Vol. 10(4), pp. 28-32, August 2018
DOI:10.5897/JECE2015.0351
Article Number: 38DA9C258235
ISSN: 2141-226X

http://www.academicjournals.org/JECE

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Journal of Environmental Chemistry and Ecotoxicology

Full Length Research Paper

Heavy metal remediation from municipal waste water using arrowroots (*Amaranta arundinacea*)

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Received 16 April, 2015; Accepted 18 July, 2018

Municipal wastewater contains high levels of pollutants since it is a collection of wastes from various sources of human activities. Municipal treatment of such wastewater is usually aimed at lowering the levels of pollutants to permissible amounts before discharge into recipient environment. Several conventional methods are available for treatment of wastewater. However, most of them are costly and not economically feasible due to their secondary environmental impact. Wastewater treatment using natural plants has been considered the most environmentally friendly method. A study has been conducted to establish the metal removal rates from waste water using arrowroots. To establish if arrowroots can tolerate high levels of pollutants under natural conditions, raw arrowroots and raw wastewater were used. Pollutant removal efficiency levels was carried out by setting up a model constructed wetland where arrowroots were planted in raw influent of municipal wastewater and concentration levels of both planted and unplanted influent and effluent determined. Pollutant removal efficiency was compared using the relative treatment efficiency index technique. The results of the metal removal rates in wastewater cultivated with arrowroots were: Fe (68%), Mn (98%), Zn (54%) and Cu (50%) while pollutant removal in wastewater without arrowroots were: Fe (38%), Mn (48%), Zn (9%) and Cu (9%). The percent pollutant removal rate when arrowroots were planted in the effluent from unplanted maturation ponds was: Fe (97%), Mn (97), Zn (48%) and Cu (50%) with relative treatment efficiency of 0.28, 0.34, 0.71, and 0.65, respectively and $p < 0.002$ at 5% confidence interval. The difference in percent removal showed that more metal ions could be removed both from the raw sewage and final effluent when cultivated with arrowroots than in uncultivated maturation ponds, suggesting that arrowroots can be of significant benefit as a tertiary wastewater treatment alternative.

Key words: Wastewater, treatment, efficiency, influent, effluent, pollutants

INTRODUCTION

Constructed wetlands of natural plants are proving to be a valid treatment option for hazardous wastewaters, petroleum refinery wastes, compost and landfill leachates, agricultural wastes and pre-treated industrial wastewaters,

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such as those from tannery, pulp and paper mills and textile mills, treatment of raw sewage among others (Igwe and Abia, 2007; Volesky, 2007; Karanthanasis and Johnson, 2003; Ramirez, 2002; Tonderski et al., 2005; Maine et al., 2006; Calheiros et al., 2007; Molle et al., 2005).

The most significant functions of wetland emergent plants in relation to water purification are the physical effects brought by the presence of the plants, which provide a huge surface area for attachment and growth of microbes. The physical components of plants stabilize the surface of the beds, slow down the water flow, thus assist in sediment settling and trapping process and finally increasing water transparency. Wetland plants play a vital role in the removal and retention of nutrients and help in preventing the eutrophication of wetlands. A range of wetland plants has shown their ability to assist in the breakdown of wastewater. These plants have a large biomass both above (leaves) and below (underground stem and roots), the surface of the substrate. Turnover of root mass in plants creates macropores in a constructed wetland soil system allowing for greater percolation of water, thus increasing effluent/plant interactions (Marchand et al., 2010). The sub-surface plant tissues grow horizontally and vertically, and create an extensive matrix, which binds the soil particles and creates a large surface area for the uptake of nutrients and ions (Reeb and Werckmann, 2005).

Contaminants are removed from wastewater through several mechanisms. Processes of sedimentation, microbial degradation, precipitation and plant uptake remove most contaminants. Heavy metals in a wetland system may be sorbed to wetland soil or sediment, or may be chelated or complexed with organic matter. Metals can precipitate out as sulfides and carbonates, or get taken up by plants. Compounds in sediment, such as iron oxides, show preference for certain metals. This behavior can affect how efficiently a metal is adsorbed in a wetland. A system that has reached the limits of its adsorption capacity can exhibit a reduction in contaminant removal rates. After a system has reached its capacity for metal sorption, metal sulfide formation becomes the main method of metal removal. Sulfate-reducing bacteria oxidize organic matter and reduce sulfate to form hydrogen sulfide. Hydrogen sulfide reacts with metals to form metal sulfides, which precipitate. Compared to sediments, plants do not take up much metal, but they are involved in oxygenation and microbiological processes that contribute to the ability of the wetland to remove metals (Reeb and Werckmann, 2005).

EXPERIMENTAL DESIGN

Pollutant removal efficiency levels from wastewater using arrowroots was carried out by setting up a model constructed wetland where arrowroots were planted in raw influent of wastewater obtained at a waste water treatment plant at a quarry in Eldoret and concentration levels of both influent and effluent determined. Pollutant removal efficiency of both treated and untreated wastewater was compared by using the RTEI technique and RII index as suggested by Marchand et al. (2010). The efficiency of the metal removal with and without the arrowroot was investigated using the differences in metal removal between the influent and the effluent for the treatment (T%) with the arrowroot and compared with the control (C%) which was wastewater without the arrowroots. To obtain this, the simplified equation

$$\text{RTEI} = \frac{T-C}{T+C} \quad (1)$$

was used. Values of RTEI approaching 1 indicated strong benefits of metal removal, values around 0 indicated no effect of the treatment when arrowroots were used, whereas values approaching -1 indicated strong inhibition of the metal removal (Marchand et al., 2010). The effluent of the planted and the unplanted treated wastewater were also compared. The findings were recorded in Tables 1 and 2 and Figure 1 and 2.

RESULTS AND DISCUSSION

Table 1 shows results of percent removal efficiency of metal ions by life arrowroots from wastewater compared to biological method.

From Table 1, the percent removal of metal ions from raw sewage without arrowroots after 7 days of allowing natural biological action in the maturation ponds was: Fe (38%), Mn (48%), Zn (9%) and Cu (9%). However, for the same raw sewage that was cultivated with arrowroots in a model constructed wetland environment, the percent reduction after 7 days was; Fe (68%), Mn (98%), Zn (54%) and Cu (50%) with order of preference of Mn > Fe > Zn > Cu. This trend could have partly been influenced by the initial concentration of the metal ions in the raw sewage and the ionic size. Mn, having higher concentration levels in raw sewage were preferentially adsorbed followed by Fe and the least was Cu probably due to its very low concentration levels. This trend was also similar to that established by Marchand et al. (2010). This percent removal rate using the arrowroots was also found to be comparable with the removal rates of other plant species (Maine et al., 2007). The difference in percent removal showed that more metal ions could be removed both from the raw sewage and final effluent when cultivated with arrowroots than in uncultivated maturation ponds. There was also higher percent removal of Mn and Fe by arrowroots in the final biologically treated effluent compared to raw sewage. This could be because of the low concentration in the final effluent after passing through the maturation ponds.

Figure 1 shows a significant difference in the removal of metal ions from waste water using unplanted maturation ponds with that cultivated with arrowroots. Further reduction of the metal ions in the final effluent after passing through natural unplanted ponds by arrowroots was also noted in the Figure 1, showing that arrowroots can either be planted in the raw sewage or

Table 1. Removal efficiency of metal ions by life arrowroots from waste water.

Ion	Before introduction of arrowroots (levels in mg/l), treatment using biological method			After introduction of the arrowroots in raw sewage in the influent A1 to produce effluent B2 whose concentration levels were measured in mg/l			After introduction of arrowroots in biologically treated sewage of effluent B1 to produce effluent B3	
	Metal ion concentration levels in influent (A1)	Metal ion concentration levels in effluent (B1)	% Pollutant removal rates using biological method without arrowroots (WA)	Metal ion concentration levels in influent (A1)	Metal ion concentration levels in effluent (B2)	% Pollutant removal rates when arrowroots were planted in the influent A1(AARS)	Metal ion concentration levels in effluent (B3)	% Pollutant removal rates when arrowroots were planted in biologically treated effluent B1 (ACIBTS)
Fe	2.372	1.464	38	2.372	0.756	68	0.036	97
Mn	2.483	1.3	48	2.483	0.042	98	0.035	97
Zn	0.233	0.211	9	0.233	0.108	54	0.109	48
Cu	0.054	0.049	9	0.054	0.027	50	0.025	49

Table 2. Values of RTEI of the metal ions using life arrowroots.

Pollutant	C%	T%	RTEI
Fe	38	68	0.28
Mn	48	98	0.34
Zn	9	54	0.71
Cu	9	50	0.65

final effluent passed through the planted arrowroots in order to reduce the level of metal ions to recommended levels before being released to rivers or streams.

In order to test the significance contribution of using life arrowroots in removal of metal ions from municipal waste water, values obtained in Table 1 were subjected to relative treatment efficiency index (RTEI). Values obtained were recorded in Table 2.

In Table 2, C% represented percent removal for the wastewater without arrowroots and represented the control, while T% represented pollutant removal in the treated wastewater with arrowroots. The RTEI in Table 2 was calculated using equation, RTEI= $\frac{T-C}{T+C}$ (Marchand et al., 2010).

From the results in Table 2, the index which represented the net metal removal due to interaction of benefits and disadvantages of the treatment using arrowroots were high for Zn^{2+} and Cu^{2+} ions but slightly low for Fe^{2+} and Mn^{2+}. All the values of RTEI were positive hence the positive benefit of arrowroots. RTEI were high for Zn and Cu hence indicated strong benefits for metal removal while RTEI values for Mn and Fe were less and hence indicating less effect on the treatment of the wastewater cultivated with arrowroots. This difference could have been again due to the difference in levels of the ions in raw sewage where high RTEI was high for Zn and Cu probably due to their low concentration levels.

This could possibly suggest that life arrowroots can be of more significant use if used to further treat recycled treated sewage by passing it through arrowroot wetlands and also as a tertiary wastewater treatment alternative. This could also imply that arrowroots can effectively be used to remove metal ions from dilute solutions containing relatively low levels of dissolved metals, thus supporting similar arguments that were made by Abdel and Elchaghaby (2007) and also Brisson and Chazarenc (2009).

Results in Figure 2 showed high percent removal of the four metal ions, when the arrowroots were cultivated in waste water. Low percent removal of the metal ion pollutant in wastewater without arrowroots was also observed. This showed that most metal ions were removed by the arrowroots. From the null hypothesis results; $t(3) = 2.110$, $p < 0.002$, the null hypothesis was rejected implying that arrowroots can significantly adsorb heavy metals from dilute solutions such as the river

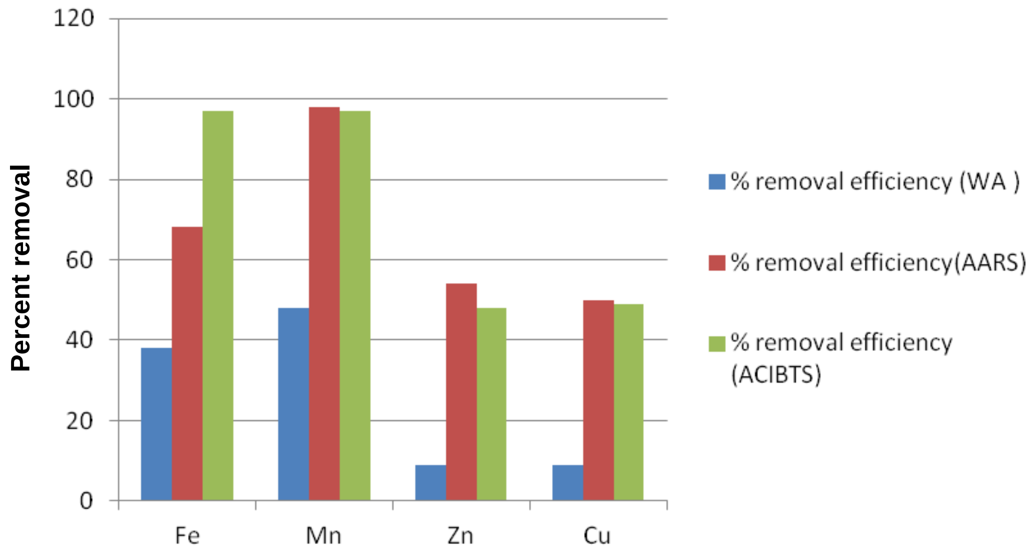

Figure 1. Percent removal of metal ions in raw sewage without arrowroots (WA) and when cultivated with arrowroots in raw sewage (AARS) and in arrowroots cultivated in biologically treated sewage (ACIBTS)

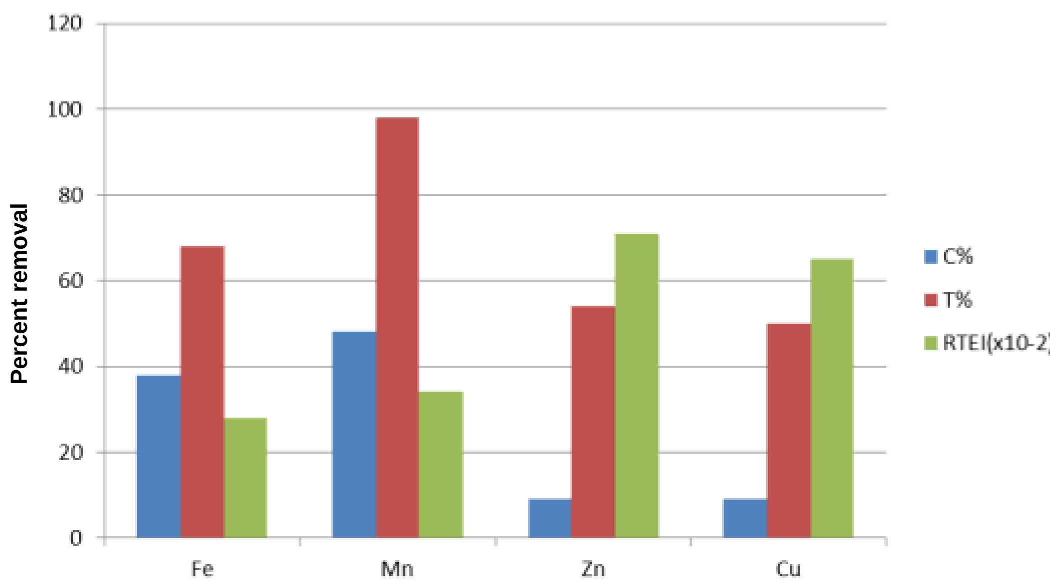

Figure 2. Percent removal efficiency with and without arrowroots and their RTEI values

water and model solutions of wastewater containing higher concentrations of metal ions.

Conclusion

Life arrowroots effectively removed Zn, Cu, Fe and Mn from both raw untreated municipal wastewater and from already naturally treated wastewater effluents from maturation ponds. The following percent removal rates were established. From raw untreated waste water, the percent removal efficiency using arrowroots was; Fe (68%), Mn (98%), Zn (54%) and Cu (50%). These percentages were found to be higher compared to the percent removal efficiency for unplanted maturation ponds when left for 7 days where the same metal ions were removed by natural process. For unplanted ponds, the percent removal efficiency was; Fe (38%), Mn (48 %), Zn (9%) and Cu (9%). Arrowroots also effectively lowered the levels of the metal ions from the already treated waste water effluents from maturation ponds to minimal levels recommended for final discharge into surface waters such as rivers and streams by the following percent removal rates; Fe (97%), Mn (97%), Zn (48%) and Cu (49%). A paired t-test that was conducted to test the null hypothesis concerning the significance of life in removing metal ions from wastewater showed that the alpha level was below 0.05 at 5% confidence level ($p < 0.002$) and hence rejecting the null hypothesis at 5% significant level and concluded that arrowroots can significantly be used to remove metal ions from municipal waste waters.

RECOMMENDATIONS

Some treatment plants such as Eldoret Water and Sanitation Company (Eldowas) that have large parcel of land should consider using arrowroots in tertiary ponds of wastewater in addition to natural unplanted biological ponds. Further research should be carried out to study the adsorption efficiency of other pollutants using arrowroots.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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