Wastewater Treatment Using Green Technology

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Abstract

Water is a vital, indispensable resource which organisms require for the sustenance of life. Currently, problem of water scarcity persists due to water pollution by heavy metals and eutrophic nutrients that have resulted in degraded environment and adverse effects on biota. Conventional methods are employed to remove heavy metals from wastewater but are un-economical especially while the metals are in low but significant concentration. Alternative method is phytoremediation which effectively removes pollutants from environments. This research was carried out to establish the ability of macrophytes to remediate pollutants from wastewater. Locally available macrophytes which included Azolla pinnata, Typha latifolia, Nymphaea spp. and Ceratophyllum demersum were collected from Marura wetland and identified. Wastewater samples were collected from University of Eldoret sewage treatment plant. Water indicator parameters, nutrients and heavy metals were determined using standard methods. Growth chambers containing wastewater samples were prepared in the laboratory. Macrophytes were established in these chambers. Wastewater analysis was carried out initially on setting up the experiment and then after every five days for 25 days to determine the changes in the levels of the parameters investigated. Means of mentioned parameters were calculated and analyzed using ANOVA and significant means separated using Tukey's test at 5% level. Reduction efficiency was calculated. The range of removal efficiency of the investigated parameters was as follows; TDS 66.01-74.03%, pH 18.15-20.30%, conductivity 51.79-57.11%, turbidity 67.55-86.10%, faecal coliforms 100%, phosphates 88.65-100%, nitrates 89.38-100%, cadmium 88.96-92.19%, copper 78.87-85.86%, nickel 100%, cobalt 94.67-95.04%, lead 100%, manganese 85.81-88.81%, zinc 91.78- 93.64% and iron 85.81-88.81%. There were significant differences in reduction of phosphates, nitrates, lead and cadmium among the macrophytes, ($P = 0.00$). The macrophytes were found to be efficient in wastewater treatment. The order of removal efficiency was Azolla pinnata > Nymphaea spp > Typha latifolia > Ceratophyllum demersum. These macrophytes can be used to treat domestic, agricultural and industrial wastewater.

Key words: Phytoremediation, Macrophytes, Heavy metals, Nutrients

INTRODUCTION

There is water poverty in the world due to lack of efficient water recycling systems, rapid increase in pollution, lack of urban planning and increase in population. The demand for water is predicted to escalate worldwide with agricultural sector abstracting more than 70% of the available water globally as nations struggle to feed their high populations. In addition, increase in urbanization and industrialization will intensify water demand (United Nations, 2017).

In Kenya, more than 80% of the total land area is regarded as Arid and Semi-Arid Land hence it is a water scarce country that needs to conserve this indispensable resource. Currently per capita available water is at $650m^3$/year, future projections indicate that this will likely drop to $359m^3$/year by 2020 and further decline to $235m^3$ by 2025 as a result of population growth. This figure is far much below the United Nations' recommended minimum value of $1000m^3$/year per capita level (United Nations, 2017). Water pollution and quality degradation is increasingly worsening the problem of water scarcity in Kenya. Nowadays, most of the surface waters receive large amounts of wastewater which contain various pollutants hence threatening the natural water sources (Yapo *et al.*, 2014). The release of these pollutants into water bodies creates serious health and environmental problems and may lead to an upsurge in wastewater treatment cost. The degradation of this essential resource can be quantified as the loss of natural systems, their biodiversity and the services that they provide.

Polluted water can be treated using variable traditional technologies such as chemical, physical and artificial methods. However, these methods are relatively inefficient, expensive and in most cases they generate a great amount of sludge that is difficult to discard. Also these treatment systems require localized well trained technical staffs as operational and management activities need to be carried out regularly. Moreover, application of non-biological wastewater treatment techniques have at times led to the generation of additional contaminants or to the formation of toxic sludge as a result of the many chemicals involved in these processes. In Kenya, such treatment technologies are capital intensive and often require environmental and social impact assessment/strategic environmental assessment during planning and implementation stages. Most local institutions and municipalities have limited resources and therefore unable to adopt these technologies (Sato, 2013). As a result efficient management of wastewater has become a big challenge resulting in environmental degradation and health hazard. There is a definite need for an alternative, non-traditional, efficient, environmentally friendly and cost-effective water treatment technology.

The economic aspects and repercussion of conventional treatment technologies on aquatic ecosystems has paved way to phytoremediation technology where plants are used to ameliorate the environment from various hazardous pollutants. The science of phytoremediation emphasizes the importance of plants in abating environmental contamination. It is an alternative approach where plants are used to stabilize, detoxify or even remove pollutants from wastewater through phytostabilization, phytodegradation, phytovolatization and phytoaccumulation mechanisms (Mitton *et al*., 2016). This method has ecological benefits such as improvement of biodiversity and sequestration of carbon dioxide. The process of phytoremediation produces environmentally friendly products that not only lessen the pollution but also benefit the ecosystem productivity. This approach is an innovative green technology because plants are solar-driven and therefore make phytoremediation a cost-effective method, with great capability to achieve sustainable environment.

METHODOLOGY

Study area

The study was carried out at University of Eldoret located in Uasin Gishu County, about 9 km north east of Eldoret town (Figure 1). Uasin Gishu County is located in mid-western Kenya, between 34°55'33" and 36°38'58"E and between 0°2'44"S and 0°55'56"N.

Sample collection and experimental set up

Young and healthy macrophytes were sampled randomly by hand from Marura wetland. These plants included *Azolla pinnata, Nymphaea* spp.*, Typha latifolia* and *Ceratophyllum demersum.* The rationale behind the selection of these plants was based on the ease of availability of the plants, documented plants efficiency in pollutants removal and their primary productivity. They were also native to the study area, hence better in terms of survival, growth and reproduction under environmental stress than plants introduced from other environments.

The plants were put in plastic containers and transported to the laboratory within few hours of collection where they were cleaned carefully using tap water to remove dirt and dust. The experimental plants were initially subject to acclimatization in stock tanks containing tap water for one week. Randomized design with three replications was used to conduct the experiments. The plants which were maintained in the stock tanks were collected, thoroughly washed with sterile distilled water before being introduced in the experimental troughs.

Approximately, 180 litres of wastewater were sampled from University of Eldoret wastewater treatment plant using clean sterilized plastic container. They were transported to University of Eldoret. Ten liters of wastewater was put in plastic troughs of 15 litres capacity. 500g (fresh weight) of each selected macrophyte was inoculated in triplicate in the plastic troughs. A control set up with ten liters of wastewater without the plants was maintained to assess the role of macrophytes in the removal of pollutants. 200 ml of wastewater from the respective treatment sets were collected in triplicate for analyzing the changes in the investigated parameters at initial level and subsequently with an interval of 5 days for 25 days. Physicochemical parameters were measured on site.

Analysis of wastewater

Water indicator parameters were analysed using standard methods according to (APHA, 2005). Physicochemical parameters that were analysed included temperature, pH, TDS and conductivity, which were determined using a multi tester digital pH meter. Dissolved oxygen was measured using a DO meter and turbidity was measured using colorimeter. BOD_5 was determined as the difference between the oxygen concentrations of an appropriately diluted sample before and after incubation for 5 days at $20 \pm 1^{o}C$ while COD was determined using micro digestion method.

Bacteriological analysis

Pour plate method was used to culture bacteria. MacConkey agar was used to culture feacal coliforms and Bile esculine azide agar were used for feacal streptococci. The number of colonies per 1ml was calculated as follows

$$\text{Cfu/ml} = \frac{\text{No.of colonies x dilution factor}}{\text{Volume plated (ml)}}$$

Nutrient analysis
Phosphates were determined using ammonium molybdate method while nitrates were determined using brucine method.

Heavy metal analysis
The wastewater samples were digested using nitric acid digestion method (APHA, 2005). Wastewater samples were analyzed in the AAS using an air/acetylene flame.

Data analysis
The reduction efficiency for the investigated parameters was calculated as follows:

$$\text{Reduction efficiency } (E_r) = \frac{\text{Initial concentration} - \text{final concentration}}{\text{initial concentration}} X\,100$$

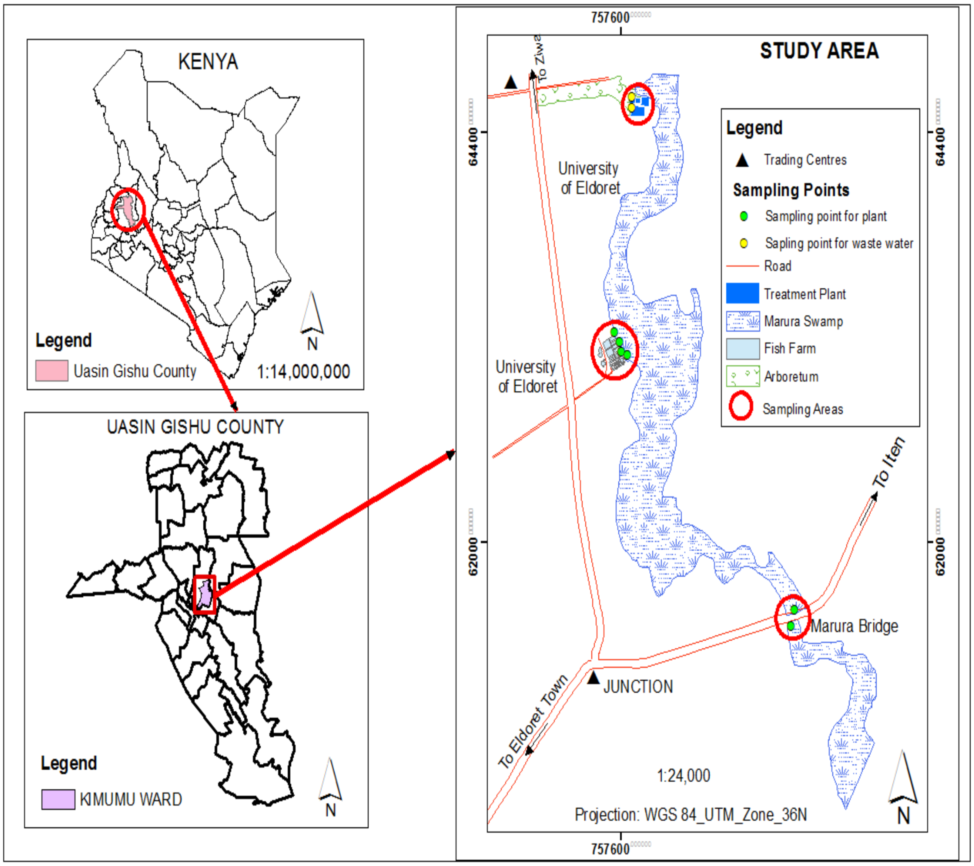

Figure 1: Location of Marura wetland and University of Eldoret wastewater treatment plant

RESULTS AND DISCUSSION

Physicochemical parameters

Temperature

There were no significant differences in the means recorded for the different macrophytes and the control during the sampling period (P = 0.593). Temperature depended on the ambient temperature (Figure 2).

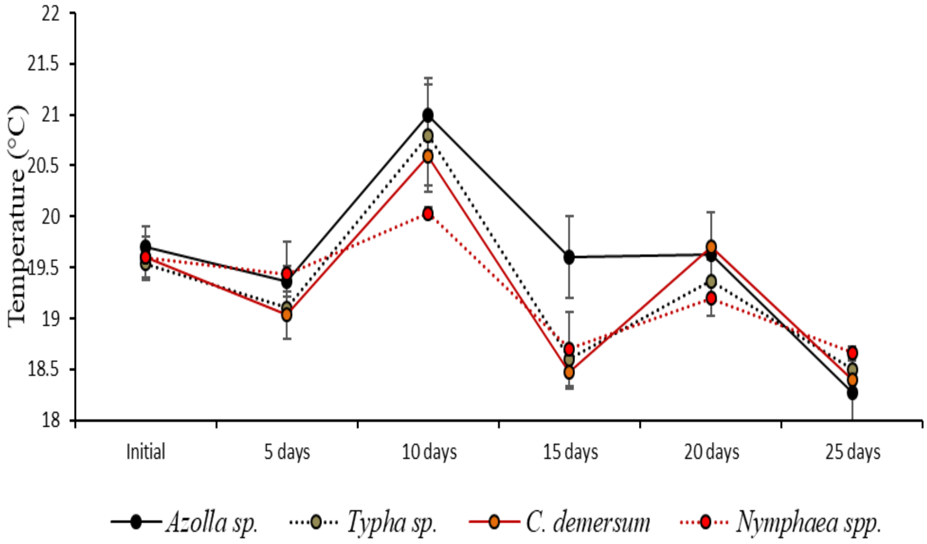

Figure 2: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to phytoremediate temperature in wastewater

Dissolved oxygen

There was an increase in dissolved oxygen in all experimental set ups (Figure 3). *Ceratophyllum demersum* increased DO by 39.12%, *Azolla pinnata* by 44.78%, *Nymphaea* spp. by 47.90% and *Typha latifolia* by 49.15%. There were no significance differences in the addition of DO among the macrophytes (P=0.65). Macrophytes carry out photosynthesis where they utilize carbon dioxide and release oxygen. This increases the amount of dissolved oxygen in water. *Typha latifolia* had the highest increase in DO, which may be attributed to its well-developed roots, rhizomes and rhizoids which oxidize the rhizosphere. *Ceratophyllum demersum* had the lowest DO increase potential. This is a submerged plant hence the amount of sunlight reaching it was influenced by physical factors such as turbidity and TDS. The amount of sunlight received reduces the rate of photosynthesis, subsequently reducing the amount of DO released by the plant.

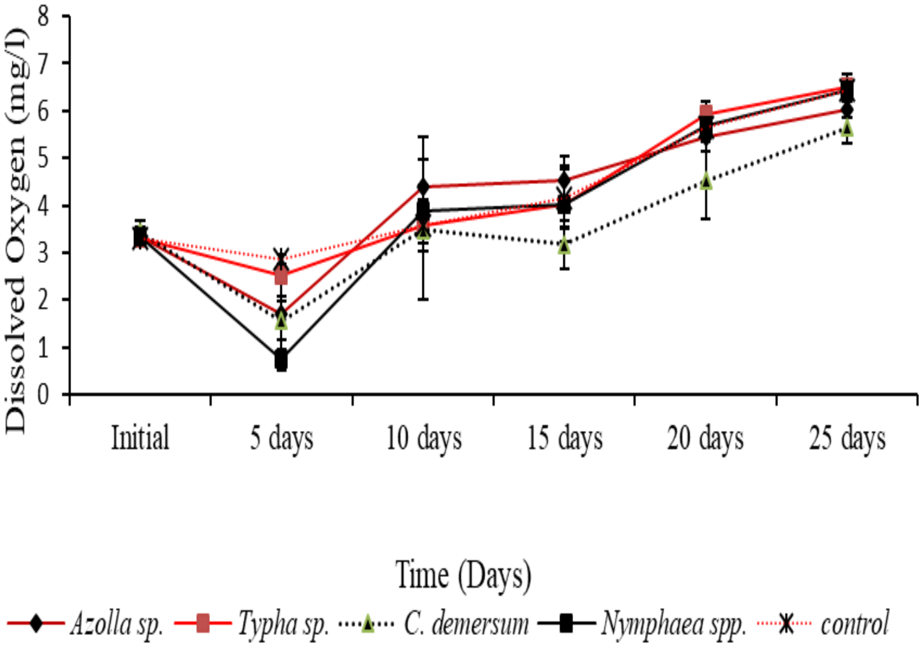

Figure 3: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to phytoremediate dissolved oxygen in wastewater

Total Dissolved Solids

Ceratophyllum demersum had the lowest reduction efficiency of 66.01% while *A. pinnata* had the highest reduction efficiency of 74.03%. *Typha latifolia* had a reduction efficiency of 69.28% while *Nymphaea* spp. had a reduction efficiency of 67.76% (Figure 4). The mean levels obtained for all the macrophytes throughout the sampling period were not significantly different (p = 0.505). Reduction in TDS may be attributed to the reduction of the dissolved organic and inorganic substances as a result of absorption and adsorption process of these substances by macrophytes. The higher efficiency in the removal of organic load by macrophyte systems could be due to the better oxygenated environmental conditions created by macrophytes which enabled the microbes associated with the macrophytes to degrade the organic matter at a faster rate. In the control, algae could have utilized some dissolved organic matter in its growth during the process of photosynthesis.

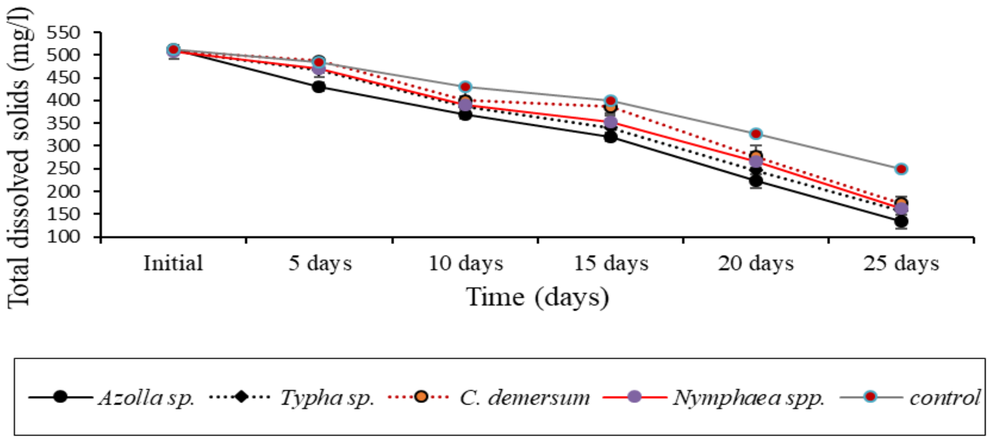

Figure 4: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to phytoremediate total dissolved solids in wastewater

pH

All macrophytes were able to reduce the level of pH in the wastewater effluents (Figure 5). *Ceratophyllum demersum* had a reduction efficiency of 20.30%, *Azolla pinnata* had 18.37%, *Nymphaea* spp. had 18.29% and T. *latifolia* had 18.15%. There were no significance differences in reduction of pH among the macrophytes (P= 0.599). Reduction of pH may be ascribed to absorption of nutrients or by simultaneous release of H+ ions with the uptake of metal ions present in the wastewater. Also, the assimilation of carbon dioxide and bicarbonates which are ultimately responsible for increase in pH during the process of photosynthesis could have resulted in reduction in pH. The results were in harmony with the findings of Snow and Ghaly (2008) who reported a decrease in pH in their study of purification of aquaculture wastewater using macrophytes.

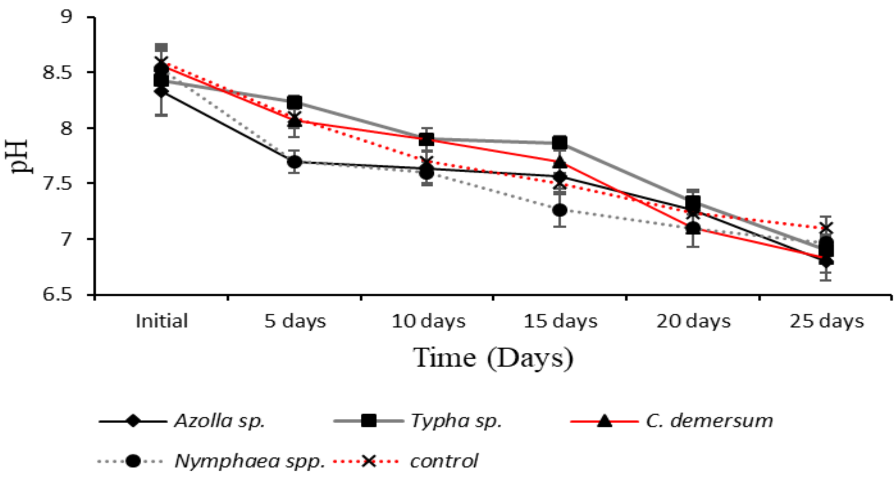

Figure 5: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to phytoremediate pH in wastewater

Conductivity

There was reduction in the levels of conductivity in all macrophyte species (Figure 6). *Typha latifolia* had a reduction efficiency of 57.11%, *Azolla pinnata* had 55.13%, *Nymphaea* spp. had 54.67% and Ceratophyllum *demersum* had the lowest reduction efficiency of 51.79%. There were no significant differences in conductivity reduction among the macrophytes and the control (p = 0.681). Reduction in conductivity may be attributed to the reduction in dissolved salts in the wastewater by plants uptake or root adsorption. In the control, there was a decrease in the levels of conductivity which may be due to utilization of some of the dissolved salts by algae in their growth and development.

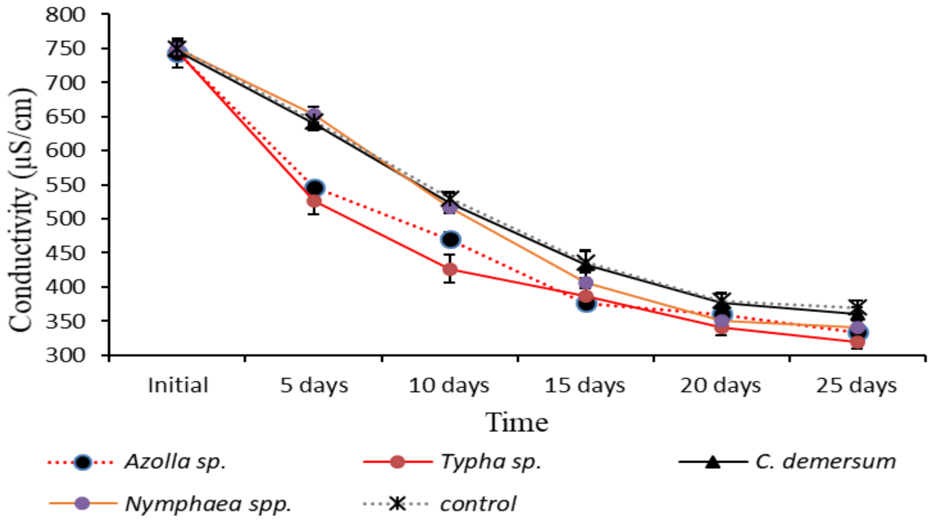

Figure 6: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to reduce conductivity in wastewater

Turbidity

Azolla pinnata had the highest reduction efficiency of 86.10%, while *T. latifolia* had the lowest reduction efficiency of 67.55%. *Nymphaea* spp had a reduction efficiency of 80.53% while *C. demersum* had a reduction efficiency of 75.98% (Figure 7). There were no significant differences in turbidity reduction among the macrophytes and the control (p = 0.48). Turbidity reduction may be attributed to the utilization of some suspended matter by the macrophytes. Also, some amount of the suspended material could have settled as a result of sedimentation process. Death of microbes such as bacteria could have led to decreased turbidity. *Azolla Pinnata* had the highest reduction efficiency that may be ascribed to the growth nature of the plant. This plants has numerous root hairs that could have accelerated the absorption of suspended matter in the water column. Kulasekaran *et al.,* (2014) reported turbidity reduction of 93.8 to 98.7% in sewage treatment by *C. demersum.* In the control, the main removal mechanisms could be due to sedimentation and algae uptake.

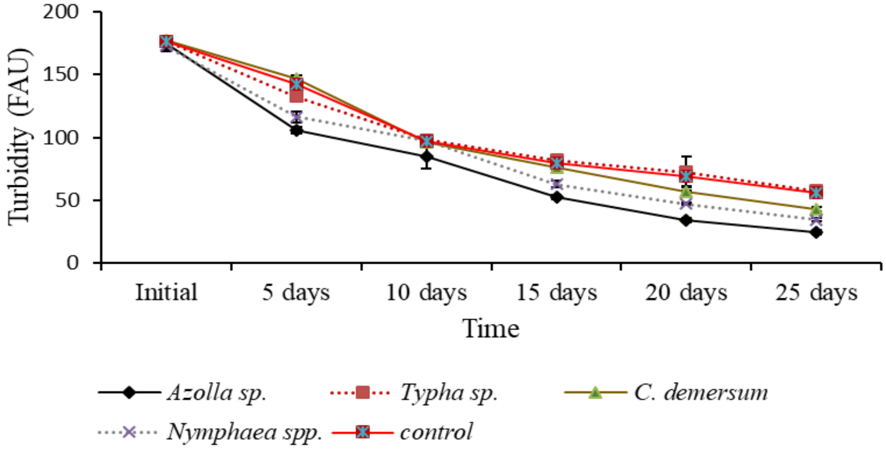

Figure 7: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to reduce turbidity in wastewater

Bacteriological parameters

Feacal coliforms and Feacal streptococcus

All the macrophytes and the control achieved a reduction efficiency of 100% for feacal coliforms and feacal streptococcus (Figure 8 and 9). There was no significant difference in the colony forming units (cfu) recorded for feacal coliforms and feacal streptococcus during the sampling period ($p = 0.502$) and ($P = 0.234$) respectively. The decrease in coliforms is attributed to the natural die off of the bacteria due to exposure to ultra violet light. UV radiation is lethal to all types of microbes due to its short wavelength and high energy. According to Kadlec and Wallace (2009), more than 90 % of the coliforms and more than 80 % of the feacal streptococci were eliminated in various systems of constructed wetlands. In the control, bacteria death may be credited to algae toxins and predation by zooplanktons.

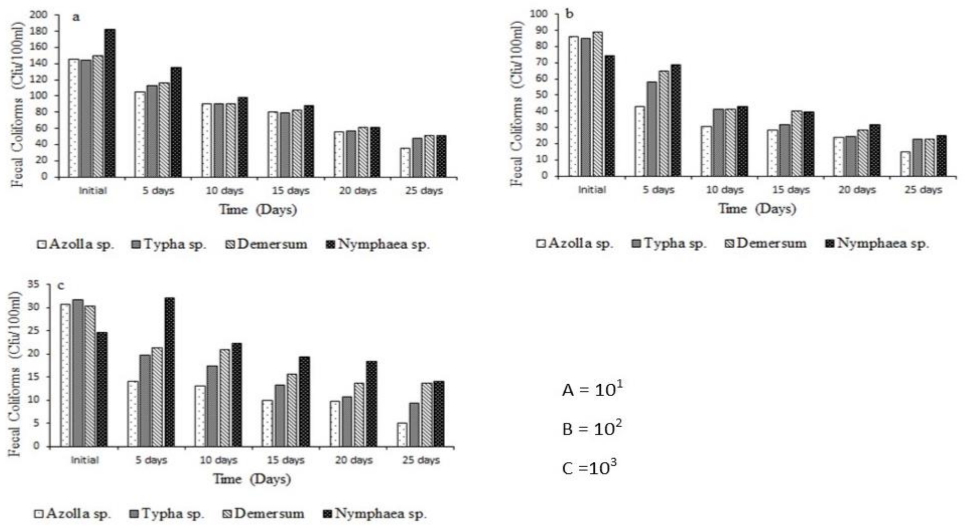

Figure 8: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to reduce feacal coliforms in wastewater

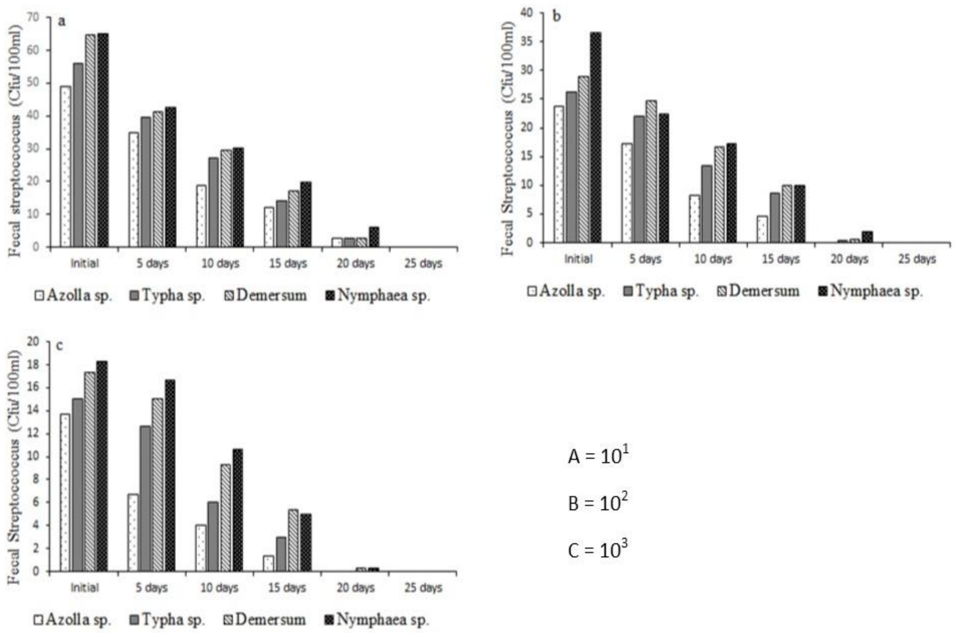

Figure 9: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to reduce feacal streptococcus in wastewater

Nutrients

Phosphates

All macrophytes were effective in removal of phosphates (Figure 10). *Azolla pinnata* and *Nymphaea* spp. had a 100% reduction efficiency. C*eratophyllum demersum* had 90.89% while *Typha latifolia* had a reduction efficiency of 88.65 %. There were significant differences in the removal of phosphates among the macrophytes (P = 0.00). Phosphates are macronutrient required by plants for their growth and development. Hence all the plants utilized the available phosphates. Kulasekaran *et al.*, (2014) reported phosphates removal efficiency of 93.5-98.3% by *C. demersum.* According to Basilico *et al*. (2015) major phosphorus removal processes in constructed wetlands are plant uptake, sorption and precipitation. There was a slight reduction in the levels of phosphates in the control which could be attributed to algae and microbial uptake, photodegradation, volatilization and sorption to troughs. The reduction in the control could also be due to biochemical and physico-chemical processes functioning in the system.

Nitrates

Azolla pinnata and *Nymphaea* spp. removed nitrates by 100%, C. *demersum* by 92.12 %, and *T. latifolia* by 89.38%. There were significant differences in nitrate removal among the macrophytes (P=0.003). All the macrophytes showed high potential to remove nitrates from eutrophic effluents (Figure 11). Nitrates are required by all living organisms for their growth and development therefore all macrophytes utilized this essential nutrient. The results were in harmony with the findings of Endut *et al.*, (2011) who observed 82.9 to 98.1% decrease in nitrate-nitrogen in wastewater using constructed wetlands. *Azolla pinnata* high removal efficiency of nitrates may be due to the thin and loose root mat that allows water-plant interaction. The main mechanisms of nitrates removal from wastewater in constructed wetlands are uptake by plants and microbial processes such as nitrification and denitrification (Basilico *et al.*, 2015). The decrease in the levels of nitrates in the control is attributed to the uptake by algae and microbes.

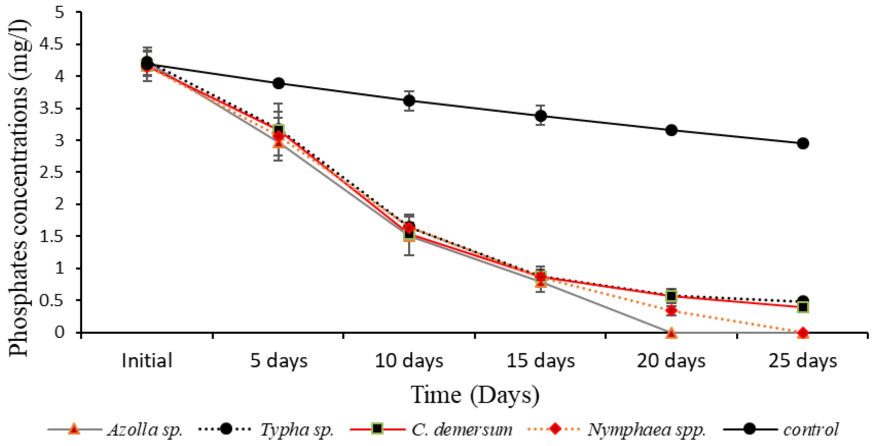

Figure 10: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp. to remove phosphates in wastewater

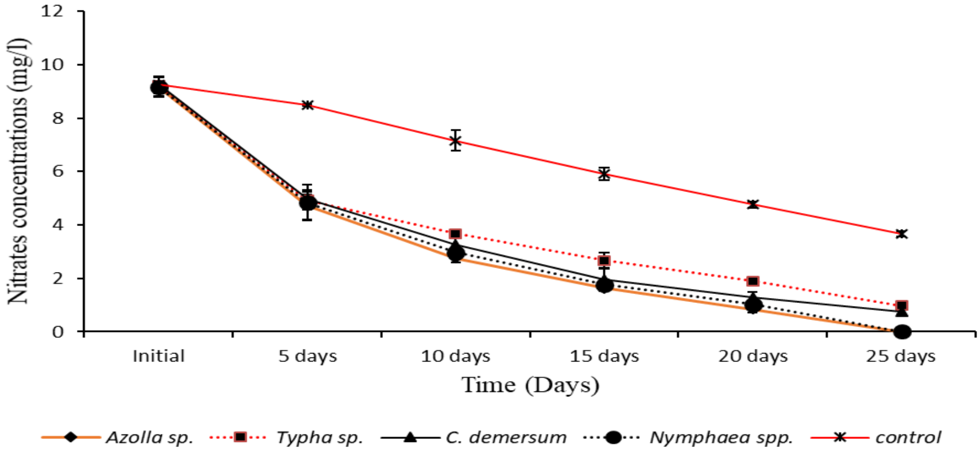

Figure 11: Potential of *A. pinnata, T. latifolia, C. demersum* and *Nymphea Sp*. to remove nitrates from wastewater

Heavy metals

Cadmium

Azolla pinnata and *T. latifolia* removed cadmium by 92.19%, *Ceratophyllum demersum* by 92.06% and *Nymphaea* spp. by 88.96% (Table 1). There were significance differences in cadmium reduction (P = 0.003). There was a slight change in the control which reduced cadmium by 21.88%. Macrophytes such as *C. demersum* has strong ability to remove cadmium in ecosystem (Al-Ubaidy and Rasheed, 2015). Floating macrophyte such as *Nymphaea* spp. has been reported to adsorb cadmium onto seeds, leaves and roots that normally occurs via a monolayer adsorption process (Galadima *et al.*, 2015).

Copper

All macrophytes exhibited high reduction efficiency with *Azolla pinnata* reducing copper by 85.83%, *T. latifolia* by 85.65%, *Ceratophyllum demersum* by 81.33% while *Nymphaea* spp. reduced copper by 78.87% (Table 1). There were no significant differences in reduction of copper among the macrophytes but there were significant differences between the macrophytes and the control, (P=0.00). According to Nuzhat *et al.*, (2015), *A. pinnata* is a hyper accumulator of copper and zinc and a moderate accumulator of lead, chromium and cadmium. Anning *et al.*, (2013), reported copper removal efficiency of 33.84% in wastewater by *Typha latifolia.*

Table 1: Removal efficiency (%) of various heavy metals by *A. pinnata, T. latifolia, C. demersum* and *Nymphaea* spp.

Parameter	Removal efficiency (%)				
Heavy metals	*A. pinnata*	*T. latifolia*	*C. demersum*	*Nymphaea* spp.	Control
Cadmium	92.19	92.19	92.06	88.96	21.88
Copper	85.86	85.65	81.33	78.87	21.38
Nickel	100	100	100	100	31.55
Cobalt	94.72	94.78	95.04	94.67	31.51
Lead	100	100	100	100	13.50
Manganese	85.81	86.13	85.99	88.81	32.40
Zinc	91.78	93.64	92.36	93.19	31.11
Iron	85.81	86.13	85.99	88.81	32.40

Nickel

All macrophytes were able to remove nickel by 100 % (Table 1). A minimal change occurred in the control which had a removal efficiency of 31.55%. The high removal of nickel may be due to its low levels in the initial concentration. Low levels of heavy metals results in higher accumulation in plants.

Cobalt

All macrophytes were effective in reduction of cobalt. *Ceratophyllum demersum* had the highest reduction efficiency of 95.04%. *Typha latifolia* had a reduction efficiency of 94.98%, *A. pinnata* 94.72% and *Nymphaea* spp. 94.67% (Table 1).

Lead

All macrophytes were able to reduce lead by 100% (Table 1). A minimal change occurred in the control which had a removal efficiency of 13.50%. Nuzhat *et al.*, (2015) revealed that *A. pinnata* has an excellent performance in removing lead. It was able to remove high amount of lead in 10 days of the experimentation period and hence concluded that *A. pinnata* is a good accumulator for lead.

Manganese

All macrophytes reduced the levels of manganese in wastewater. *Nymphaea* spp. reduced manganese by 88.81%, *T. latifolia* by 86.13%, *C. dermesum* by 85.99% and *Azolla pinnata* by 85.81% (Table 1). There were no significant differences in reduction of manganese among the macrophytes but there were significant differences between the macrophytes and the control, (P=0.00). The results coincided with Moushumi *et al.*, (2015) who said that *T. latifolia* was able to accumulate manganese, iron, copper, zinc and nickel. The well-developed roots of *Typha sp*. have high retention capacity of heavy metals and hence can be used in phytostabilization.

Zinc

Zinc was significantly removed by all macrophytes (P = 0.00). *Typha latifolia* had the highest reduction efficiency, 93.64%, *Nymphaea* spp. had 93.19%, *Ceratophyllum demersum* had 92.36% while *A. pinnata* had a reduction efficiency of 91.78% (Table 1). Zinc is essential for plants growth and development.

Iron

Nymphaea spp. had the highest reduction of iron, 95.69%. *Ceratophyllum demersum* had a reduction efficiency of 94.85%, *Typha latifolia* 94.21% while *A. pinnata* had a reduction efficiency of 94.16% (Table 1). The high reduction efficiency of iron by macrophytes is due to its necessity for plants growth and development. Iron is an essential micronutrient for all living organisms because it plays a critical role in metabolic processes such as DNA synthesis, respiration and photosynthesis. Macrophytes needed iron for various physiological and biochemical pathways and for chlorophyll production. Yen and Saiber (2013) reported that *Typha sp*. accumulated high concentration of iron and copper, these two metals are essential for plants growth and development.

CONCLUSION

The four macrophyte species were able to attain significant reduction efficiency for physicochemical and bacteriological parameters, nutrients and heavy metals. The order of removal efficiency was *Azolla pinnata* > *Nymphaea* spp > *Typha latifolia* > *Ceratophyllum demersum*. These macrophytes can be used to treat wastewater effluents from domestic, agricultural and industrial sources.

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