Pollutants Removal Efficiency of two Mangroves Species (*Avicennia marina* and *Rhizophora mucronata*) in Treating Domestic Sewage

A. K. Kondo[1], A. Nyomora[1] and K.N. Njau[2]
[1]University of Dar es Salaam, Botany department, [2]Nelson Mandela Institute of Technology, Arusha
E-mail:nyomora@amu.udsm.ac.tz

***Abstract**: Bucket experiments were conducted to evaluate the effect of domestic sewage loading and inundation time on pollutants removal efficiency for cells planted with Avicennia marina and Rhizophora mucronata mangroves species. Domestic sewage from the University of Dar es Salaam primary facultative waste stabilization pond was loaded onto buckets planted with the two mangroves species and unplanted buckets (bare sediment) used as control units. Sea water was used to dilute the sewage to make desired sewage strength of 0, 25%, 50%, 75% and 100%. Inundation times of 1 week, 24 hours and 12 hours were used in these experiments. Based on the obtained results, units planted with mangroves showed optimal removal of phosphates, total phosphorous and ammonium-nitrogen at sewage loading of 100% when inundated for 1 week. There was a significant reduction in concentration of phosphorous, total phosphorous and ammonium-nitrogen observed in planted units. However, there was insignificant difference in nutrients removal between the two mangrove species. While Avicennia marina units removed phosphorous, total phosphorous and ammonium-nitrogen by 94.49%, 93.25% and 94.76% respectively, removal efficiency of the same pollutants by Rhizophora mucronata units were 94.00%, 92.82% and 94.05%, respectively. Generally, the removal percentage of phosphorous, total phosphorous and ammonium-nitrogen were significantly higher in 1 week inundation time than in both 24 hours and 12 hours inundation time. Based on the performance of mangrove on nutrient removal, it was concluded that the two mangrove species could be used as phytoremediators of domestic wastewater in mangroves constructed wetlands in coastal areas.*

Key words: *Avicennia marina, Rhizophora mucronata,* domestic sewage, inundation.

INTRODUCTION

Mangroves are a diverse group of trees and shrubs that usually grow in the intertidal zone of tropical and subtropical coastlines. They are able to live in very wet, mud soils found along the ocean shores and can tolerate low oxygen level as well as high salt content of the seawater (Lugo and Snedaker, 1974; Enger and Smith, 2004). Like other wetlands, the mangrove ecosystem can be used as an alternative low-cost wastewater treatment system, and has a large capacity in retaining nutrients from wastewater (Tam and Wong, 1996; Wong *et al*., 1995).

Mangrove forests along the coast of Tanzania occur on gently sloping shores and around river estuaries, creeks and bays (Wang *et al*., 2003). The most common mangrove species found in these forests include *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Rhizophora mucronata, Xylocarpus granatum* and *Sonneratia alba* but with few *Lumnitzera racemosa* and *Heritiera littoralis*. Of these, *A. marina*, *R. mucronata* and *C. tagal* are most predominant (Semesi, 2001; Richmond, 2002).

The rapid growing of coastal cities as is the case in Tanzania results into increasing discharge of domestic sewage into the environment and finally into the ocean. This accelerates coastal pollution through addition of excess nutrients contained in wastewater (Holguin *et al*., 2001), which in turn may lead to eutrophication and ultimately to deterioration of water quality. Additionally, mangrove wetlands are frequently inundated by saline water at different intervals depending on the distances from low water mark. This causes the soil to be saline and anoxic with variable redox potential depending on the degree of inundations (Shunula, 1996) and because of high organic matter, mangrove soils are generally reduced. Prolonged inundation time is believed to enhance development of anoxic conditions in mangrove soils. This causes accumulation of soil phytotoxins as a result of breakdown of carbohydrates by soil microorganism through anaerobic pathways (Mackee *et al*., 1988), which in turn might affect mangrove efficiency of pollutants removal.

There is evidence from pollution studies (Marshall, 1994; Tam and Wong, 1993; Wong *et al*., 1997; Rivera-Monroy *et al*., 1999) that suggests mangroves to be capable of sewage filtration and thus preventing coastal pollution. Results from these studies done in Puerto Rico and China showed that, mangrove ecosystems have considerable capacity to accept sewage loading from sewage effluent without suffering any damage to their growth (Tam and Wong, 1993).

However, no related studies have been done in Tanzania to assess the effect of sewage loading and inundation time in the removal efficiency of pollutants among mangrove species. Therefore this study was initiated to compare the effect of sewage loading and inundation time on pollutants removal efficiency between two predominant mangrove species in Tanzania, *Avicennia marina* and *Rhizophora mucronata*.

MATERIALS AND METHODS

Study Area

This study was carried out at the University of Dar es Salaam, Botany department, nursery area. The area receives monthly mean maximum and minimum air temperature of 28 ºC and 23 ºC, respectively.

Experimental Methods

Soil from around the mangroves seedlings close to the experimental plots constructed at Jangwani Beach within the Kunduchi mangrove forest were used to plant *Avicennia mar*ina and *Rhizophora mucronata* seedlings in 72 plastic buckets each measuring 25.5 cm in diameter and 28 cm in height. Other 12 plastic buckets of the same size but without seedlings were used as control (Figure 1). Sewage drawn from oxidation treatment pond No. 2 of UDSM waste stabilization ponds at indicated times was loaded to a depth of 10cm above the potting media in the bucket. The experiments consisted of three series of inundation times of sewage loading namely 1 week, 24 hours and 12 hours.

Each series comprised of 24 buckets, 12 for *Avicennia marina* and the other 12 for *Rhizophora mucronata*. Each series was divided into 4 subgroups of sewage treatment. These buckets were loaded with domestic sewage from the University of Dar es Salaam (UDSM) primary facultative waste stabilization pond. Sea water was used to dilute the sewage to make sewage treatment concentrations of 0, 25%, 50%, 75% and 100%. Each treatment was replicated 3 times. Samples of 1 litre size were collected into plastic bottles for laboratory analyses.

The initial samples were taken at the time of sewage loading in the buckets for the initial measurement of phosphate, total phosphorous and ammonium-nitrogen. Also in situ measurement of pH, electrical conductivity (EC) and salinity were done. Sewage samples for the final measurements were collected at the end of each duration of 1 week, 24 hours and12 hours inundation. After each sample collection, the remaining sewage in the buckets was poured off and the seedlings left to rest for 48 hours for aeration before starting of another round of treatment (sewage loading). In both series 4 control buckets with bare soil were treated the same way as those with mangrove seedlings. The experimentation period lasted for one month, during which sampling for 1 week, 24 hours and 12 hours were repeated four, five and seven times, respectively.

Figure 1: Bucket experiments layout

Table 1: Experimental Design for the Effect of Sewage Loading and Inundation Time on Mangrove Removal Efficiency of Pollutants (Bucket Experiment)

Mangrove species	**Inundation time**	**Sewage concentration**											
		25%			**50%**			**75%**			100%		
Avicennia marina	1week (1st series)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
	24 hours (2nd series)	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24
	12 hours (3rd series)	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36
Rhizophora mucronata	1week (1st series)	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
	24 hours (2nd series)	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22	R23	R24
	12 hours (3rd series)	R25	R26	R27	R28	R29	R30	R31	R32	R33	R34	R35	R36
Control	1week (1st series)	C1			C2			C3			C4		
	24 hours (2nd series)	C5			C6			C7			C8		
	12 hours (3rd series)	C9			C10			C11			C12		

Measurement of Physical-chemical Parameters

The water quality parameters analyzed were pH (in situ measurement, using Fisher brand Hydrus 200 pH-meter), salinity and electrical conductivity (EC) (in situ measurement, using YSI Model 85 hand held system meter), phosphates (ascorbic acid method, Emteryd, 1989; APHA, 1998), total phosphorous (persulfate digesting method followed by ascorbic acid method, Emteryd, 1989; APHA, 1998) and ammonium-nitrogen, (indophenol blue method, Stewart, 1989).

Data Analysis

The mean and standard error values of replicate samples were calculated. The collected data were statistically analyzed using Instat Statistical Software version 3.06. The significance of the removal efficiency of pollutants between *A. marina* and *R. mucronata* was tested using repeated measure ANOVA test followed by Tukey-Kramer Multiple Comparison Test that gave mean separation. The same test was used to determine significant difference among different levels of domestic sewage loading and inundation time on pollutants removal efficiency of the two mangroves species.

The removal efficiency (RE) equation used was as follows:

$$RE\ (\%) = \frac{\text{(Initial pollutant concentration – Final pollutant concentration)}}{\text{Initial pollutant concentration}} * 100\%$$

RESULTS AND DISCUSSION

Sediment Reaction (pH)

The final pH of the sewage loaded into *A. Marina*, *R. mucronata* and bare sediment units was generally found to increase significantly ($p<0.0001$) from the initial value as shown in the figures 2, 3 and 4. The increase in final pH might have been caused by increased alkalinity due to continual addition of neutral salts such as NaCl, $CaCl_2$ and $MgCl_2$ in the system from the mixture of sewage and sea water as well as evaporation that leaves behind soluble salts present in the mixture of sewage and sea water that was used in diluting the sewage. The addition of these neutral salts ensures continued formation of highly ionized compounds of both bicarbonate (HCO_3^-) and carbonate ions (CO_3^{-2}) which in turn dissociates to form hydroxyl (OH^-) ions and thereby increase pH (Brady and Weil, 1999).

There was no significant difference ($p>0.05$) among the final pH at all levels of sewage loadings between planted and control units in all series of inundations time. This may be due to the fact that pH variation is a result of interaction between the substrate and its biofilms rather than to the plants (Bavor *et al.,* 1988; Kadlec and Knight, 1996). Normally bare sediment (control unit) have higher value of pH than planted units when coverage of plants in the planted units is enough to block penetration of light through their canopy (Boonsong *et al.,* 2002; Senzia, 2003). Light penetration to the bottom, made the system to be more photosynthesized which in turn caused high consumption of carbon dioxide gas by algae (Boonsong *et al.,* 2002). Depletion of carbon dioxide gas lead to shift in the carbonate and bicarbonate ions equilibrium ending up with a higher pH (Kadlec and Knight, 1996).

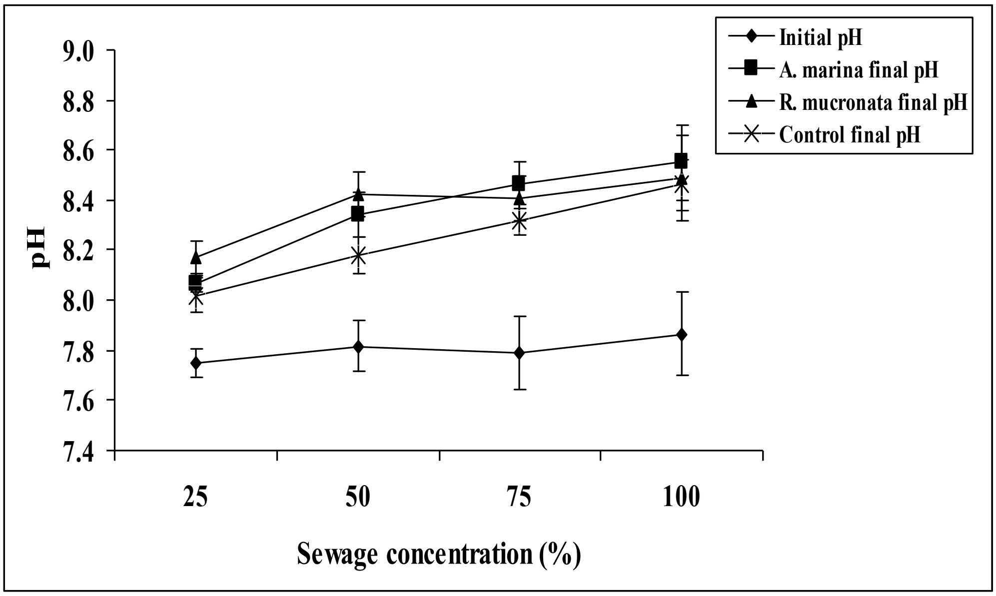

Figure 2: Variation of pH in *A. marina* and *R. mucronata* units Inundated for 1 week at Various Sewage Concentrations

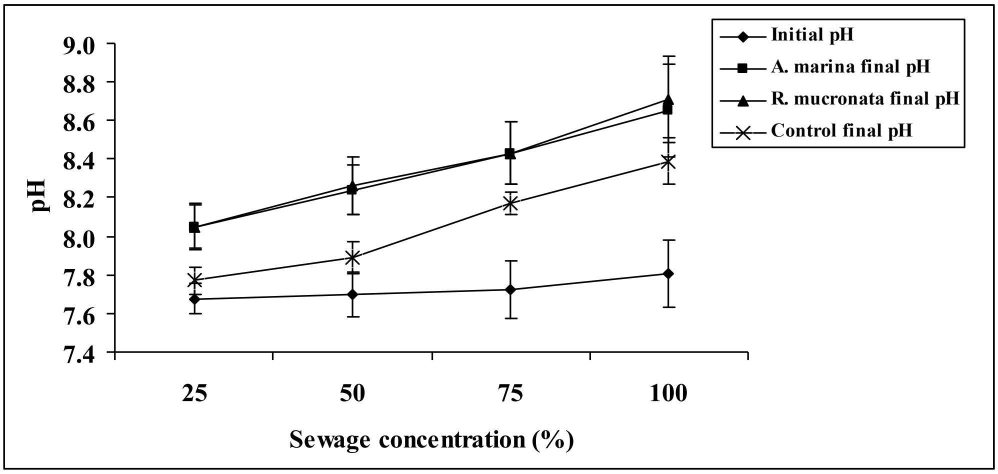

Figure 3: Variation of pH in *A. marina* and *R. mucronata* units inundated for 24 hours at various sewage concentrations

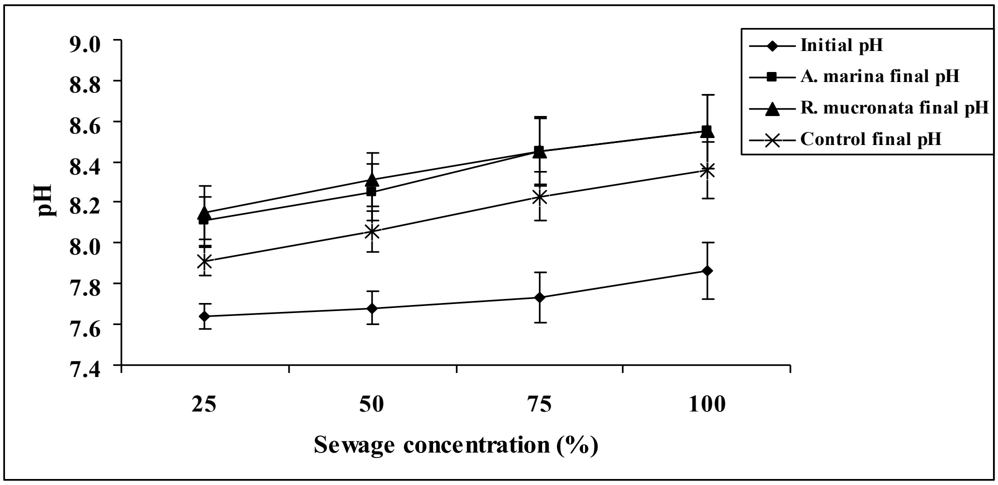

Figure 4: Variation of pH in *A. marina* and *R. mucronata* Units Inundated for 12 hours at various Sewage Concentrations

Salinity and Electrical Conductivity (EC)

In general there was significant difference ($p<0.0001$) in salinity and EC between treatments with different levels of sewage concentrations in all three series of inundation times. Both salinity and EC were found to increase from the initial to the final measurements taken after each inundation time (Figures 5 - 10). However, one week inundation time showed the largest difference between the initial and final salinity and EC. The increase in salinity and EC was due to the evaporation of water from the surface of sewage in the buckets. As water evaporates, dissolved solids in the remaining sewage gets concentrated and cause increase in salinities and EC. Additionally, in all three series of inundation time the values of salinity and EC were found to be decreasing with the increasing sewage concentration that was loaded into *A. marina*, *R. mucronata* and control units. This is because of dilution effect caused by sewage on seawater which has higher salinity and EC values.

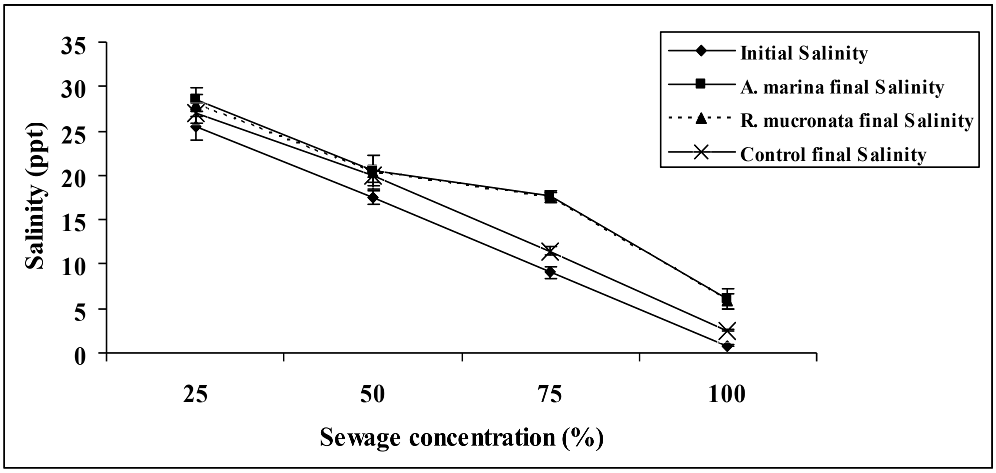

Figure 5: Variation of salinity in *A. marina* and *R. mucronata* Units Inundated for 1 Week at Various Sewage Concentrations

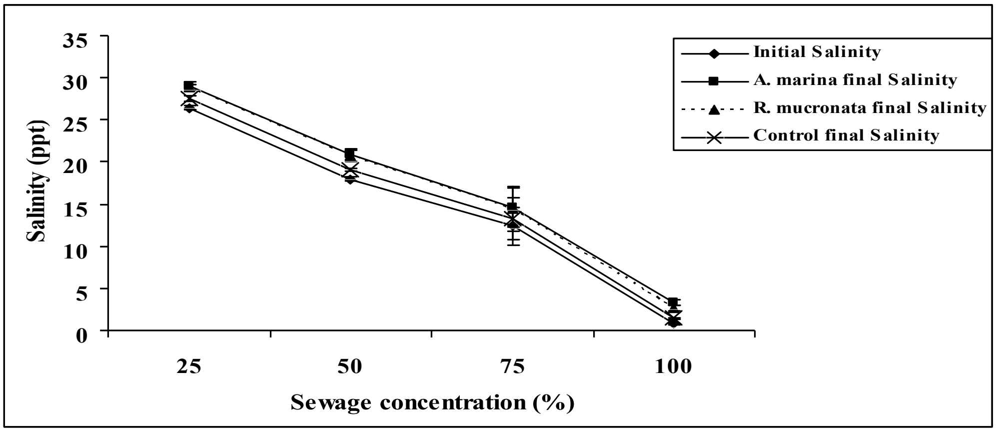

Figure 6: Variation of Salinity in *A. marina* and *R. mucronata* Units Inundated for 24 Hours at Various Sewage Concentrations

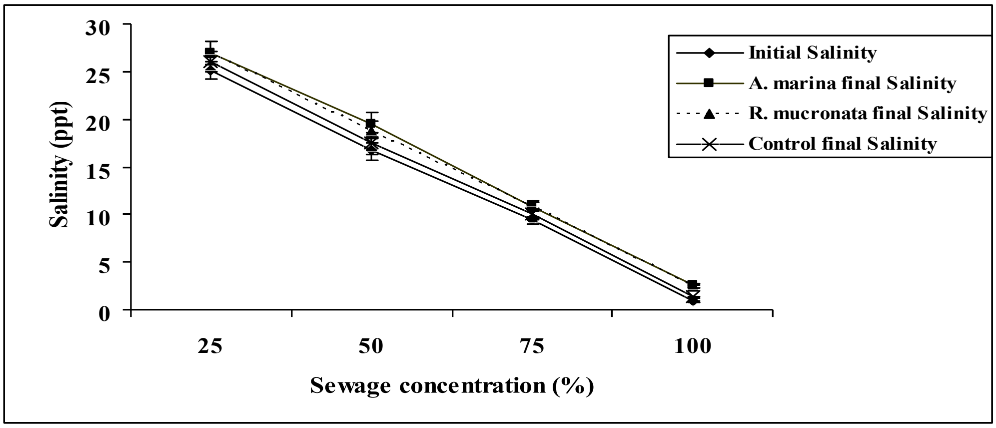

Figure 7: Variation of Salinity in *A. marina* and *R. mucronata* Units Inundated for 12 Hours at Various Sewage Concentrations

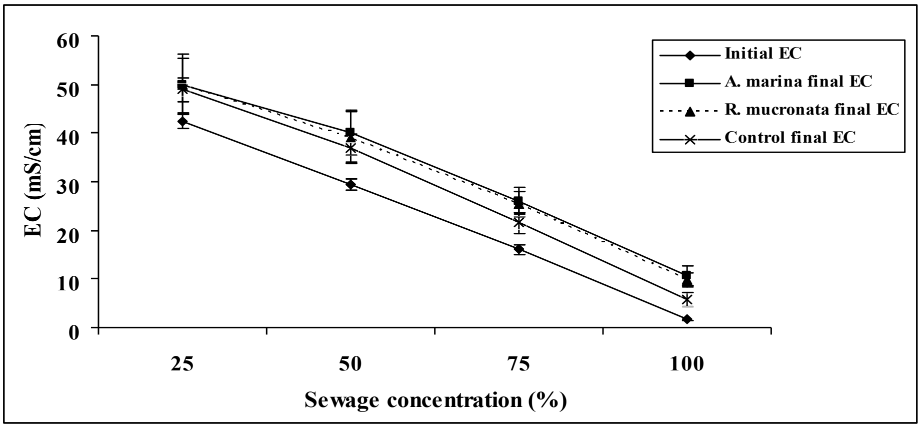

Figure 8: Variation of EC in *A. marina* and *R. mucronata* Units Inundated for 1 week at Various Sewage Concentrations

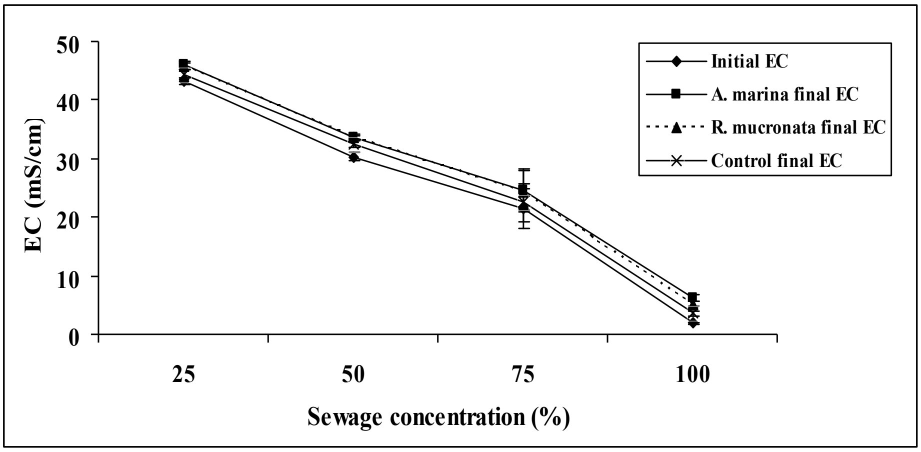

Figure 9: Variation of EC in *A. marina* and *R. mucronata* Units Inundated for 24 Hours at Various Sewage Concentrations

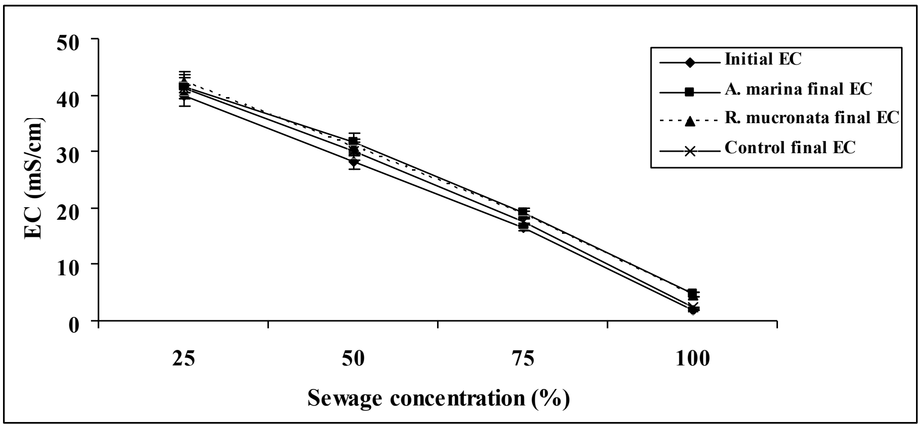

Figure 10: Variation of EC in *A. marina* and *R. mucronata* Units Inundated for 12 Hours at Various Sewage Concentrations

Removal of Phosphate (PO_4-P) and Total Phosphorous (TP)

Tables 2 and 3 summarise the average initial and final phosphates and total phosphorous concetrations in *A. marina*, *R. mucronata* and control units inundated for one week, 24 hours and 12 hours at various sewage concentrations. As explained by Reddy and D'Angelo, (1997), the low value in final concentrations of phosphates are caused by retention in the sediments and uptake by plants and microbes for their growth.

Table 2: Phosphates Concentration of Sewage Inundated at Various Concentrations and Inundation Times in *A. marina*, *R. mucronata* and Control units

Inundation time	***Avicennia marina* unit**				***Rhizophora mucronata* unit**				**Control unit**			
	C1 25%	**C2 50%**	**C3 75%**	**C4 100%**	**C1 25%**	**C2 50%**	**C3 75%**	**C4 100%**	**C1 25%**	**C2 50%**	**C3 75%**	**C4 100%**
Initial(mg/l)	2.49	3.44	4.15	4.52	2.49	3.44	4.15	4.52	2.49	3.44	4.15	4.52
Final (mg/l) 1 week	0.76	0.51	0.58	0.25	0.88	0.69	0.70	0.27	1.41	1.64	1.94	0.94
Initial(mg/l)	2.99	3.61	4.04	4.56	2.99	3.61	4.04	4.56	2.99	3.61	4.04	4.56
Final (mg/l) 24 hours	1.49	1.35	1.29	0.28	1.69	1.52	1.54	0.45	2.14	2.25	2.54	1.38
Initial(mg/l)	2.57	3.40	3.96	4.15	2.57	3.40	3.96	4.15	2.57	3.40	3.96	4.15
Final (mg/l) 12 hours	1.59	1.67	2.30	1.08	1.74	1.88	2.29	1.15	2.04	2.32	2.99	2.50

Table 3: Total Phosphorous Concentration of Sewage Inundated at Various Concentrations and Inundation Times in *A. marina*, *R. mucronata* and Control units

Inundation time	***Avicennia marina* unit**				***Rhizophora mucronata* units**				**Control unit**			
	C1 25%	**C2 50%**	**C3 75%**	**C4 100%**	**C1 25%**	**C2 50%**	**C3 75%**	**C4 100%**	**C1 25%**	**C2 50%**	**C3 75%**	**C4 100%**
Initial(mg/l)	8.26	10.47	12.39	15.09	8.26	10.47	12.39	15.09	8.26	10.47	12.39	15.09
Final (mg/l) 1 week	3.20	2.86	2.33	1.01	3.62	3.38	2.54	1.07	5.08	5.18	5.80	3.38
Initial(mg/l)	7.21	9.45	12.46	14.19	7.21	9.45	12.46	14.19	7.21	9.45	12.46	14.19
Final (mg/l) 24 hours	3.22	2.92	4.85	2.12	3.49	3.32	5.29	2.76	4.64	5.18	7.30	5.99
Initial(mg/l)	7.02	10.75	13.22	15.32	7.02	10.75	13.22	15.32	7.02	10.75	13.22	15.32
Final (mg/l) 12 hours	3.67	4.52	6.61	3.75	4.19	5.52	7.34	3.97	4.61	6.45	8.37	8.10

Figures 11 - 13 and 14 – 16 show removal efficiencies of phosphates and total phosphorous in *A. marina*, *R. mucronata* and control units for various inundation times. The results showed that in one week and 24 hours inundation times there was statistically significant difference ($p<0.0001$) in phosphates and total phosphorous removal between planted and control units. However, the 12 hours inundation time experiment showed no statistically significant differences ($p>0.05$). The reason for this observation might have been due to the relatively short period of inundation. According to Crites (1994), long retention times (15 to 25 days) of sewage is required for significant phosphorous removal; therefore inundating sewage in the system for 12 hours provided very short time for both nutrients adsorption by sediments and uptake of nutrients by plants and microbes.

The maximum phosphates removal by *A. marina* units were 94.5%, 84.3% and 73.9% for one week, 24 hours and 12 hours of inundation time respectively, at 100% sewage concentration and maximum removal of total phosphorous also at 100% sewage concentration by the same units were 93.3%, 85.2% and 75.1% with respect to the series of inundation. At the same sewage concentration maximum phosphates removal in *R. mucronata* units for one week, 24 hours and 12 hours of inundation time were 94.0%, 78.6% and 72.2% respectively, while maximum removal of total phosphorous were 92.8%, 80.7% and 73.7% with respect to the series of inundation. Also at 100% sewage concentration control units showed maximum removal of phosphates of 79.2%, 52.4% and 40.1% for one week, 24 hours and 12 hours of inundation time and that of total phosphorous were 77.6%, 57.1% and 47.3% with respect to the series of inundation time (Figure 11 - 16).

On the other hand, the minimum phosphates removal by the *A. marina* units were 69.9%, 48.9% and 38.5% for the one week, 24 hours and 12 hours of inundation time respectively observed at 25% sewage concentration, while the minimum removal of total phosphorous were 62.9%, 55.8% and 44.8% with respect to the series of inundation also observed at 25% sewage concentration.

At the same sewage concentration, the minimum phosphates removal by the *R. mucronata* units were 65.2%, 43.6% and 33.6% and that of total phosphorous were 56.6%, 51.8% and 37.1% with respect to the series of inundation and only phosphates removal of 43.9%, 30.1% and 21.2% as well as total phosphorous removal of 39.2%, 34.6% and 31.8% were observed at 25% sewage concentration in the control units with respect to the series of inundation (Figure 11 - 16). This showed that the two mangroves species played an important part in phosphates removal compared to the bare sediments since there was a considerable reduction of phosphates and total phosphorous in these systems. Although buckets containing *A. marina* performed relatively better than that of *R. mucronata*, the performance of these two mangroves species was statistically not significantly different ($p>0.05$) in the removal of phosphates and total phosphorous at all the three inundation times tested.

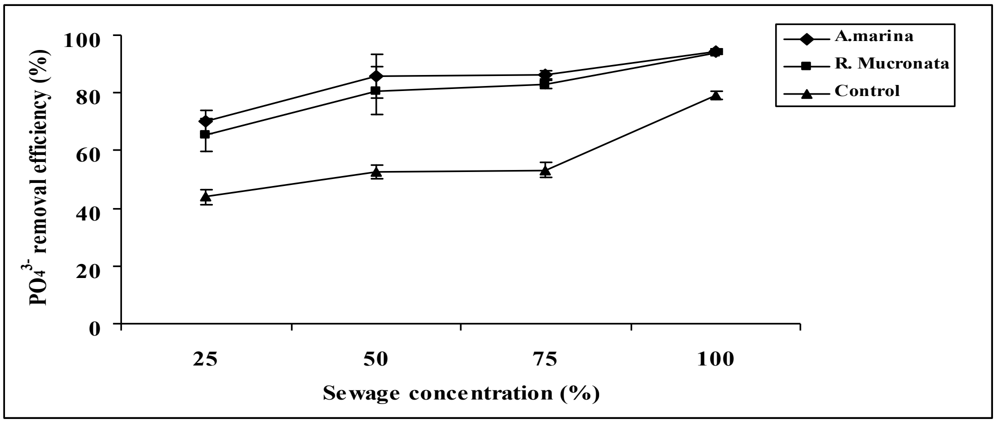

Figure 11: A Comparison of Phosphates Removal between *A. marina* and *R. mucronata* Units Inundated for One Week At Various Sewage Concentrations

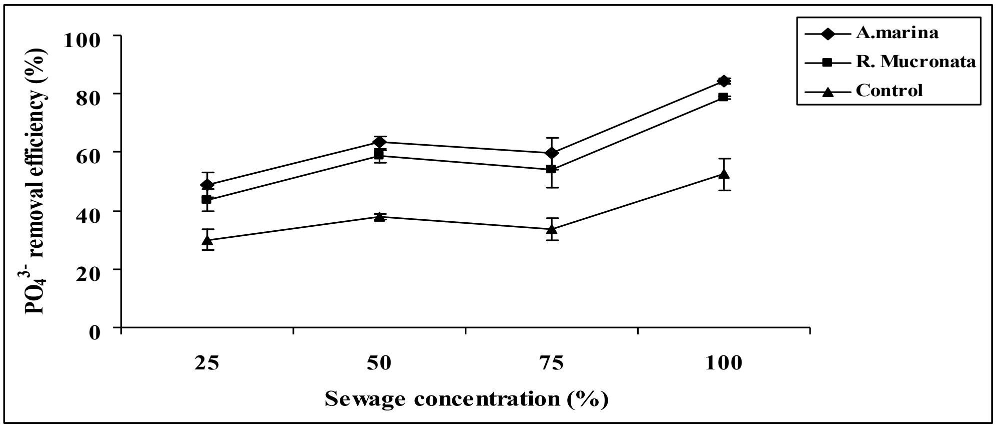

Figure 12: A Comparison Of Phosphates Removal between *A. marina* and *R. mucronata* Units Inundated for 24 Hours at Various Sewage Concentrations

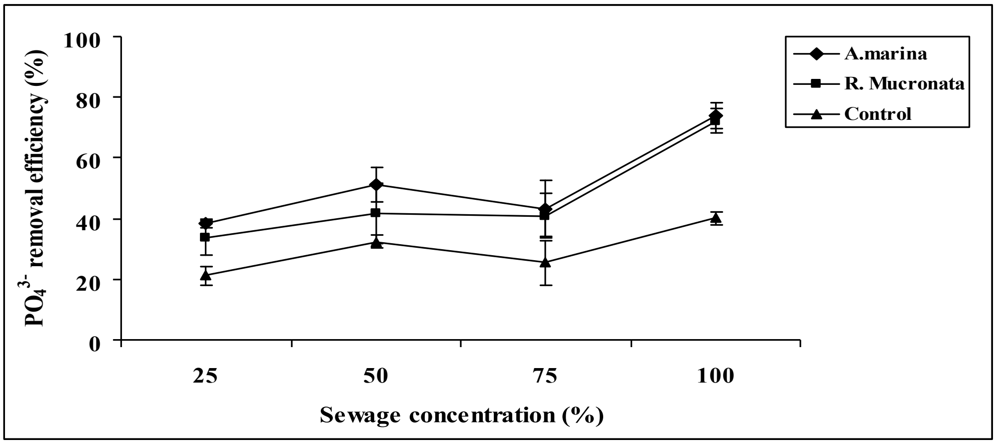

Figure 13: A Comparison of Phosphates Removal between *A. marina* and *R. mucronata* Units Inundated for 12 Hours at Various Sewage Concentrations

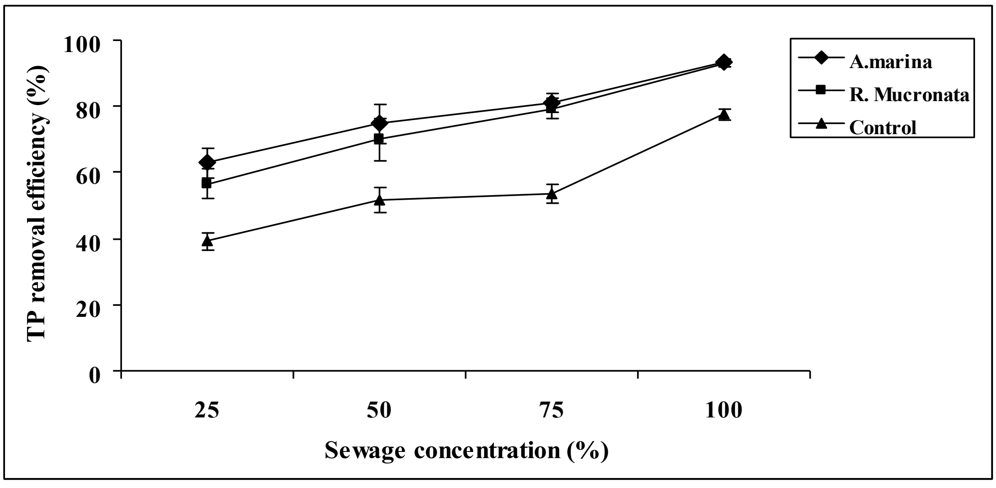

Figure 14: A comparison of Total Phosphorous Removal between *A. marina* and *R. mucronata* units inundated for 1 Week at Various Sewage Concentrations

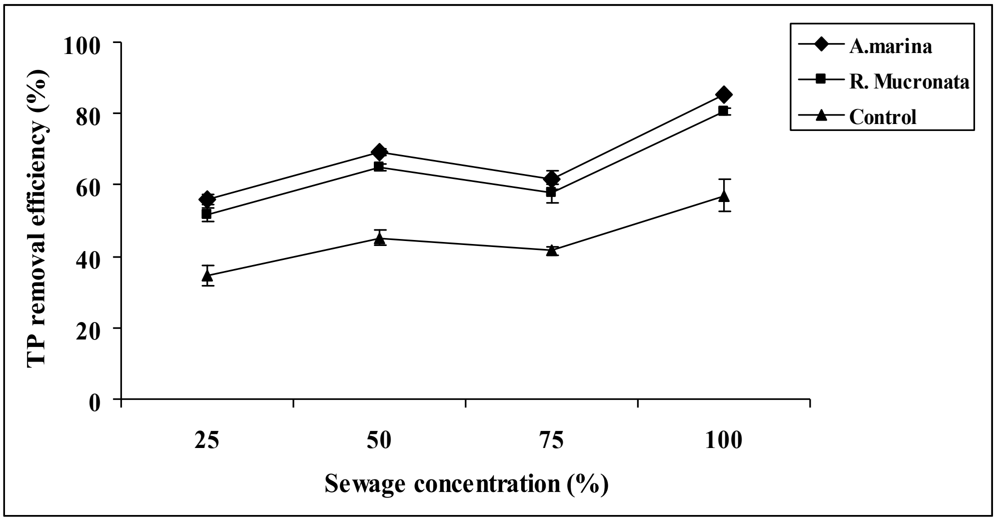

Figure 15: A comparison of Total Phosphorous removal between *A. marina* and *R. mucronata* Units Inundated for 24 Hours at Various Sewage Concentrations

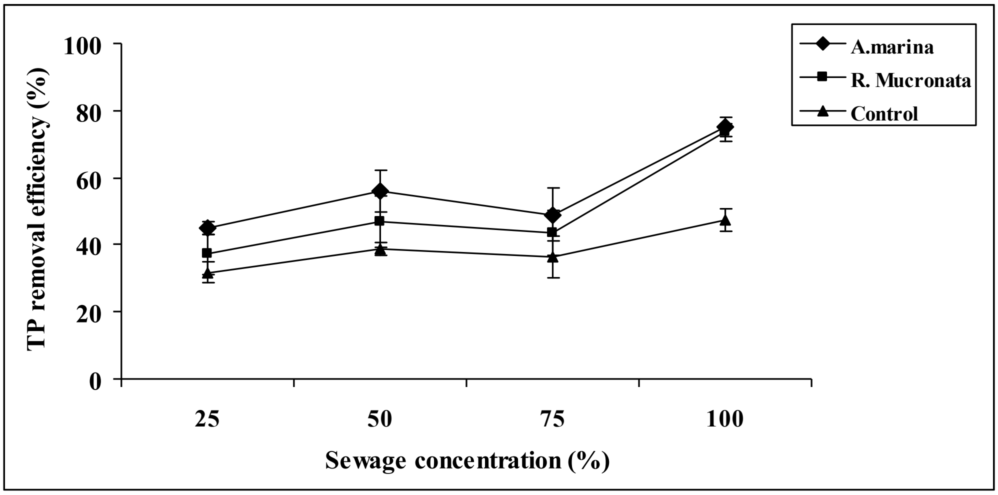

Figure 16: A comparison of Total Phosphorous Removal between *A. marina* and *R. mucronata* units inundated for 12 Hours At Various Sewage Concentrations

Removal of Ammonium-nitrogen (NH_4^+-N)

The average initial and final ammonium-nitrogen concentrations between *A. Marina*, *R. Mucronata* and control units inundated for one week, 24 hours and 12 hours at various sewage concentrations is summarised in Table 4. The low value in final concentrations of ammonium-nitrogen may be due to soil absorption and uptake by plants and microbes for their growth. Neel *et al.*, (1961) and Fritz *et al.*, (1970), reported that ammmonium-nitrogen is a prefered source of nitrogen by plants and microbes. In this study ammonia volitilization was very unlikely because ammonia stripping occurs at pH values 9.5 (Kadlec and Knight, 1996). The pH values of all units ranged from 7.64 to 8.71.

Table 4: Ammonium-nitrogen Concentration of Sewage Inundated at Various Concentrations and Inundation Times in *A. marina*, *R. mucronata* and Control units

Inundation time	*Avicennia marina*				*Rhizophora mucronata*				**Control**			
	C1 25%	C2 50%	C3 75%	C4 100%	C1 25%	C2 50%	C3 75%	C4 100%	C1 25%	C2 50%	C3 75%	C4 100%
Initial(mg/l)	3.73	4.84	6.52	7.38	3.73	4.84	6.52	7.38	3.73	4.84	6.52	7.38
Final (mg/l)	1.14	0.41	0.74	0.37	1.35	0.59	0.94	0.43	2.48	2.49	3.37	1.59
1 week												
Initial(mg/l)	4.26	6.14	6.83	8.10	4.26	6.14	6.83	8.10	4.26	6.14	6.83	8.10
Final (mg/l)	1.83	1.98	2.48	1.00	1.99	2.22	2.88	1.34	2.95	3.83	4.47	3.55
24 hours												
Initial(mg/l)	3.83	5.32	7.27	8.34	3.83	5.32	7.27	8.34	3.83	5.32	7.27	8.34
Final (mg/l)	1.99	1.79	2.94	1.68	2.10	2.09	3.04	1.82	2.73	3.47	4.77	4.47
12 hours												

The results showed that there was extremely high statistically significant difference ($p<0.0001$) in ammonium-nitrogen removal between control (bare buckets) and the planted ones (*A. marina* and *R. mucronata*) in all series of inundations but not between the two mangrove species.The maximum ammonium-nitrogen removal by the *A. marina* units were 94.8%, 87.9% and 79.8% at 100% sewage concentration for the first, second and third series respectively, and *R. mucronata* units were 94.1%, 83.4% and 78.2% at 100% sewage concentration while control were 77.8%, 56.2% and 46.7% at 100% sewage concentration with respect to the series of inundation time (Figure 17, 18 and 19).

On the other hand the minimum ammonium-nitrogen removal by the *A. marina* units were 73.2%, 58.0% and 51.2% at 25% sewage concentration for the first, second and third series respectively, while for *R. mucronata* units were 67.3%, 54.0% and 48.1% at 25% sewage concentration and control units were 36.1%, 30.9% and 28.5% at 25% sewage concentration with respect to the series of inundation time (Figure 17, 18 and 19). This showed that the two mangroves species performed better in ammonium-nitrogen removal as compared to the control (bare sediment).

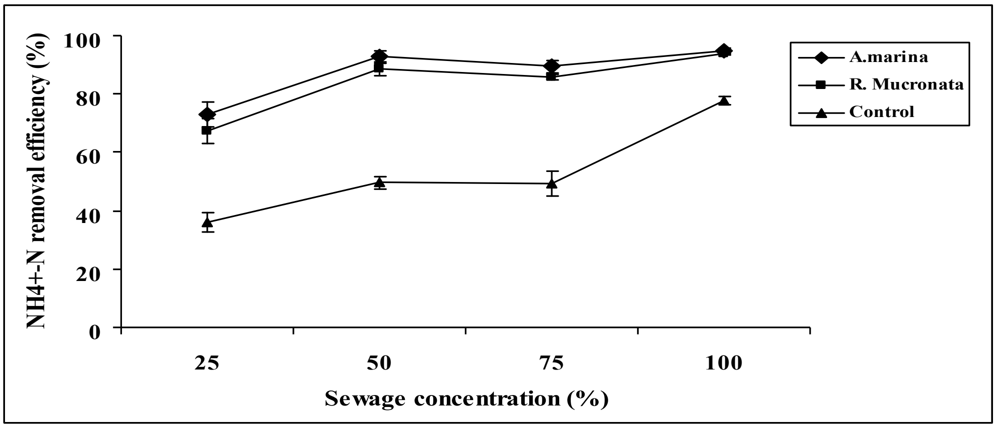

Figure 17: A comparison of Ammonium-nitrogen removal between *A. marina* and *R. mucronata* units inundated for 1 week at Various Sewage Concentrations

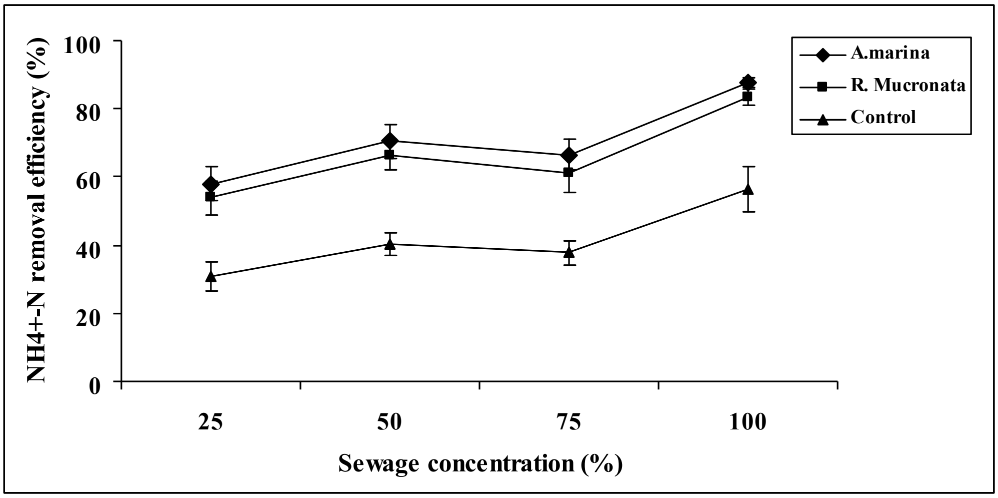

Figure 18: A comparison of Ammonium-nitrogen removal between *A. marina* and *R. mucronata* units inundated for 24 Hours at Various Sewage Concentrations

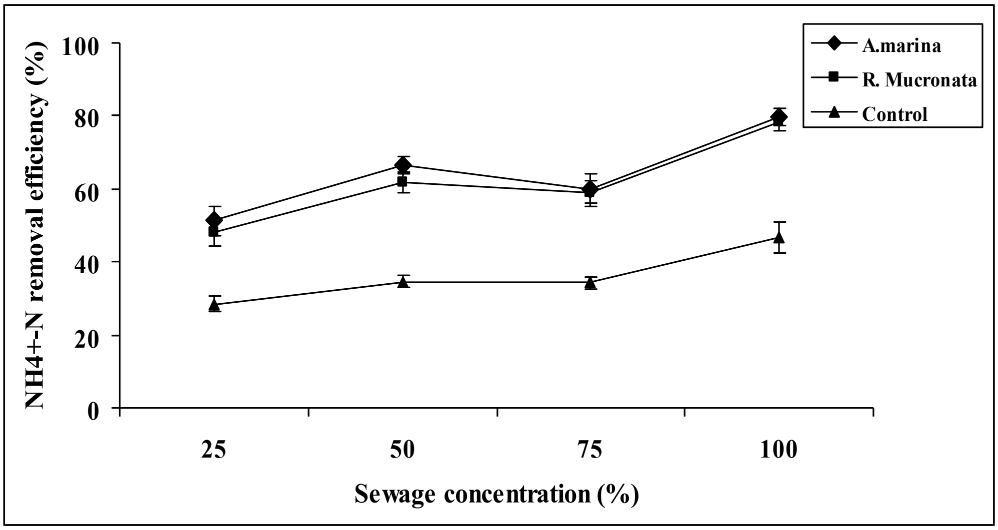

Figure 19: A comparison of Ammonium-nitrogen removal between *A. marina* and *R. mucronata* units inundated for 12 hours at various sewage concentrations

Effect of Sewage Loading on Removal Efficiency of Pollutants

The obtained results of pollutants (PO_4-P, TP and NH_4^+-N) removal efficiency of *A. marina* and *R. mucronata* units showed a significant difference ($p<0.0001$) among different levels of domestic sewage loadings. Removal of these pollutants was generally found to increase as sewage loading concentrations increases i.e. from 25% to 100% sewage concentrations. As shown in the figures 11 to 19, 25% sewage concentration has lower removal of phosphates, total phosphorous and ammonium-nitrogen than other strength of sewage loadings. The lower removal efficiency at 25% sewage concentration might be contributed by the presence of high salinity (figures 5 to 7) caused by dilution of sea water. A media with high salinity concentration affects plant growth which in turn reduces plant uptake of nutrients as it causes low water potential, ion toxicities, nutrients deficiencies or a combination of both factors (Khan *et al.,* 2000).

On the other hand, at 100% sewage loading there was higher removal of phosphates, total phosphorous and ammonium-nitrogen than other strengths of sewage loadings due to effects of low salinity. At this sewage strength there is high concentration of nutrients such as nitrogen and phosphorous which promote plant and microbial growth. Promotion of both plant and microbial growth resulted in the increase in plant uptake of nutrients and thereby cause increase in the removal of pollutants.

However, in some cases as it was observed by Aksorkoae (1993), best growth occurs where plants live in seawater diluted in half concentration with that of fresh water. This might account for higher removal of phosphates, total phosphorous and ammonium-nitrogen at 50% as compared to 25% and 75% sewage concentrations. Similar results were obtained in the study done by Khan and Aziz (2001), on the salinity tolerance in some mangrove species from Pakistan, in which *A. marina, C. tagal* and *R. mucronata* showed optimal growth at 50% seawater fortified with nitrogen.

Effect of Inundation Time on Removal Efficiency of Pollutants

The obtained results showed that there was significant differences ($p<0.0001$) among different levels of inundation time on removal of phosphates, total phosphorous and ammonium-nitrogen in both planted and control units. Table 4 shows the effect of inundation time on removal of phosphates, total phosphorous and ammonium-nitrogen by *A. marina*, *R. mucronata* and control units at various sewage concentrations.

Table 5: Removal of PO_4-P, TP and NH_4^+-N by *A. marina, R. mucronata* and Control units at various sewage concentrations

Inundation time	Parameter (mg/m^2.day)	*Avicennia marina*				*Rhizophora mucronata*				Control			
		C1 25%	C2 50%	C3 75%	C4 100%	C1 25%	C2 50%	C3 75%	C4 100%	C1 25%	C2 50%	C3 75%	C4 100%
1 week	PO_4^-	53	90	109	131	49	84	106	130	34	55	67	110
24 hours		43	69	81	129	37	62	71	123	24	41	41	94
12 hours		31	49	66	91	23	42	49	89	16	34	41	49
1 week	TP	155	233	308	431	142	217	301	429	97	162	202	358
24 hours		109	184	224	357	100	172	211	339	65	119	149	221
12 hours		87	146	213	344	62	112	141	334	56	104	158	212
1 week	NH_4^+-N	80	136	177	214	72	131	170	212	38	72	96	177
24 hours		72	126	135	207	68	118	120	195	36	70	78	121
12 hours		48	96	117	182	45	90	113	182	27	51	66	112

As shown in Table 5, inundation time of one week was found to have higher removal of phosphates, total phosphorous and ammonium-nitrogen than inundation time of both 24 and 12 hours. This implies that removal of phosphates, total phosphorous and ammonium-nitrogen increases as inundation time of sewage loading increases. This is due to the fact that longer inundation time provides adequate time for pollutants degradation to occur (Stephenson *et al.*, 1980) and thus enough time for plants and microbes to take in nutrients that are present in the sewage as well as other removal mechanisms of pollutants in the constructed wetlands.

CONCLUSION

Findings from this study showed that a significant removal of phosphorous, total phosphorous and ammonium- nitrogen occurred in planted buckets inundated for one week at 100% sewage concentration. *Avicennia marina* had relatively higher removal efficiency than *Rhizophora mucronata* but these two mangrove species can be used as phytoremediators of domestic wastewater in constructed wetlands in coastal areas.

Longer inundation time (1 week) with domestic sewage in mangrove constructed wetlands would not be prohibitive although more studies that span between dry and wet season be conducted to get a clearer picture of the long-term performance of the system.

ACKNOWLEDGEMENT

The field research was partly supported by the PUMSEA (Peri-urban Mangrove forests as filters and potential phytoremediators of domestic sewage in East Africa) project to whom the authors are grateful.

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