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Wastewater Management Using an Aquatic and Semi-aquatic Plant species, Cattail (*Typha domingensis*) and Duckweed (*Spirodela polyrhiza* L.)

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Authors' contributions

This work was carried out in collaboration between all authors. Author CAB designed the study, conducted experiments and wrote the first draft of the manuscript. Authors AN and AAA coordinated, analyzed the study performed and discussed the conclusion. All authors read and approved the final manuscript.

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ABSTRACT

Constructed wetlands are excellent chemical-free system, for reducing physico-chemical parameters and faecal coliform densities. Present research work was carried from 2013 to 2014 with the objective of wastewater management using two plant species cattail (*Typha domingensis*) and duckweed (*Spirodela polyrhiza* L.), singly and in combination. The results indicated that parameters such as NH_3^+, DO, pH and turbidity, decreased in effluent from wetland containing cattails, duckweeds and both in combination. Other parameters such as EC, K, P, Cl and Na increased in effluent from one or more wetland trials. Faecal coliform reduction close to 47% was also noted. Absorption and uptake, by plants and microorganisms, appears to be the primary mechanism for nutrient removal, while parameters such as P, SO_4^{2-} and Fe are removed through

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formation of bonds with particles in the soil. The study revealed wetlands containing both floating and emergent macrophytes play significant role in improving wastewater quality.

Keywords: Constructed wetlands; cattails; domestic wastewater; duckweed; effluent; influent; pollution.

1. INTRODUCTION

Domestic or municipal wastewater includes water from household activities such as cleaning and cooking as well as human excreta and contains residuals of urine which may include effluents contributing large amounts of rotting materials and organic and inorganic compounds in addition to pathogenic microorganisms and helminthes [1]. Constructed wetlands are chemical-free filtration apparatus designed to remove physical and chemical impurities improving wastewater to satisfactory standards for reuse [2]. Duckweed plants removes between 50-80% of nitrogen and 50% phosphates from wastewater, while cattails enhance sedimentation and flocculation in constructed wetlands [3]. Report on wastewater quality of the Demerara River by Cimab [4] highlighted high levels of nitrates, ammonia and temperature as well as low pH of 4.5. Guyana's vulnerability to flooding and unhygienic wastewater disposal practices has contributed largely to disease outbreaks. Leptospirosis outbreak in 2005 was spread by flood waters, containing pathogenic microorganisms. Pathogenic microorganisms were recorded in urine and faeces from infected animals [5]. Recently in 2009 and 2010, *Escherichia coli* outbreak in North-West of Guyana was caused by faecal coliform contamination of water sources. The objectives of this study are: 1) to test constructed wetlands using Duckweed and cattail solely and combined) to compare physicochemical parameters of wastewater before and after filtration and 3) to determine the abundance of the faecal coliform before and after filtration and their potential human health risks.

2. MATERIALS AND METHODS

Present research work was carried during the year 2013-14 with the objective of waste water management using two plant species (aquatic and semi-aquatic) cattail (*Typha domingensis*) and duckweed (*Spirodela polyrhiza* L.) singly and in combination. The experiments were conducted for period of three months.

The constructed wetland is an outdoor setup, in full access to the environment such as rain and sun. Three (3) chambers (60 cm × 60 cm × 30 cm) were constructed with plastic insulation (in triplicate-RBD). The plants used for this experiment are Southern cattail (*Typha domingensis*), an emergent macrophytes and a free-floating macrophyte, duckweed (*Spirodela polyrrhiza* L.). All cattail and duckweed plants were of the same size and maturity. Both plants have proven to improve physical and physico-chemical parameters of wastewater. Each chamber was constructed (bottom to top) as described in Table 1.

A sedimentation tank was filled with wastewater collected from trenches within the Golden Grove Housing. After 24 hours wastewater from the tank (influent) flooded each chamber with approximately 10L per hour. Within 48 hours after flooding, wastewater samples from each chamber were collected via individual effluent pipes. Samples for physico-chemical analysis were collected in sterile 300 ml containers while samples for faecal coliform tests were collected in 100 ml sterile containers. These containers were sealed and stored in an ice box for transport. Samples were collected at two weeks intervals over two months period.

All physico-chemical tests were done at Central Laboratory, Research Center, Agriculture Department, LBI Compound, GuySuCo. Physico-chemical parameters analyzed included; EC, pH, DO, Turbidity, Nitrates (NO_3^-), Ammonia (NH_3), Phosphorous (P), Sulphates (SO_4^{2-}), Potassium (K), iron (Fe), Chlorides (Cl) and Sodium (Na^+).

Faecal coliform counts were conducted at University of Guyana Laboratory. Eosin-methylene Blue (EMB) agar plates were prepared one day in advance and labeled. Serial dilutions of 0.1 ml and 0.01 ml concentrations of all the effluent samples collected were made. Using streak plate technique, wastewater was distributed over the surface of agar plates. These plates were sealed and incubated for 17 hours at 30ºC.

Table 1. Experimental treatments

Chambers	Depth			Plants
	Gravel	Sand	Soil (clay)	
1 (CH1)	15 cm	15 cm	15 cm	Duckweed + Cattail
2 (CH2)	15 cm	15 cm	15 cm	Cattail
3 (CH3)	15 cm	15 cm	15 cm	Duckweed

Data collected were analyzed on Microsoft Excel 2007. ANOVA one-way (F-Test) and ANOVA: Single factor were used to calculate the significant of physico-chemical parameter and faecal coliform respectively, in the 95% interval.

3. RESULTS AND DISCUSSION

EC is a measure of water conductivity, the average influent EC recorded was 1.64±0.03 dS/m (Table 2). EC levels in effluent samples from CH2 and CH3 showed increases in EC level by 7.9% and 12.2% while CH1 recorded a significance ($p \leq 0.05$) decrease by 4.8% (Tables 3 & 4). These changes are influenced by the concentrations of Na^+ ions present in the water (Belmont, 2004). Effluent samples from CH2 and CH3 noted increases in EC due to subsequent increases in Na^+ levels. Similarly, CH 1 Na^+ concentration decreases causing a reduction in EC levels. These EC levels observed are within permissible limits [6].

DO concentrations in wastewater are dependent of the rate of O_2 transfer and rate of O_2 uptake. From an initial DO influent concentration, 2.63±1.62 mg/L, CH3 recorded the highest reduction of 87%, to 0.34±0.14 mg/L, while CH2 recorded the lowest reduction of 5.1% to 1.29±0.52 mg/L (Tables 2 & 3). These oxygen changes are a result of microorganisms' activities and decay of dead plants on soil surface [7]. DO effluent levels are well below established levels for irrigation purposes (5 mg/L) [8]. pH level showed marginal decreased from 7.18±0.14 initial influent concentrations (Table 2). These changes were influenced by atmospheric conditions and plants and microorganisms activities. There was significant decrease in all three experiments, however, the highest reduction rate (4.5%) and the lowest reduction rate (1.2%) were observed in CH2 and CH3 respectively (Table 2). pH levels in effluent are acceptable for irrigation [9, 10]. Average influent turbidity, 344±146 mg/L, was reduced by 68.3%, 57.5% and 43.9% in effluent from CH2, CH3 and CH1 respectively (Table 3).

Turbidity is a measure of water clarity and is dependent on Total Suspended Solids (TSS). Cattail plants are famous for sedimentation and flocculation in constructed wetlands, hence CH2 high reduction rate. Even though, all three wetlands recorded a decrease in turbidity [11].

Duckweeds have a great affinity for NO_3^- absorption, compared to NH_3, while significant amounts of K and P are also absorbed. Cattails are on the higher end of net nitrogen and phosphorous uptake during growing season, among emergent plants. This accounts for NH_3 reduction of 86.2% in CH1 and 27.8% in CH3 effluent while CH2 had no net change (Table 3). Phosphates increased in CH1 effluent by 0.04 mg/L (21%). This was a result of phosphates release by hydrolysis under anoxic conditions and from decay of dead duckweed plants [12,13,14]. However, CH2 and CH3 P effluent levels increased, these changes were a result of the bonding of negative phosphate particles with positive clay particles due to the presence of Fe and Al ions. It was evident P decreases were significant ($p=0.009$ and $p=0.020$) in CH2 and CH3 respectively (Table 4). SO_4^{2-} concentrations from CH1 and CH3 effluent decreased to 183mg/L and 202.84mg/L respectively (Table 2), due to the absorption of insoluble sulphide salts which are formed in the absence of NO_3^- [15].

Fe ions are filtered from wastewater by sedimentation and flocculation of particles containing Fe. Fe concentration in effluent from all three chambers recorded increases by the least by 3.3% (observed on CH2) (Table 3). These particles are formed from the association of the ions with soil particles. K, Na^+, and Cl^- reduction is due to simple absorption of these soluble ions from wastewater. Conversely, increases in effluents concentration is an outcome of degraded matter of dead plant tissue. These ions are either actively pumped into the water or are released from cells of dead plants. These concentrations are acceptable for irrigation purposes [6]. Results suggest CH1 effluent containing both plants, showed decreases in Na^+ (by 6.7% from initial 404.67±48.35 mg/L) and Cl^- by (6.7% from

139.71±42.74 mg/L) but recorded and increase in K (by 48.7%) ions (Table 3).

Cattail plants are important agents of sedimentation and flocculation. Their ability to trap particles reduced the formation of caters and fissures cause by water erosion, in constructed wetlands. Optimum performance of constructed wetlands depends on the microorganisms. Microorganisms are critical in transformation of inorganic to organic substances, altering reduction/oxidation reacting, influencing the wetland's processing capacity and most importantly recycling of nutrients. Microbial populations, particularly faecal coliforms, can expand rapidly in environment with substantial nutrient sources (Hilton, 1993). From an initial count of 8860 CFU/ml, CH3 recorded the highest decrease in faecal coliform population by 4030 CFU/ml (45.5%).

While CH2 recorded the lowest decrease of 2725 CFU/ml (30.8%) and CH1 in a close second with 3950 CFU/ml (44.6%) (Table 5). ANOVA shows that there is no significant difference among the three treatments in terms of decreases in coliform count (Table 6*).* The faecal coliform populations observed, were not suitable for irrigation of agricultural land especially in cases where human contact is unavoidable. WHO established standards for irrigation water is ≤1000 CFU/100ml [16]. Faecal coliforms are microorganisms excreted in faecal matter of vertebrate, mainly mammals. When these organisms enter the body they are responsible for illness, that maybe fatal. Guyana has experience two causes of disease outbreaks cause by ingestion of faecal coliforms. In, 2009 and 2010, North-West District suffered from *E. coli* outbreak, reporting 66,000 and 11,000 cases respectively. The 2005 flood, along the Low Coast Plains, lead to the outbreak of Leptospirosis. The pathogenic species responsible is present in the faeces and urine of infected animals [17,5].

Table 2. Physico-chemical properties of influent and effluent from FWS wetland over 9 weeks (Mean±SD)

Parameters	Influent	Effluent		
		CH 1	CH 2	CH3
EC(dS/m)	1.64±0.03	1.56±0.24	1.77±0.05	1.84±0.21
pH	7.18±0.14	7.07±0.15	6.89±0.16	7.09±0.05
DO (mg/l)	2.63±1.62	0.71±0.13	1.29±0.52	0.34±0.14
Turbidity (NTU)	344±146.06	193±84.72	109±44.11	146±41.58
Ammonia (NH_3) (mg/L)	6±0	0.83±0.29	6±3.31	4.33±2.89
Phosphorous (P) (mg/L)	0.21±0.08	0.25±0.22	0.08±0.02	0.16±0.03
Sulphates (SO_4^{2-}) (mg/L)	239.55±1.87.68	183.41±148.20	302.3±149.19	202.84±170.03
Potassium (K) (mg/L)	13±5.57	19.33±6.43	12±1	9.67±4.04
Iron (Fe) (mg/L)	0.45±0.3	1.05±0.31	0.46±0.41	1.28±0.35
Chlorides (Cl) (mg/L)	139.71±42.74	132.35±24.90	141.8±33.51	141.8±25.56
Sodium (Na) (mg/L)	404.67±48.35	377.33±58.56	496±104.73	475.33±90.16

Table 3. Percentage decrease in physico-chemical properties

Parameters	Quantity decreased			% decreased		
	CH1	CH2	CH3	CH1	CH2	CH3
EC	0.08	-0.13	-0.20	4.8	-7.9	-12.2
pH	0.11	0.29	0.09	1.5	4.0	1.2
DO (mg/L)	1.92	1.34	2.29	73	5.1	87
Turbidity (NTU)	151	235	198	43.9	68.3	57.5
Ammonia (NH_3) (mg/L)	5.17	0	1.67	86.2	0	27.8
Phosphorous (P) (mg/L)	-0.04	0.13	0.05	-19.0	61.9	23.8
Sulphates (SO_4^{2-}) (mg/L)	56.14	-62.72	36.71	23.4	26.2	15.3
Potassium (K) (mg/L)	-6.33	1	3.33	-48.7	7.7	25.6
Iron (Fe) (mg/L)	-0.60	-0.01	-0.83	-133.3	-2.2	-184.4
Chlorides (Cl) (mg/L)	7.36	-2.09	-2.09	5.3	-1.5	-1.5
Sodium (Na) (mg/L)	27.33	-91.33	-70.66	6.7	-22.6	-17.5

-indicates values that increased; + indicates values that decreased

Table 4. ANOVA (Physico-chemical properties of different treatments)

Parameters	p-values		
	CH1	CH2	CH3
EC	S*	S	S
pH	S*	S*	S*
DO	NS*	NS*	NS*
Turbidity	S*	S*	S*
Ammonia (NH^{3+})	S*	S*	S*
Phosphorous (P)	NS	S*	S*
Sulphates ($SO_4^{-2)}$	NS*	NS	NS*
Potassium (K)	NS	S*	S*
Iron (Fe)	NS	NS	NS
Chlorides (Cl)	S*	S	S
Sodium (Na)	S*	S	S

** represents values that decreased; S-Significant; NS-Not significant*

Table 5. Totalfaecal coliform (CFU)

	Influent (CFU/ml)	Effluent		
		CH1 (CFU/ml)	CH2 (CFU/ml)	CH3 (CFU/ml)
Trial 2	8020	2850	6770	5970
Trial 3	9700	6970	5500	3690
AVERAGE	8860.00	4910.00	6135.00	4830.00

Table 6. ANOVA (Faecal coliform)

Source of variation	SS	df	MS	F	P-value	F crit	
Between Groups	21400.3	2	10700.2	0.27	0.780	9.55	Not
Within Groups	118928.5	3	39642.8				Significant
Total	140328.8	5					

4. CONCLUSION

The experiments conducted indicated significant impact on the physico-chemical properties using the three different treatments. The Cattail plants grow efficiently in water rich in NH_3, P, DO, SO_4^{2-} and Na. constructed wetlands with emergent and free floating macrophytes showed relatively better performance in treating wastewater. Constructed wetlands with duckweeds seem to be relatively more efficient in removing faecal coliforms than those planted with cattail. The overall water quality from each constructed wetland improved in terms of nutrients and coliform counts; however, further studies are needed to ensure the enhanced quality of wastewaters through the plant-based treatment methods.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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