Nitrogen Removal in Mangroves Constructed Wetland

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Abstract— *The potential use of Mangroves Constructed Wetland (MCW) as a low cost, efficient and suitable method for nitrogen removal from sewage in coastal zone of urban cities was examined in Dar es Salaam, Tanzania. In-situ examinations were done in horizontal surface flow Mangrove Constructed Wetland situated at Kunduchi beach area in Dar es Salaam. A wetland of 40 meters by 7 meters was constructed to receive domestic sewage from septic tank of Belinda Beach Hotel and was operated in an intermittent continuous flow mode. The wetland employed the already existing mangrove plants known as Avicennia Marina. The plants had an average breast height of 4 meters during commencement of experiments. The wetland collected the mixture of sewage and seawater at strength of 60% to 40%, respectively. The treatment efficiency of the wetland in nitrogen removal from sewage was determined. The observed removal rates of nitrogen inform of ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3^--N) were 85% and 76%, respectively. Mangrove Constructed Wetland has a potential in nitrogen removal from sewages and it is suggested to be used for sewage treatment in coastal areas.*

Keywords— Constructed Wetlands, Coastal Area, Mangroves, Sewage, Treatment Performance.

I. INTRODUCTION

Mangroves are woody trees, palm or shrubs that occupy shallow water and grow at the interface between land and sea in tropical and subtropical coastal regions. They are characterized by muddy or fine sediment substrata. These plants, and the associated microbes, animals, and abiotic factors (like nutrients, minerals, water, oxygen, carbon dioxide, and organic substances) constitute the mangrove ecosystem [1]. Naturally, mangrove ecosystems play important role in preventing pollutants from entering the water body by up-taking of pollutants and creating conducive environments for growth of decomposing microorganisms [2, 3]. Many tropical cities that are built around natural harbors or waterways are lined by mangrove swamps. Examples from Africa are: Mombasa, Dar es Salaam and Maputo [4]. However peri-urban mangroves (*A. Marina*, *R. Mucronata* and *S. Alba*) of most coast cities examples are Tudor and Mtwapa creeks in Mombasa, and the Msimbazi River and Kunduchi beach area in Dar es Salaam [5], are recipients of sewage-polluted rivers and are extensively used for sewage dumping. The consequence is a potential risk to human health and ecosystems of estuaries and oceans [1]. This could be attributed to lack of adequate sewage treatment facilities in these cities. For example in Dar es Salaam, the coverage of sewerage system is 7% [6] of service area. Upgrading of the sewage infrastructure therefore, is urgently required in developing countries, where majority of these cannot afford conventional wastewater treatment systems in order to protect receiving environment. The Waste Stabilization Pond and Constructed Wetland (WSP and CW) Research Group at the University of Dar es Salaam in Tanzania has been developing low-cost technologies such as waste stabilization ponds and constructed wetlands [7]. These systems use nature to treat waste, are easy to maintain, are simple to construct and they are very effective technologies in treatment of wastewater [7]. Mangroves constructed wetlands are therefore considered ideal to protect peri-urban mangrove ecosystem. The mechanisms of natural mangrove wetlands to remove nitrogen and other pollutants from sewage are similar to wetland treatment systems using other types of vegetation. Therefore, it is expected that by applying appropriate engineering design and construction, the natural mangrove wetland can be used as an efficient sewage treatment system of the wastes generated from urban and peri-urban areas located along the coast as example in Thailand and China [8]. It is known that mangroves wetlands elsewhere intercept land-derived nitrogen and limit their spreading offshore and hence preventing risk to estuaries' and oceans' ecosystems [9], however their treatment performance on the removal processes of nitrogen, varies widely due to influence of various forcing functions like pH, temperature, Dissolved Oxygen Furthermore. In Tanzania, no efforts have been made to examine the performance of Mangroves Constructed Wetland in the treatment of sewage; as a result no information is available on removal of nitrogen in this kind of treatment system. However, similar studies of nitrogen removal have been conducted in Tanzania the

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differences are; one study was conducted on small scale constructed mangroves cells (microcosms) operated in batch [10] while others conducted the study by using subsurface constructed wetlands planted with terrestrial plants [11].

II. MATERIALS AND METHODS

Mangrove wetland treatment system was constructed at Kunduchi beach area in Dar es Salaam to perform secondary treatment of domestic sewage discharged from septic tank. The climate of the area is typically tropical. The site area inhabits a changeable environment with tides (at low tides the area is just wet and flooded during high tide). The area receives maximum tide range at new and full moon (spring tides) and minimum tide (neap tides) in between full moon and new moon. Also, the site area is dominated by mangrove type - *Avicennia marina* which had an average height of 4 meters. The sewage from septic tank of Belinda Resort Hotel was collected in sewage pond and the seawater from nearby ocean was collected in 10,000 litres tank.

2.1 Experimental Set-up and Operation of Surface Flow Mangrove Constructed Wetland

A wetland cell (unit 01) of *40m x 7m* was designed and constructed (Fig. 1) and its design criteria and features are shown in Table 1.

As presented in Fig. 2, the wetland cell received a mixture sewage and seawater from sewage pond and seawater tank, respectively. The liquid mixture was flowing by gravity at a rate of 5 m^3/day through a 100 mm diameter pipe. To make a mixing ratio of 60% sewage and 40% seawater, the sewage was flowing at a rate of 3 m^3/day while seawater at a rate of 2 m^3/day. The employed mixing ratio was established from pilot experiments that were carried by Pamba [10]. Since the study area is dominated by mangrove of type *Avicennia marina;* this mangrove specie was used as macrophytes for the wetland cell.

In order to imitate the natural phenomenon of alternating flooding with seawater and drying up of mangroves, the wetland cell was operated in an intermitted continuous flow mode of 3 days (inundation time) flooding with sewage and 3 days drying up cycles. The depth of sewage flow was kept 4 centimeters to enable mangrove roots to respire.

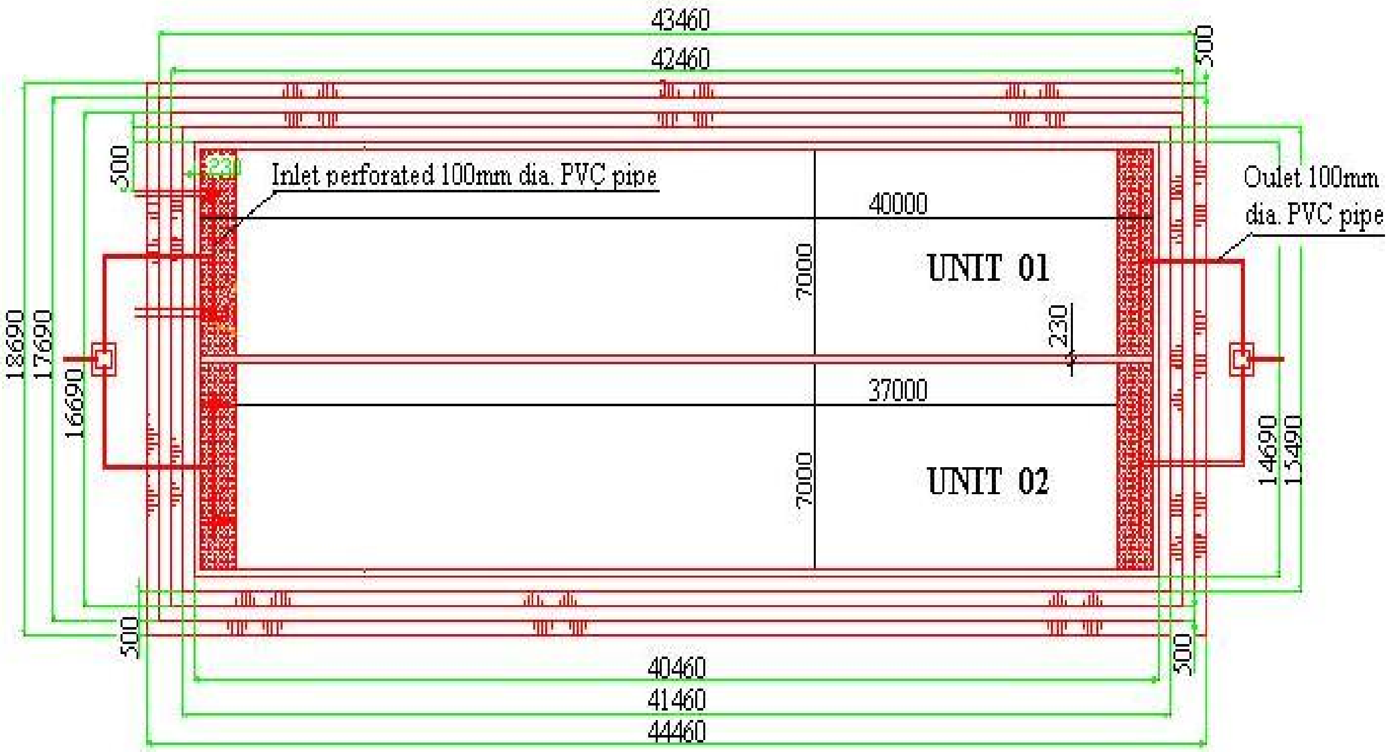

Fig.1: Floor plan for horizontal surface flow Mangroves Constructed Wetland (units are in mm)

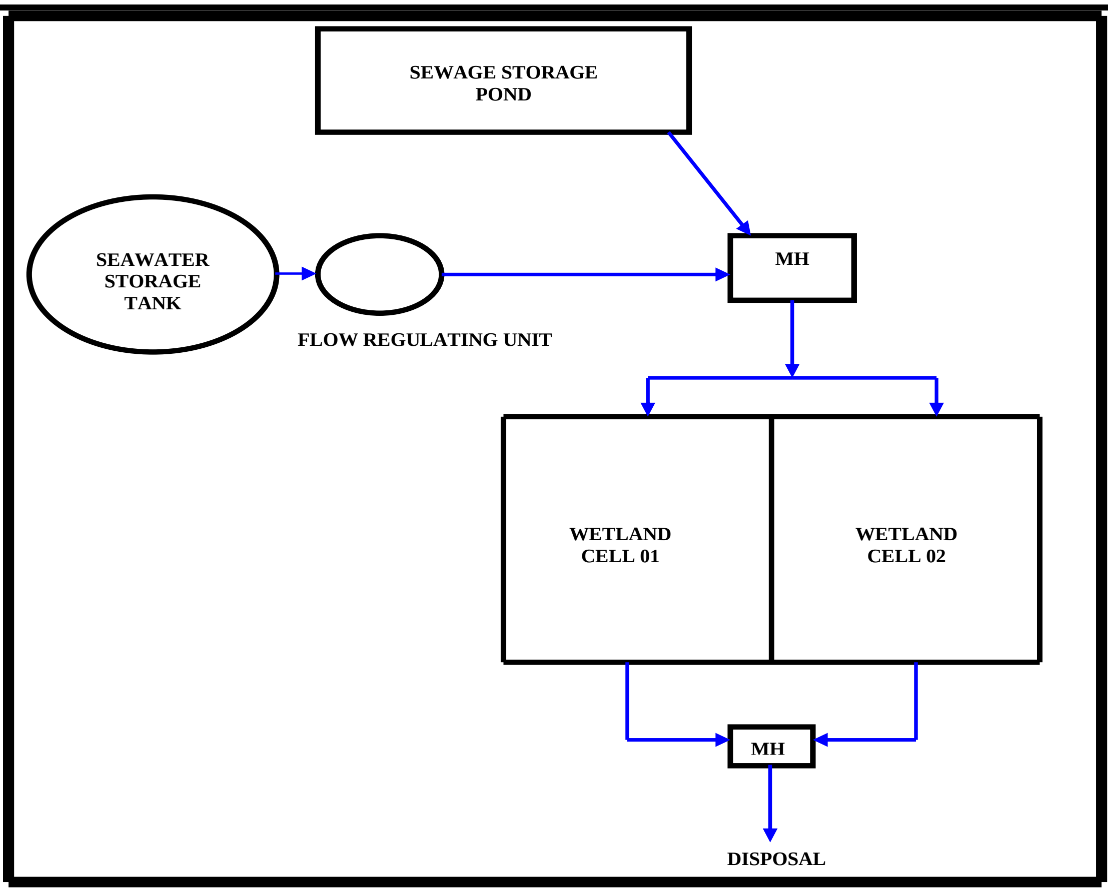

Fig.2: Experimental Set-Up

Table.1: Design Criteria, Dimensions and Characteristics of MCW system

FACTOR	DESIGN CRITERIA FOR SURFACE FLOW WETLANDS	WETLAND CELL DESIGN DIMENSIONS AND CHARACTERISTICS
Length (m)	-	40
Width (m)	-	7
Substrate (soil) depth (m)	Maximum, 1	0.6
Water depth (cm)	Maximum, 10	4
Organic Loading Rate, OLR (kg/ha.d)	Maximum, 80	44.64
Hydraulic Loading Rate, HLR (cm/d)	7-60	4.5
Aspect ratio (L/W)	2-10	
Retention time (d)	5 – 14	7
Slope (%)	Maximum 1	1

2.2 Sampling procedure for physical and chemical parameters

The samples were collected twice per week on the first day when wastewater enters into the wetland cell and on the last day (3rd day) when the wastewater gets out of the wetland cell. The samples were collected at 6:00 am in the morning, 12:00 noon, 6:00 pm in the evening and 11:30 pm in the night. Five (5) sampling locations were established inside the wetland cell. In this manner the cells were divided into four sections and the sampling locations were designated "Inlet, A1, A2, A3 and Outlet". The distances from each sampling location was 10 meters and at each sampling point a composite sample was taken crosswise the cell.

2.3 Analysis of physicochemical parameters

Analysis of physicochemical parameters was according to standard procedures for analysis of water and wastewater [12]. The physical parameters such as Dissolved Oxygen (DO), salinity, water temperature, pH and depth of water flow, were measured in situ, then the samples were covered, stored in a box and transported from the site to the laboratory for analysis of chemical parameters: Ammonia Nitrogen (NH_3-N) and Nitrate Nitrogen (NO_3-N). In order to remove probable particulate matters that might interfere with analysis of nitrogen, samples were filtered before analysis by using a filter paper (Whatmen No. 42). The majority of samples upon reaching the laboratory were immediately analyzed. Samples which were not able to be analyzed on the same day of sampling were preserved by being acidified and stored in the refrigerator.

2.3.1 Analysis of physical parameters

Temperature and pH were measured by the pH probe meter (WTW ino-Lab, pH Level 1 type, German, Accuracy is ± 0.01). DO was measured by DO probe meter (WTW inoLab type, German, Accuracy is ± 0.5% of the value). Salinity measured by WTW Cond probe meter (inoLab, Cond Level 1 type, German, Accuracy is ± 0.5% of the value).

2.3.2 Analysis of chemical parameters

Ammonia Nitrogen was determined according to American Standard Test Method [12] by a method known as Phenate method (the accuracy was ± 0.01 mg/L. Nitrate Nitrogen was determined according to American Standard Test Method [12] by a method known cadmium reduction method (Accuracy is ± 1.1% of the value).

2.4 Determination of the treatment efficiency of Mangrove Constructed Wetland in removal of NH_3-N and NO_3-N

For determination of the efficiency of Mangrove Constructed Wetland in wastewater treatment, the influent and effluent wastewater samples on the first and last day of the specified inundation (retention) time were analyzed for ammonia and nitrate and the removal percentages were determined according to equation (1).

$$\text{.Removal efficiency} = \left(\frac{C1-C2}{C1}\right) X\ 100\% \ldots\ldots\ldots\ldots\ldots (1)$$

Where; C1 is concentration of ammonia or nitrate in the influent and C2 is concentration of ammonia or nitrate in the effluent.

III. RESULTS AND DISCUSSION

3.1 Sewage characteristics

The sewage characteristics during loading to the system are presented in *Table 2.*

Table 2: Sewage Characteristics at the Inlet of a Wetland Cell

Parameters	**Mean ± SD**
pH	7.36±0.31
Salinity (ppt)	11.46±10.03
DO (mg/L)	0.54±0.35
Temperature (º C)	29.3 ±0.87
NH_3-N (mg/L)	4.70±1.87
NO_3-N (mg/L)	0.0126±0.0102

3.2 Dissolved Oxygen, DO

The average DO concentrations as a function of location along the wetland are presented in Fig. 3. The average inlet DO was 0.54±0.35 mg/L and the average outlet DO was 1.22±0.99 mg/L. The average DO within a wetland cell (i.e. along the location A1 – A3), was 1.55 mg/L. The levels of DO within the wetland cell were significantly lower than the ones reported in the newly planted mangrove wetlands (experimental microcosms, DO was 18.75±2.82 mg/l) [10]. This may attributed to the lack of sunlight penetration into the water column and wind effect due to plant cover over the trial wetland which was not the case with microcosms. Oxygen is introduced into water column during photosynthesis process of algae and mangroves. Since average DO in wetland system was 1.55 mg/L during the day, this DO creates aerobic conditions that favor growth of aerobic bacteria. Aerobic bacteria are responsible for nitrification processes.

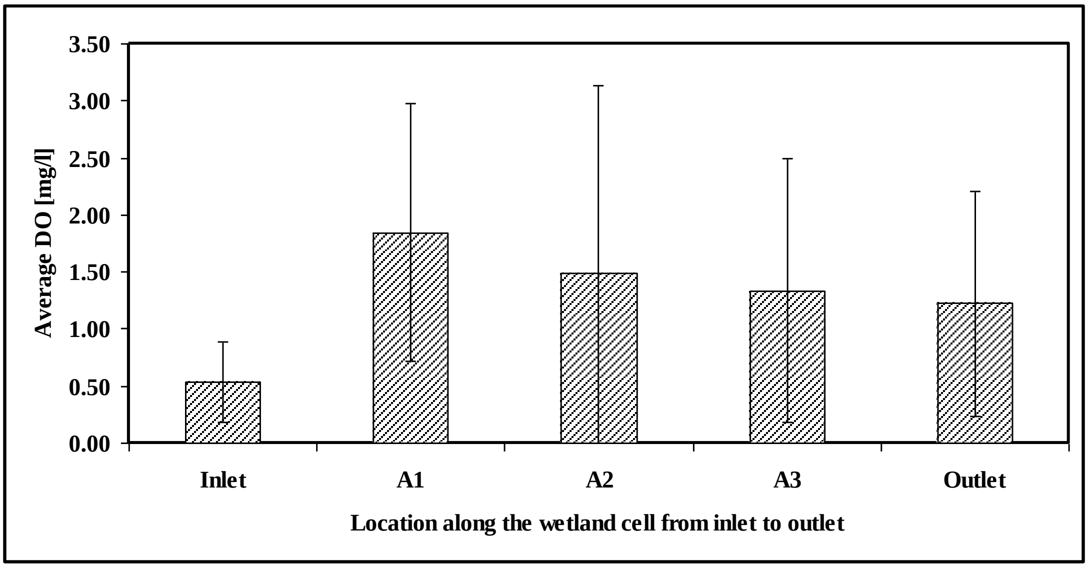

Fig.3: Variation of Average DO Concentration along the Wetland Cell from Inlet to Outlet

3.3 pH

The variation of pH with location along the wetland is shown in Fig. 4. The average pH value in the inlet was 7.36±0.32 and it improved slightly through the wetland to a pH of 7.90±0.23 in the outlet. The average pH within the wetland cell (i.e. along the location A1 – A3), was 7.75. Comparing the pH values obtained in this wetland cell to the values obtained in the experimental microcosms with new-planted mangroves *Avicennia marina* [10], it is noticed that the later was slightly higher (pH was 8.26 ±0.37). Difference of pH between these two systems could be due to decomposition of detritus plant tissues on forest floor and the penetration of light through plant canopy. In new-planted system where plants were small and not fully covered the area, the light could penetrate to the bottom and make the water treatment to be more photosynthetic driven system which is accompanied with pH rise [8, 13]. Usually, the microorganisms work better at certain ranges of pH values. Most bacteria operate well at the pH range of 7.0 to 9.5 [14]. Since average pH in the wetland system was 7.75 during the day, this pH favors most of the decomposing bacteria to decompose nitrogen.

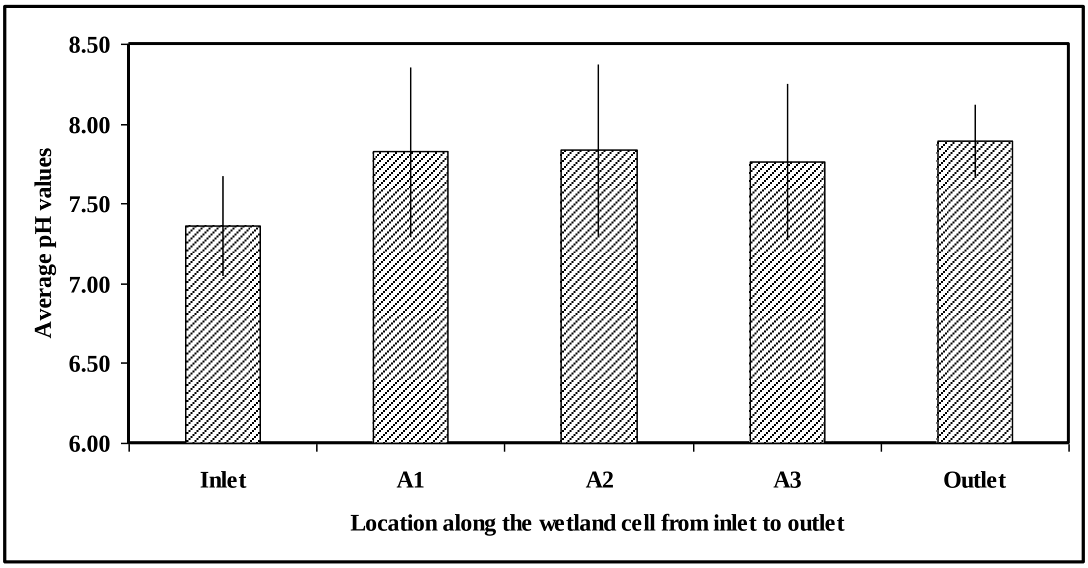

Fig.4: Variation of pH Values along the Wetland Cell from Inlet to Outlet

3.4 Salinity

The average salinity concentrations as a function of location along the wetland are shown in Fig. 5. There was a gradual increase of salinity from 7.21 ± 5.24 ppt in the inlet to 13.75±3.10 ppt in the outlet. The average salinity within the wetland cell (i.e. along the location A1 – A3), was 10 ppt. The low salinity in the inlet is explained by dilution of the sewage by seawater. As the sewage was

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travelling through the wetland salinity increased most likely due to evapo-transpiration from the fully grown *Avicennia* mangrove plants.

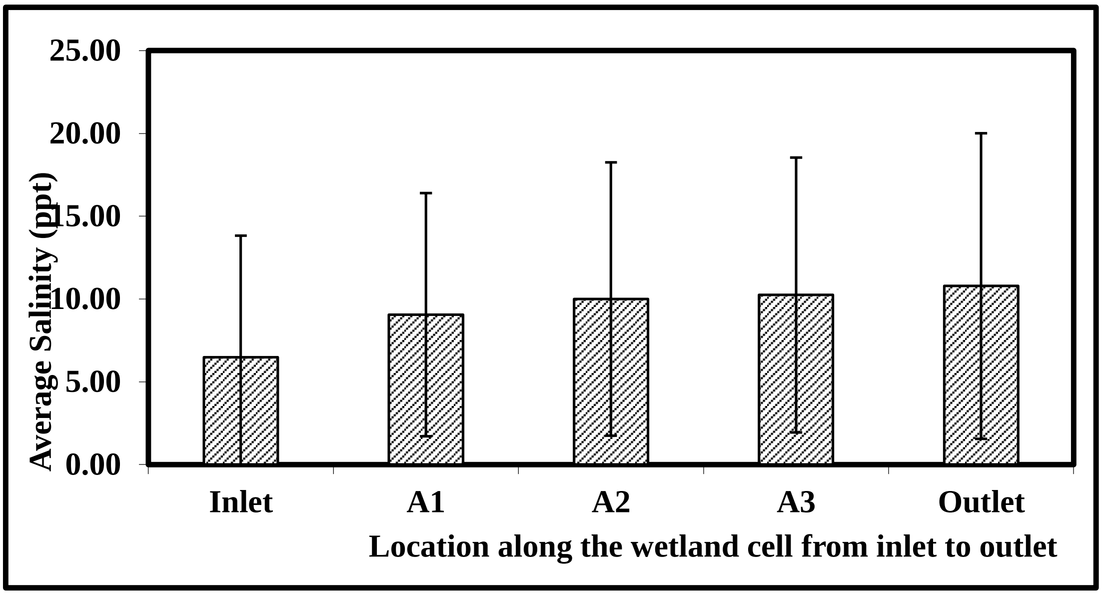

Fig.5: Variation of Average Salinity along the Wetland Cell from Inlet to Outlet

3.5 Temperature

Variation of temperature is as presented in Fig. 6. During the day, average inflow temperature was 30.1 ± 0.22 and average temperature in the system was 29.3 ± 0.27. During the night, average inflow temperature was 29 ± 0.45 and average temperature in the system was 28.9 ± 0.46. Generally temperature inside the wetland cell was slightly lower during the day and night compared to influent water temperature because of the shading effect of plants. The growth rate constants of decomposing bacteria are influenced by temperature changes within the wetland system. The optimum temperature for the growth of nitrifying bacteria ranges from 28 to 36^o C [11]. Since average temperature in wetland system was 29.3 ^{o} C during the day, this temperature favors the decomposing bacteria to decompose nitrogen.

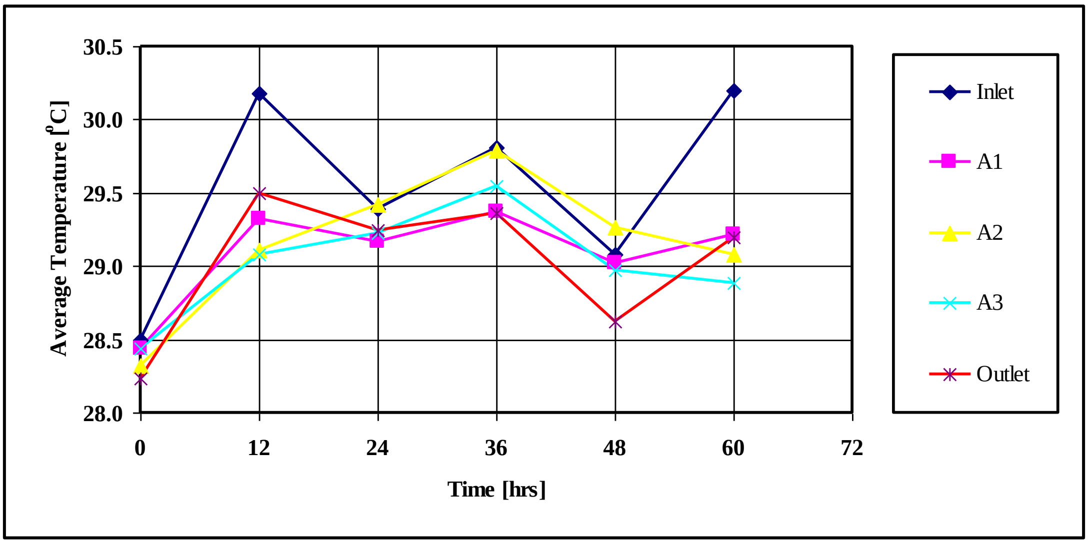

Fig.6: Variation of Average Temperature with Inundation Time

3.6 Ammonia Nitrogen (NH_3-N)

Fig. 7 shows the variation of average NH_3-N concentration with time at different sections in the wetland and Fig. 8 shows the variation of NH_3-N along the wetland cell. It is clear from these figures that the concentration of NH_3-N in the water column typically varied with time and distance from the inlet to the outlet. This observation was made from the five sampling points namely Inlet, A1, A2, A3 and Outlet. The distribution of NH_3-N along the mangrove wetland was less uniform within the wetland region indicating that there was an inefficient surface circulation pattern.

High NH_3-N concentration were determined at the inlet and tended to be varying with time due to non-uniform quality of the feed. At the inlet the average concentration of NH_3-N was 4.7 ± 1.87mg/l. The average outlet concentration of NH_3-N after 60 hours was 0.7 ± 0.9 mg/l and the average percentage removal was 85.11.

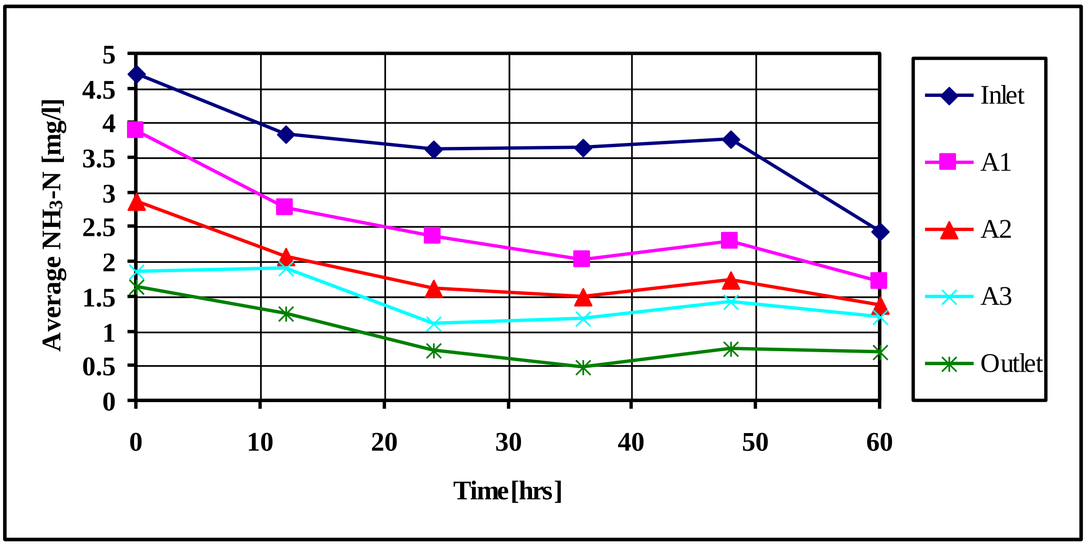

Fig.7: Variation of Average NH_3-N Concentrations with Inundation Times

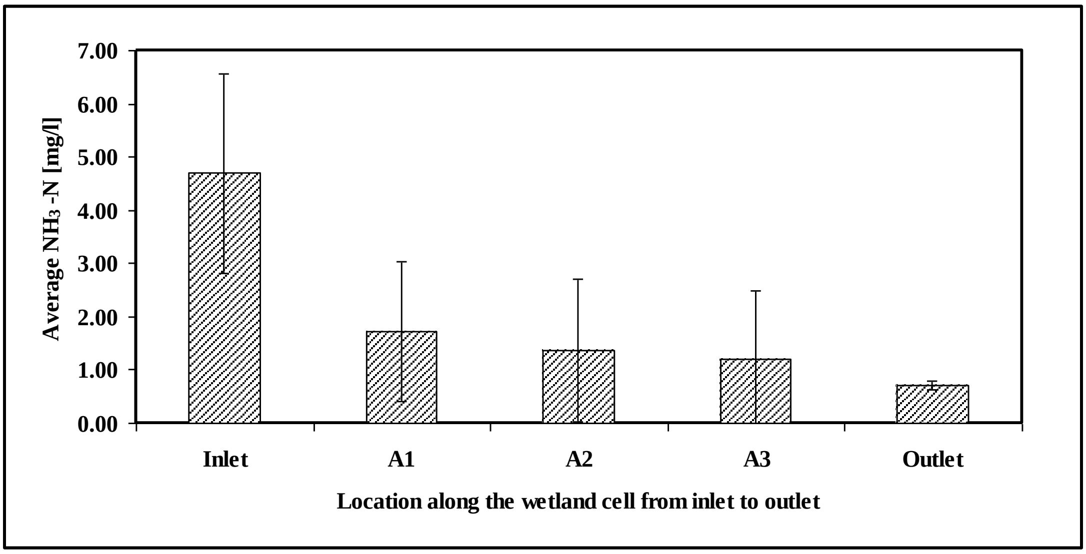

Fig.8: Variation of Average NH_3-N Concentrations along the Wetland Cell from Inlet to Outlet

Ammonia showed very good distribution from inlet to outlet (Fig. 8). The average effluent NH_3-N concentration from the system was 0.7 mg/l which is within the allowable discharge limit used for design (1.5mg/l). The calculated NH_3-N removal rate of the system ranged from 0.31 to 0.57 kg/ha.d with an average removal rate of 0.49 kg/ha.d. The removal of NH_3-N might be achieved by mangroves and algal uptake, volatilization, nitrification and sedimentation [11]. Based on the results of NH_3-N distribution it is evident that, despite the non-steady state operation of the wetland, the continuous removal of NH_3-N over the cell within three days indicated satisfactory performance of the system.

By increasing the water retention time up to about 7-14 days, it is expected that the system will reach equilibrium and the ammonia removal rates would be even better [9].

3.7 Nitrate Nitrogen (NO_3-N)

The average concentration of NO_3-N at the inlet was 0.126 ± 0.1 mg/l while at the outlet after 60 hours was 0.055 ± 0.007 mg/l (Fig. 9). The average percentage removal for the NO_3-N was 76.2 and the removal rate was 0.26 kg/ha.d. By observing variations of nitrate with time

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(Fig. 9), NO_3-N showed non-uniform behavior within the wetland, since there was a net production of NO_3-N in the system (Fig. 9). However, good removals were observed along the wetland cell (Fig. 10). Non-uniform behavior of NO_3-N in the wetland cell was also observed by Mayo and Bigambo [11]. This could also be caused by co-existence of aerobic and anaerobic areas in the bed that encourages losses of nitrogen through nitrification and denitrification process [15].

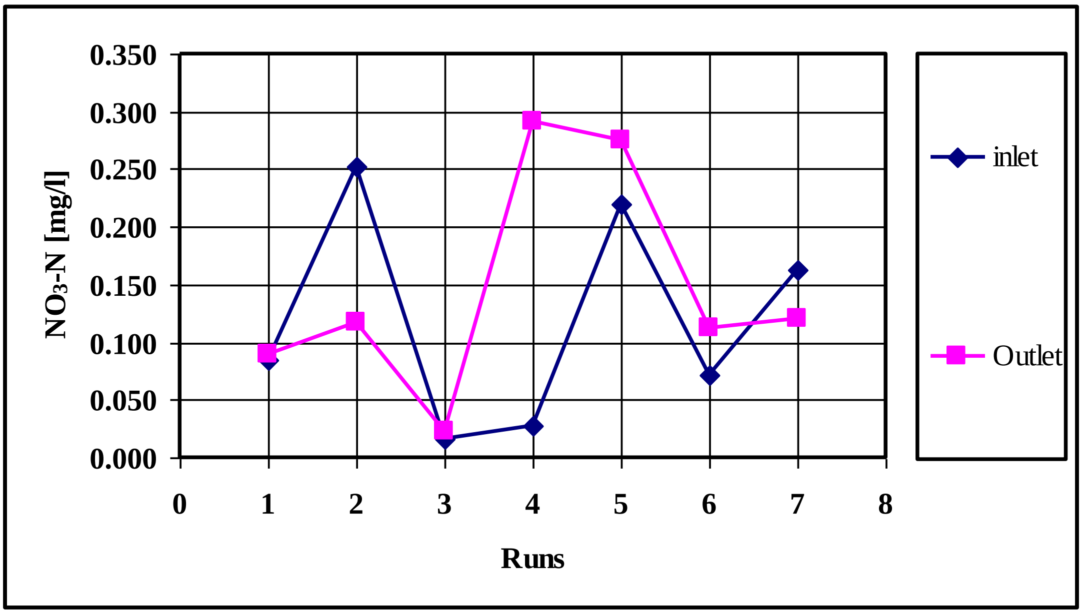

Fig.9: Variation of NO_3-N concentration with inundation time

The removal of NO_3-N in system is mainly through denitrification, plant and algal uptake. According to Vymazal *et al.*, [16], the optimum pH for *Nitrosomonas* (i.e. bacteria that oxidize NH_3-N to NO_2-N) and *Nitrobacter* (i.e. bacteria that oxidize NO_2-N to NO_3-N) is 8.3, and that the nitrification rate falls almost to zero at a pH of 9.6. Experiments by Mayo and Bigambo [11] showed that the optimum pH range for *Nitrosomonas* was from 7.5 to 8.5 and that for *Nitrobacter* was from 8.3 to 9.3. Vymazal *et al.*, [16] quote the optimum pH for *Nitrosomonas* as 8.3 and affirm that the nitrification rate falls to zero at a pH of 9.6. About 90% of the maximum nitrification occurs between pH 7.8 and 8.9. The maximum average pH obtained in this research was 7.9, therefore according to others researcher's results indicate that the pH of 7.9 favored more *Nitrosomonas* oxidation than *Nitrobacter* oxidation and hence it means there was net productivity of NO_2-N in the system by which it shortly oxidize to NO_3-N [17].

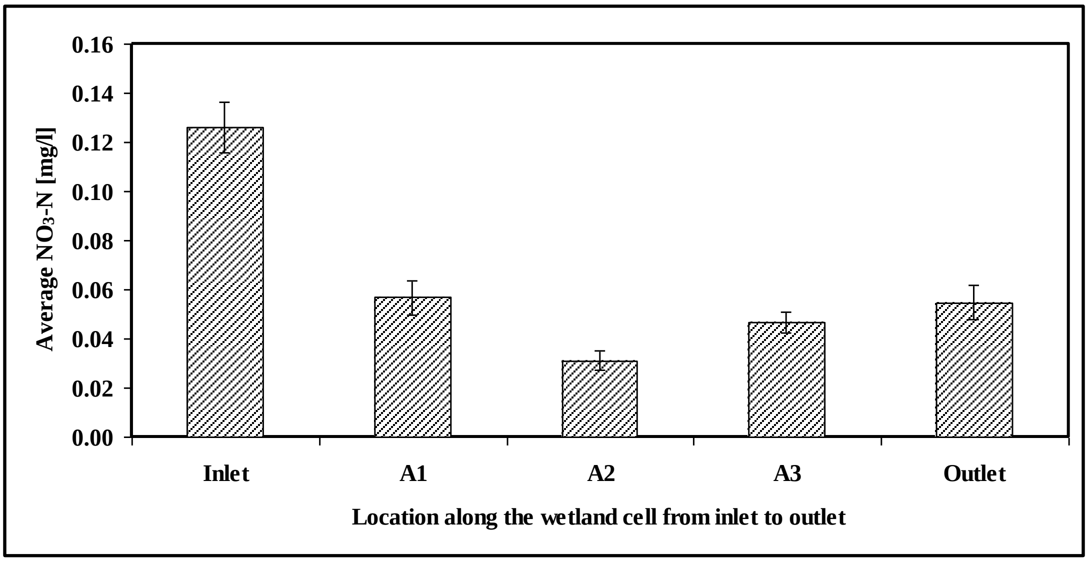

Fig.10: Variation of Average NO_3-N Concentration along the Wetland Cell from Inlet to Outlet

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IV. CONCLUSION AND RECOMMENDATION

Based on the results presented, reduction in concentration of nitrogen was observed. The removal rates of NH_3-N, and NO_3-N were 85%, 76%, respectively. The removal processes were attributed by the forcing functions pH, temperature and DO with averages of 7.75, 29°C and 1.55 mg/L, respectively.

For optimization of system treatment performance with respect to nitrogen and other pollutants removal, it is recommended that, inundation time (retention time) should be long enough (> 5 – 15 days) to allow the system to operate more in a steady state conditions for treatment of sewage to acceptable levels for safe use or discharge. For mangrove root-nodes to respire, water depth must be as low as possible (< 10 cm). Since raw sewage may cause anaerobic conditions in which may produce Hydrogen Sulphide gas (H_2S) which is harmful to mangroves, only primary treated sewage should be used. The primary treatment can be achieved in oxidation ponds, septic tanks, UASB reactors e.t.c. For maintaining of saline conditions, the wetland system should be located in a point where it can receive tidal seawater both neap and spring tide. It is recommended that further research on nitrogen removal in Horizontal Surface Flow Mangrove Constructed Wetland should be conducted on long term basis in order to establish a best database, which will be useful for design of Mangroves Constructed Wetland in coastal zones in tropical and subtropical countries.

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