline nature of the wastewater. Biological Oxygen Demand of sewage and paper mill raw effluents were 256 and 180 mg L^{-1}. Chemical Oxygen Demand of sewage and paper mill raw effluents were 469 and 534 mg L^{-1}. The values of TDS, TSS and TS for sewage raw effluent were 1880 mg L^{-1}, 810 mg L^{-1} and 2690 mg L^{-1}, whereas for paper mill raw effluent was 2020 mg L^{-1}, 1560 mg L^{-1} and 3580 mg L^{-1} respectively. The anion and cations of sewage and paper mill effluents were given in table 1.

Table 1. Initial characteristics of wastewater

Parameters	Raw Sewage Wastewater	Raw Paper mill Effluent
pH	7.84	7.20
Electrical conductivity (dS m^{-1})	2.62	3.03
Total Solids (mg L^{-1})	2690	3580
Total Dissolved Solids (mg L^{-1})	1880	2020
Total Suspended Solids (mg L^{-1})	810	1560
Biological Oxygen Demand (mg L^{-1})	256	180
Chemical Oxygen Demand (mg L^{-1})	469	534
Carbonates (mg L^{-1})	39	46
Bicarbonates (mg L^{-1})	413	424
Chloride (mg L^{-1})	721	730
Sulphate (mg L^{-1})	24.2	22.9
Calcium (mg L^{-1})	213	206
Magnesium (mg L^{-1})	53.1	52.5
Sodium (mg L^{-1})	273	398
Potassium (mg L^{-1})	32.6	32.8
Total Nitrogen (%)	0.27	0.28
Total Phosphorus (%)	0.34	0.37

The total nitrogen and total phosphorus in sewage and paper mill raw effluent were 0.27% & 0.34% and 0.28 & 0.37% respectively. The characteristics of the substrates used for the reed bed system are furnished in table 2. The soil used for the study was categorised as black soil which had a porosity of 48 per cent with a pH, EC, Redox potential and mass of 7.81, 1.03 dS m^{-1}, -694 mV and 3.5 kg respectively. Porosity, pH, EC, Redox potential and mass of the fine sand used for the reed bed system are 43 per cent, 7.32, 0.18 dS m^{-1}, -272 mV and 2 kg respectively. The total mass of the gravel used in the reed bed system is 2.50 kg. The growth parameters of different reeds growing in both the effluents were given in table 3. The highest increase in plant biomass, plant height, shoot height and root height were

Table 2. Characteristics of the substrates used for the reed bed system

Parameters	Soil	Sand	Gravel
Porosity (%)	28	43	-
pH	7.81	7.32	-
EC (dS m^{-1})	1.03	0.18	-
Redox potential (mV)	-694	-272	-
Mass (kg)	3.5	2	2.50

Table 3. Biometric observation of reed plants

Reeds	Plant Biomass (g)		Plant Height (cm)		Shoot Length (cm)		Root Length (cm)	
	Initial (D1)*	Final (D7) *	Initial (D1)*	Final (D7)*	Initial (D1)*	Final (D7)*	Initial (D1)*	Final (D7)*
Canna indica	99.78	123.52	64.2	71.2	43.2	47.5	21.00	23.7
Colocasia esculenta	139.12	156.35	105.2	108.3	78.2	79.1	27.00	29.2
Xanthosoma sagittifolium	123.56	124.62	60.2	61.1	50.1	50.2	10.1	11.1
Typha domingensis	103.54	106.23	135.4	138.2	128.5	130.4	6.9	7.8

(*Note: D1 - day 1; D7 - day 7)

observed in *Canna indica* which recorded 25.23g, 7cm, 4.3cm and 2.7 cm respectively. The growth of reeds in were observed in the order of *Canna indica* > *Colocasia esculenta* > *Typha domingensis* > *Xanthosoma sagittifolium*.

Impact of Reeds and retention time on physical characteristics of effluent

Occurrences of pH variation were observed in every stage of the screening experiment. It was observed that there was a change in electrical conductivity in both effluents. The reduction is due to the plant's ability to uptake the soluble ions through roots (17). With a retention period of seven days, *Canna indica* had the highest percentage removal of total dissolved solids (62.18%) and *Colocasia esculenta* had the high potential to remove total suspended solids (83.67 percent) in sewage effluent. In contrast, Canna indica showed a higher percent removal of TDS and TSS in paper mill effluent. Fig. 2 depicts the trend of the pollutant removal percentage in both the effluents. This reduction in the pollutant removal percentage of TSS and TDS may be due to the physical action of substrates utilized in the reed bed system, such as filtration and settlement (18).

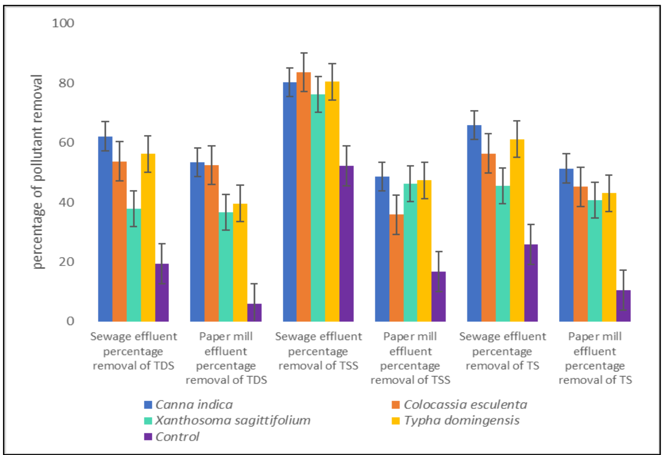

Fig. 2. Trend in pollutant removal of TDS, TSS and TS.

Additionally, the active layer of biofilm known as periphyton, which may absorb both soluble and colloidal particles, may have been deposited on the surface of the macrophytes used in the study (19). According to a review by Wang *et al.* (20), the gravitational interception of solid items between sand and stone particles, as well as the blocking impact of macrophyte roots, contribute significantly to the removal of suspended solids in reed beds. He suggested that ionized pollutants can be eliminated through adsorption on macrophyte root surfaces.

Impact of reeds and retention time on BOD and COD of effluents

After a seven-day retention period, *Colocasia esculenta* and *Xanthosoma sagittifolium* showed the highest percentage elimination of BOD (77.22% and 76.67%) in the paper mill effluent. In contrast, in sewage effluent, *Canna indica* (75.39%) and *Typha domingensis* (67.19%) showed a higher reduction in the BOD level (Fig. 3). This kind of decrease in the effluent's organic matter may result from hydrolysis, which changes the organic matter into a soluble state so that it can enter the media and attach itself to biofilm to decompose. According to a study, oxygen released through a plant's roots improves the aerobic bacteria in the biofilm, promoting the breakdown of organic pollutants (21). Redox processes result in the breakdown of pollutants into more unstable chemicals, according to a review (20). An increase in organic load causes a greater BOD concentration in the effluent. The elimination of organic materials by both attached and free-living bacteria may cause BOD reduction (22). The aquatic plants' root systems provide more surface area for microorganisms, speeding up the breakdown of organic materials. *Canna indica* showed better for removal of BOD and COD upto 80% from various effluents (19).

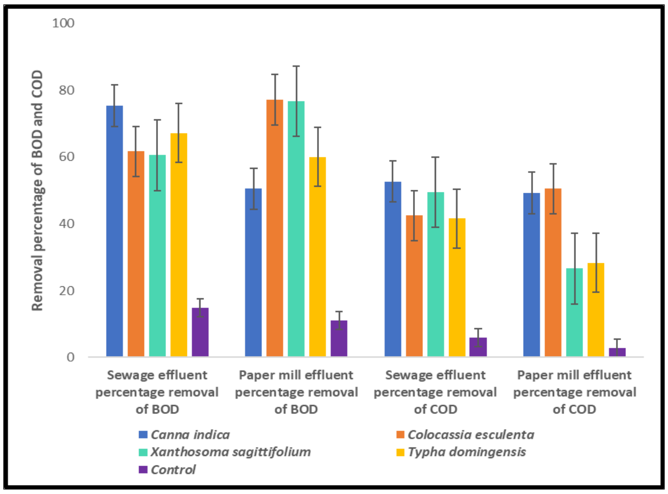

Fig. 3. Pollutant reduction of BOD and COD in the effluents.

It has been observed that the reed plants had the potential to reduce COD in both the wastewater. This may result from the physical processes of filtration and sedimentation working in tandem with the breakdown of aerobic and anaerobic microorganisms. Within seven days of retention time, *Colocasia esculenta* (50.56%) showed the most significant percentage of COD removal in the effluent, followed by *Canna indica* (49.25%) in treated paper mill effluent. Similarly, in the sewage effluent, *Canna indica* (52.72%) and *Xanthosoma sagittifolium* (49.45%) showed the highest percentage elimination of COD compared to paper mill effluent. The total decrease in organic and inorganic materials is caused by the coupling effects between microbes and plants, as well as the breakdown of microorganisms (20). *Canna indica and Typha domingensis* showed better for removal of BOD and COD upto 80% from various effluents (23). Aeration can boost system efficiency by creating a favourable oxidative environment, which will enhance organic biodegradation and nitrification. Because of its high treatment efficacy, spray aeration is regarded as an economical method for treating domestic sewage on-site. Like other plat species found in CWs, *Canna indica* is vulnerable to pollutants found in wastewater. Studies show that ornamental plant-based CWs are frequently used as secondary or tertiary treatments. To create a positive visual impression, CWs use ornamental plants, such as *Canna indica* (19).

Impact of reeds and retention time on anions of effluents

Three days later, 90% of the carbonates were reduced by all the reed plants used in this study. Regarding retention time and reeds, the values converge toward 0 mg L^{-1}. Regarding the reeds treating the paper mill effluent, *Colocasia esculenta* removed the greatest amount of bicarbonate content (42.92%) on the seventh day, followed by *Xanthosoma sagittifolium* (37.74%) (Fig. 4). Similarly, in the sewage effluent, Canna indica (46.49%) and Typha domingensis (41.40%) showed the highest percentage of carbonate elimination when compared with paper mill effluent. The production and processing of pulp and paper, mining, tanning, textile dyeing and other industrial sectors are likely to produce highly saline wastewater with more complex pollutants than sources from agriculture or aquaculture. Salts can reduce seedling survival, growth and yield; they can also interfere with the internal ionic pressure of cells and prevent plant germination.

By reducing species diversity or swapping halophilic species for halo-sensitive species, these impacts will further alter the communities of plants, microbes and aquatic animals within the environment (24). During the seven-day retention period, *Canna indica* showed a chloride reduction, going from 721 to 570 mg L^{-1}, with a removal percentage of 21 percent. *Typha domingensis* came in second with 19.5 percent in sewage effluent. However, chloride removal efficiency is higher than that of treated sewage effluent. The greatest chloride reduction was found in *Colocassia esculenta*, from 730 to 400 mg L^{-1}. The strain *Typha domingensis* had the highest rate of sulphate content reduction (46.15 percent) in treated sewage effluent. Like chloride removal, sulphate removal is also slightly higher in paper mill effluent. The efficiency of removal was found to be higher in *Typha domingensis* (48.03%). Plants accumulate cations and anions, which are also utilized by bacteria in their mechanisms of precipitation and biochemical transformation (25).

Impact of reeds and retention time on cations of effluents

Fig. 5 shows the variations in the calcium, magnesium, sodium and potassium concentrations of effluent treated with different reeds in this study were shown. Calcium concentration in *Typha domingensis* decreased most from 213 mg L^{-1} on the first day to 141 mg L^{-1} on the seventh day, followed by *Colocassia esculenta*, which decreased from 213 mg L^{-1} on the first day to 148 mg L^{-1} on the seventh day. Between the first and seventh days, there was no discernible variation in the calcium removal capacity of the three types of reeds: *Colocasia esculenta*, *Canna indica* and *Typha domingensis*. A high percentage of pollutants were removed in

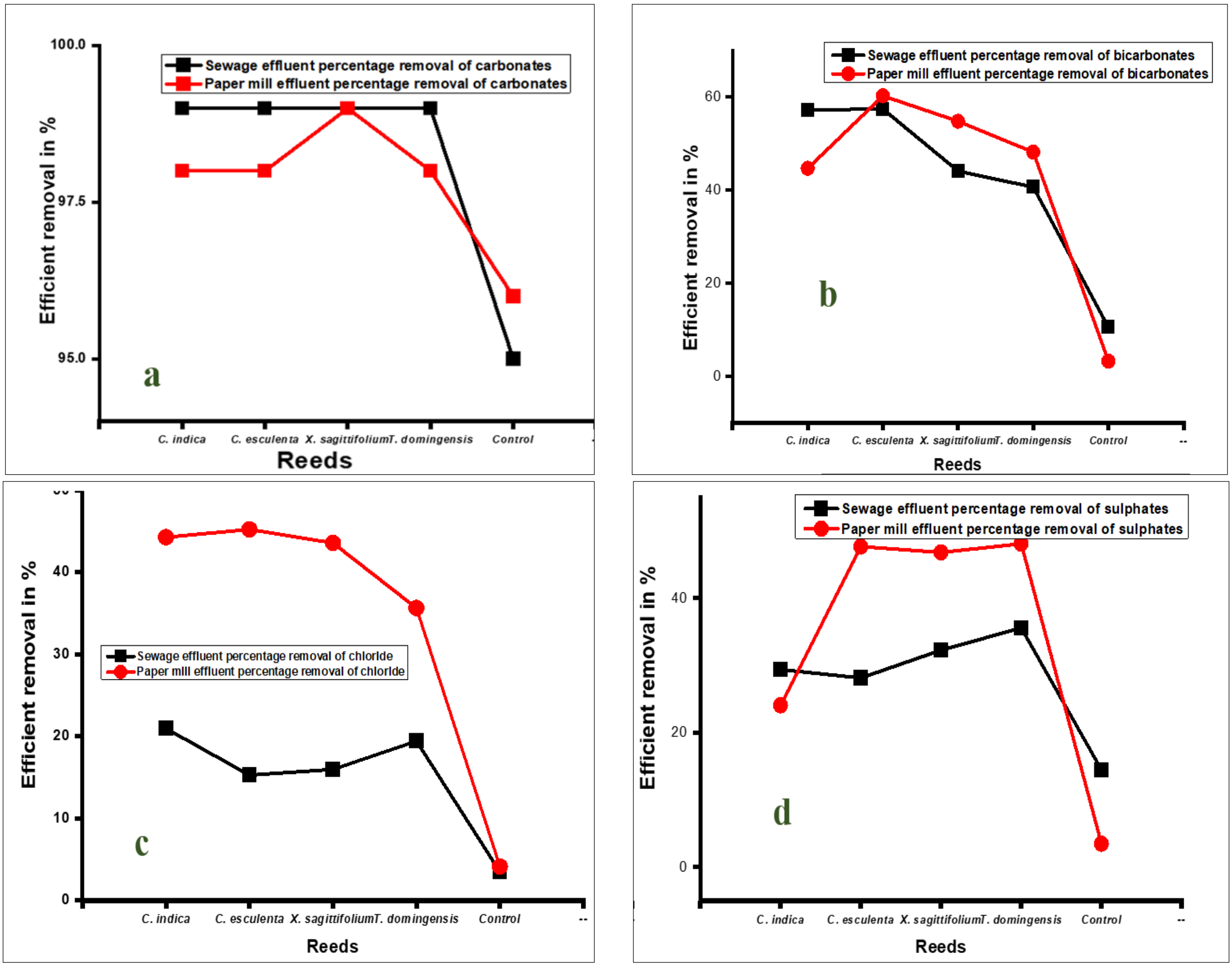

Fig. 4. Efficient reduction percentage in anions; a) removal percentage in carbonates; b) removal percentage in bicarbonates; c) removal percentage in chlorides and d) removal percentage of sulphates in both the wastewater.

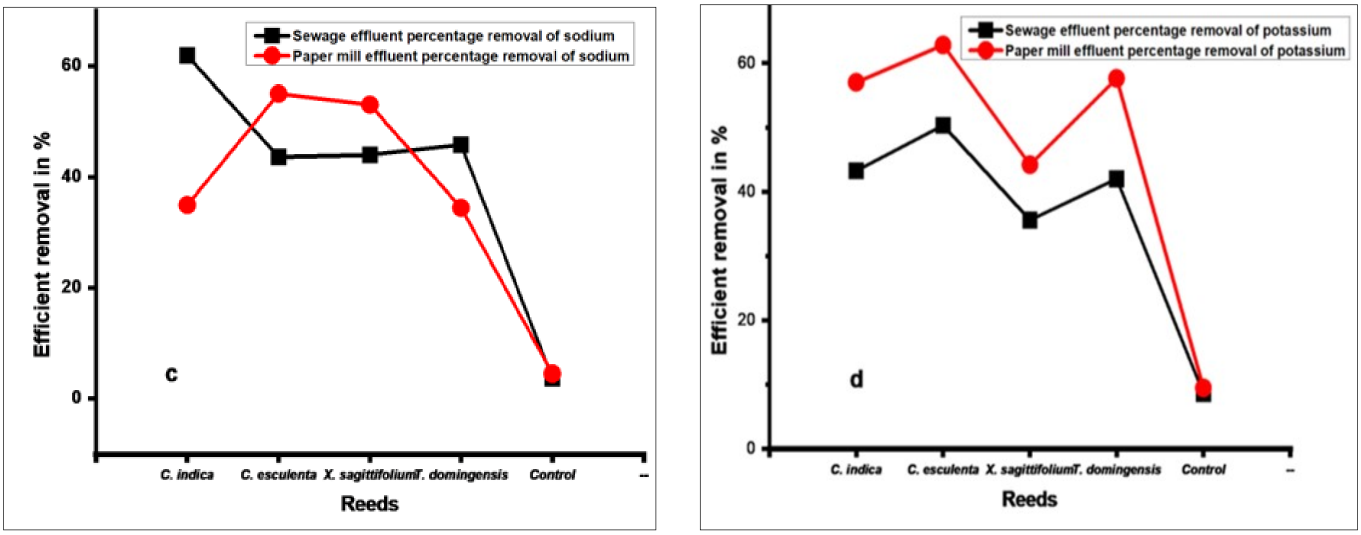

Fig. 5. Cation reduction percentage in both the effluents; a) removal percentage in calcium; b) removal percentage in magnesium; c) removal percentage in sodium and d) removal percentage of potassium in both the wastewater.

paper mill effluent in *Colocassia esculenta* (69%). After seven days, *Colocassia esculenta* showed a reasonable reduction of magnesium concentration (53.1 to 22.6 mg L^{-1}) in treated sewage similarly in paper mill effluent also, *Colocassia esculenta* showed the most reduction of magnesium concentration (52.5 to 20.8 mg L^{-1}). *Colocassia esculenta*, one of the reeds, had the greatest sodium reduction in treated paper mill effluent with a low sodium level of 179 mg L^{-1} following a 7-day retention period. Canna indica had the greatest sodium reduction in treated sewage effluent with a low sodium level of 104 mg L^{-1} following a 7-day retention period. In treated sewage effluent, *Colocassia esculenta,* a type of reed, showed the greatest potassium reduction with a low potassium concentration of 16.2 mg L^{-1} following a 7-day retention period. Colocasia esculenta showed the greatest potassium reduction in treated paper mill effluent with a low potassium concentration of 12.2 mg L^{-1} following a 7-day retention period due to Na^+ and Cl^- competing with nutrients like K^+, Ca^{2+} and NO^{3-}. Hu and Schmidhalter (26) found that salinity led to plant nutritional imbalances or deficits. These adverse consequences could be caused by a change in the kind of ion carrier or competition for absorption into ion channels (27).

Impact of reeds and retention time on total nitrogen and total phosphorus of effluents

Fig. 6 illustrates the tendency of the total nitrogen and phosphorus concentrations to decline with reeds. *Canna indica* and *Typha domingensis* showed a greater overall nitrogen reduction (59.26%) among the reeds over a seven-day retention period in treated sewage effluent (19). Alternatively, the declining trend is more in *Colocassia esculenta* (67.86%) for paper mill effluent. After seven days of retention, the total nitrogen concentration was at its lowest, measuring 0.09 percent. The nitrogen content decreased as the retention period extended from the first to the seventh day. This elimination might be brought about by ammonification, volatilization, plant absorption (28), or microbial metabolism in the rhizosphere zone (29). In wastewater, nitrification and denitrification are the primary methods to remove nitrogen (30). Anaerobic heterotrophic microbial denitrification is frequently regulated by the availability of labile carbon substrates and oxygen (O_2). Ong *et al.* (31) state that nitrification is an anaerobic chemoautotrophic process.

Regarding reducing total phosphorus after seven days of

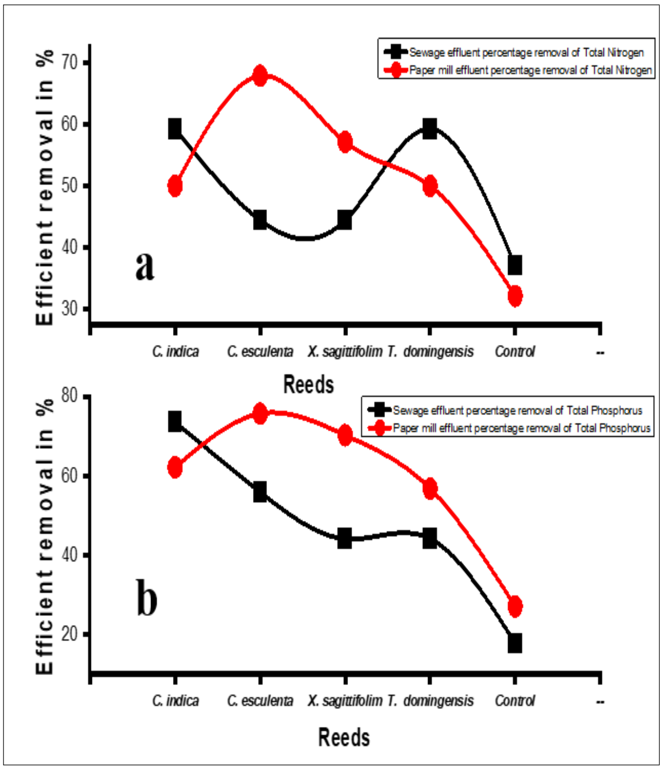

Fig. 6. Efficient pollutant removal in percentage of (a) total nitrogen and (b) total phosphorus.

retention, *Canna indica* (73.53%) outperformed the other reeds (19). Apart from *Canna indica*, *Typha domingensis* and *Colocasia esculenta* have been found to remove 44.12% and 55.88% of the total phosphorus, respectively. In treating the paper mill effluent, the highest removal efficiency was found in *Colocassia esculenta* (75.68%). The order for paper mill effluent was found to be in *Colocassia esculenta* > *Xanthosoma sagittifolium* > *Canna indica* > *Typha domingensis*.

In the process of eutrophicating lakes or any other body of water, phosphorus plays a significant part. It is, therefore, essential to treat wastewater to remove phosphorus. According to the experimental study, the total phosphorus declined steadily from the first to the seventh day. This is because most phosphorus exists as organophosphate, which the macrophytes utilized in the experiment could readily absorb. Similar findings are corroborated by Sayadi et al. (32), who found that phosphorus removal effectiveness in a hybrid reed bed system treating wastewater with *Cyperus alternifolices* and *Canna indica* was 76%.

Conclusion

These experimental results depicted that the reed bed system has the greater potential to reduce the concentration of the organic pollutants from both the sewage and paper mill effluents. All the reed plants in this experimental study performed better than those in the control pot treatment. In particular, the screening of the reed plant shows that *Canna indica* and *Colocassia esculenta* perform well in removing pollutants. The difference in efficiency between the species may be due to the lower tolerance level and the rhizosphere's natural microbial processes capable of reducing the pollutants. Incoming high nutrients and other compounds in the effluents aid in plants' growth, which supports rhizosphere microorganism, forming a chain. These efficient pollutants removal occurred by the presence of microbes in the rhizosphere. These microbes play a vital role in the biochemical transformation of pollutants, adsorptions, precipitation and plant uptake. Reed plants provide oxygen through root hairs, which proliferate the microbes to break down organic substances. Overall, *Canna indica* and *Colocassia esculenta* were more efficient for removing physical and chemical parameters from the sewage and paper mill effluent through reed bed system technology. The four reed plant species used in the screening showed a clear difference in their wastewater treatment function. Therefore, it is necessary to have a more profound study of rhizosphere microbial diversity and the interaction between the macrophytes and effluents in reed bed system technology.

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Authors' contributions

All authors contributed to all stages of the research, including idea generation, data analysis, writing and review of the research. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: No competing interests are disclosed by the authors.

Ethical issues: None

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