

Original Research Article

WASTEWATER MANAGEMENT USING AN AQUATIC AND SEMI-AQUATIC PLANT SPECIES, CATTAILS (*TYPHA DOMINGENSIS*) AND DUCKWEED (*LEMNA* (*POLYVIA*)

ABSTRACT: Domestic wastewater is waste water from household activities, such as cleaning and cooking, usually containing traces of faecal matter and urine. Constructed wetlands are excellent chemical free mechanism, for reducing physico-chemical and faecal coliform concentrations. 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 atleast one wetland. Faecal coliform population reduction was as high as 46.6%. Absorption, by plants and microorganisms, is the primary mechanism for nutrient removal. While, parameters such as P, SO_4^{2-} and Fe are removed through formation of bonds with particles in the soil. Conclusively, wetlands containing both floating and emergent macrophytes have significant impact on the wastewater quality.

Keywords: Constructed wetlands, Cattails, Domestic wastewater, Duckweed, Effluent, Influent, Pollution

INTRODUCTION

Domestic or municipal wastewater is a type of wastewater, which includes water from household activities such as cleaning and cooking as well as human wastewater which may contain urine and bits of faecal matter, contributing large amounts of rotting materials and organic and inorganic compounds in addition to pathogenic microorganisms and helminthes (Bakir, 2001). Constructed wetlands are chemical-free filtration apparatus designed to remove physical and chemical impurities improving wastewater to satisfactory standards for reuse (Vazquez-Montielet *al.*, 1996). Duckweed plants removes between 50-80% of nitrogen and 50% phosphates from wastewater, while cattails are popular for sedimentation and flocculation in constructed wetlands (Oron, 1984). An environmental report, done in 2010, on wastewater quality of the Demerara River by Cimab, 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 through contact with flood waters, containing pathogenic microorganisms. These microorganisms are found in urine and faeces from infected animals (Parson *et al.*, 2012). Recently in 2009 and 2010, *Escherichia coli* outbreak in North-West was caused by faecal coliform contamination of water sources. The objectives of this study are to first construct a

constructed wetlands using Duckweed and cattail singly and in combination. Second, is to compare physico-chemical parameters of wastewater before and after filtration and third, to determine the abundance of the faecal coliform before and after filtration and their related health risks.

MATERIALS AND METHOD

The constructed wetland is an outdoor setup, in full access to the environmental conditions such as rain and sun. Three (3) chambers (60cm × 60cm × 30cm) were compartmentalized, plastic insulated to prevent leakages. The plants used for this experiment are Southern cattail (*Typhadomingensis*), an emergent macrophytes and a free-floating macrophyte, duckweed (*Spirodelapolyrrhiza*). Duckweed plants were collected on the same day chambers were flooded, while cattails were planted 1 week before. 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 built (bottom to top) as follows:

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

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 300ml containers while samples for faecal coliform tests were collected in 100ml sterile containers. These containers were sealed and stored in an ice box for transport. Samples were collected at two (2) weeks intervals over two (2) 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 tests were conducted at University of Guyana Laboratory. Eosin-methylene Blue (EMB) agar plates were prepared one (1) day in advance and labeled. Serial dilutions of 0.1ml and 0.01ml concentrations of all twelve (12) effluent samples collected were made. Using streak plate technique, wastewater was introduced to the surface of agar plates. These plates were sealed and incubated for 17 hours at 30°C.

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.

RESULTS AND DISCUSSION

Physico-chemical Parameters

EC is a measure of water conductivity, the average influent EC recorded was 1.64 ± 0.03 (Table 1). EC levels in effluent samples from CH2 and CH3 showed increases in EC level by 7% and 12% while CH1 recorded a significance ($p \leq 0.05$) decrease by 6% (Table 2&3). These changes are influenced by the concentrations of Na^+ ions present in the water (Sooknah, 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 (Usharani *et al.*, 2010).

PARAMETERS	Influent	Effluent		
		CH 1	CH 2	CH3
EC	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 ± 2.98	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
Nitrates (NO_3) (mg/L)	Nd	Nd	Nd	Nd
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 ± 187.68	183.41 ± 148.20	302.3 ± 149.19	202.84 ± 170.03
Potassium (P) (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 1: showing (mean $\pm$ S.D.) of physico-chemical parameters for influent and effluent from FWS wetland over 9 weeks

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 51% to 1.29 ± 0.52 mg/L (Table 1&2). These oxygen changes are a result of microorganisms' activities (for respiratory functions), endogenous respiration and decay of dead plants on soil surface (Kadlec and Knight (1996)). DO effluent levels are well below established levels for irrigation purposes (5mg/L) (Bramwel *et al.*, 2004). pH level showed marginal decreased from 7.18 ± 0.14 initial influent concentrations (table 1). 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%) and the lowest reduction rate (1%) were observed in CH2 and CH3 respectively (table 2). pH levels in effluent are acceptable for drinking irrigation (WHO, 1993; Belmont *et al.*, 2004). Average influent turbidity, 344±146 mg/L, was reduced by 68%, 58% and 44% in effluent from CH2, CH3 and CH1 respectively (table 2).

PARAMETERS	Amt. decreased			% decreased		
	CH1	CH2	CH3	CH1	CH2	CH3
EC	0.009	-0.12	-0.19	6	7	12
pH	0.11	0.29	0.08	2	4	1
DO (mg/L)	1.92	1.34	2.29	73	51	87
Turbidity (NTU)	151	235	198	44	68	58
Nitrates (mg/L)	Nd	Nd	Nd			
Ammonia (NH ₃ ⁺) (mg/L)	5.17	0	1.67	86	28	0
Phosphorous (P) (mg/L)	-0.04	0.13	0.05	21	61	23
Sulphates (SO ₄ ²⁻) (mg/L)	56.14	-62.75	36.71	23	26	15
Potassium (K) (mg/L)	-6.33	1	3.33	49	8	26
Iron (Fe) (mg/L)	-0.61	-0.01	-0.83	136	3	186
Chlorides (Cl) (mg/L)	7.09	-2.36	-2.36	5	2	2
Sodium (Na) (mg/L)	27.33	-91.33	-70.67	7	23	17

-indicates values that increased; + indicates values that decreased; **Bold** values indicates parameter that decreased

Table 2: shows the amount decrease and the percentage decrease of parameters from each treatment

PARAMETERS	p-values		
	CH1	CH2	CH3
EC	<0.05*	<0.05	<0.05
pH	<0.05*	<0.05*	<0.05*
DO (mg/l)	0.133*	0.117*	0.108*
Turbidity (NTU)	0.014*	0.006*	0.007*
Nitrates (NO ₃) (mg/L)	-	-	-
Ammonia (NH ₃ ⁺) (mg/L)	<0.05*	0.010*	0.007*
Phosphorous (P) (mg/L)	0.371	0.009*	0.020*
Sulphates (SO ₄ ²⁻) (mg/L)	0.059*	0.238	0.228*
Potassium (K) (mg/L)	0.319	0.026*	0.020*
Iron (Fe) (mg/L)	0.699	0.949	0.346
Chlorides (Cl) (mg/L)	0.006*	0.005	0.010
Sodium (Na) (mg/L)	0.003*	0.007	0.017

<0.05 represents values more than 3 decimal places long;

* represents values that decreased

Table 3: shows the significance level (p-value) of each parameter from each test using ANOVA One-way (F-Test) in 95% confidence

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 (Wittgren and Maehlum, 1996).

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. Undetectable levels of NO_3^- lead to the dead of duckweed plants within 24 hours after flooding (Kadlec and Knight, 1996). This accounts for NH_3^+ reduction of 86% in CH1 and 28% in CH2 effluent while CH3 had not net change (0%) (Table 2). P increased in CH1 effluent by 0.04mg/L (21%). This was a result of phosphates release by hydrolysis under anoxic conditions and from decay of dead duckweed plants (George *et al.*, 2000; Reddy and DeBusk, 1985; Stumm and Morgan, 1970). 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 3). SO_4^{2-} concentrations from CH1 and CH3 effluent decreased to 183mg/L and 202.84mg/L respectively (table 1), due to the absorption of insoluble sulphide salts which are formed in the absence of NO_3^- (Gersburg *et al.*, 1984).

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% (observed on CH2) (table 2). 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 dying plants. These ions are either actively pumped into the water or are released from cells of dead plants. These concentrations are acceptable for irrigation purposes (Usharani, 2010). Results suggest CH1 effluent containing both plants, showed decreases in Na^+ (by 7% from initial $404.67 \pm 48.35 \text{mg/L}$) and Cl^- by (5% from $139.71 \pm 42.74 \text{mg/L}$) but recorded and increase in K (by 49%) ions (Table 2).

Faecal coliform

	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 4: Showing the total number of colonies recorded from plate count

EPA's manual listed cattail plants as 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 88560 CFU/ml, CH3 recorded the highest decrease in faecal coliform population by 4030 CFU/ml (45.5%).

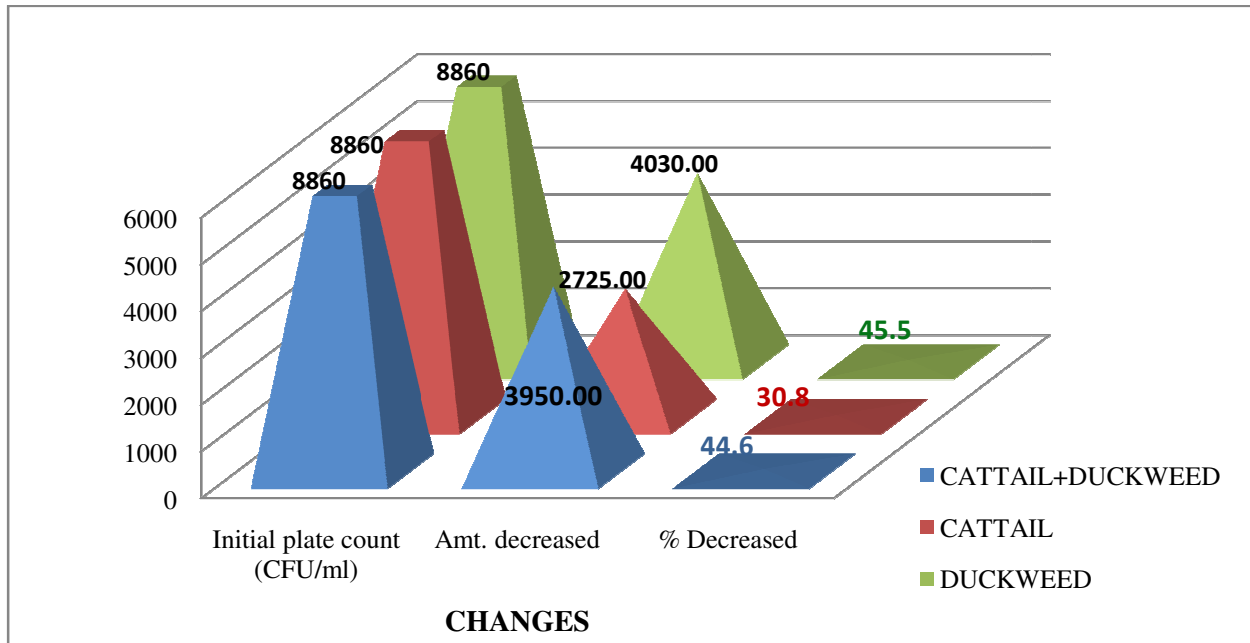


Figure 1 Bar Graph showing the average change in faecal coliform over 9 weeks from each chamber

Source of Variation	SS	df	MS	F	P-value	F crit	
Between Groups	21400.3	2	10700.2	0.27	0.780	9.55	No Significant
Within Groups	118928.5	3	39642.8				
Total	140328.8	5					

Table 5: ANOVA Single factor table showing the significant level of faecal coliform decrease throughout the experiment

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 4). The significant level is $p=0.78$ (table 5). 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 (Blumenthal *et al.*, 2000). 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 (Parsons *et al*, 2012).

CONCLUSION

Based on the information cited from this report the following were deduced;

- Cattail plants grow efficiently in water rich in NH_3^+ , P, DO, SO_4^{2-} and Na.
- The most effective constructed wetland is one containing both emergent and free floating macrophytes.
- The most effective constructed wetland for faecal coliform removal is duckweed.
- The overall water quality from each constructed wetland is unsafe for agricultural and domestic reuse but sufficient for aquatic environment.

REFERENCES

Ayyasamy, P M; Lakshmanaperumalsamu, P; Shanthi, K; Usharani, K (2010). Physico-chemical and Bacteriological Characteristics of Nayyal River and Ground Water Quality of Perur, India. *Journal of Applied Science and Environmental Management* (2010) Vol.14 (2) pp.29-35.

Bakir, H. (2000). Sustainable wastewater management for small communities in the Middle East and North Africa. Jordan. *Journal of Environmental Management* (2001) Vol.61 pp.319-328

Bramwell, S.; Prasad, P. (1994). Performance of a Small Aquatic Plant Wastewater Treatment System under Caribbean Conditions. USA. *Journal of Environmental Management* (1995) vol.43 pp.213-220.

Belmont, M.; Cantellano, E.; Metcalf, C.; Sánchez, A.; Thompson, S.; Williamson, M. (2004). Treatment of Domestic wastewater in a pilot-scale natural treatment system in central Mexico. USA. *Ecological Engineering* (2004) Vol.23 pp.299-311.

Blumenthal, U.; Mara, D.; Peasey, A.; Ruiz-Palacios, G.; Stott, R. (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bulletin of the World Health Organization* (2000) Vol.78 (9).

Breaux, A.; Day, J.; Farber, S. (1994). Using Natural Coastal Wetlands Systems for Wastewater Treatment: An Economic Benefit Analysis. USA. *Journal of Environmental Management* (1995) Vol.44, pp.285-291.

Cimab, 2010. Baseline analysis on domestic wastewater management in the Wider Caribbean Region. Final Report, 41pp.

212 Dechet, A.; Parsons, M.; Rambaran, M.; Mohamed-Rambaran, P.; Florendo-Cumbermack, A.; et
 213 al. (2012) Leptospirosis Outbreak following Severe Flooding: A Rapid Assessment and Mass
 214 Prophylaxis Campaign; Guyana, January–February 2005. PLoS ONE 7(7): e39672.
 215 doi:10.1371/journal.pone.0039672

216 Gersberg, R.M., Lyon, S.R., Elkins B.V, Goldman C.R. (1984). The removal of heavy metals by
 217 artificial wetlands. Chicago. In: *Proceedings Water Reuse Symposium, III. Vol 2. AWWA*
 218 *Research Foundation, pp. 639.*

219 George, D.B., Combs, D.L., Andrews, H.T., Berk, S.G., Kemp, M.C., O'Brien, K.L., Tsai, P.J.
 220 (2000). Development of guidelines and design equations for subsurface flow constructed
 221 wetlands treating municipal wastewater. *Us Environmental Protection Agency, Office of*
 222 *Research and Development: Cincinnati, Ohio.*

223 Hilton, B. (1993). Performance evaluation of a closed ecological life support system (CELSS)
 224 employing constructed wetlands. Boca raton Fl. *Constructed wetlands for Water Quality*
 225 *Improvement, G. A. Moshiri (ed.). pp. 117-125*

226 Kadlec, R.H. and R.L. Knight. (1996). Constructed wetlands. CRC Press LLC. Boca Raton,
 227 Florida, Lewis Publishers. Pp 893.

228 Oron, G.; Porath, D; Wildschut, L. (1984). Waste Water Recycling by Duckweed for Protein
 229 Production and Effluent Renovation. Amsterdam. *WaterScience technology Vol. 17 pp. 803-817.*

230 Ramsammy L., 2010, Acute Gastroenteritis (Diarrheal illness) in Guyana. Minsitry of Health
 231 publication. <http://www.health.gov.gy/MOH/Notices/Acute%20Gastroenteritis.pdf> (Retrieved 2013,
 232 09).
 233

234 Reedy, J. And Liehr, S.(1985). Nutrient removal potential of selected aquatic macrophytes.
 235 *Journal of Environmental Quality Vol.19 pp.261.*

236 Stumm, W. and J.J. Morgan. 1970. Aquatic chemistry: An introduction emphasizing chemical
 237 equilibria in natural waters. New York, NY: *John Wiley & Sons, pp. 583.*

238 United States Environmental Protection Agency (1999) Constructed Wetlands Treatment of
 239 Municipal Wastewaters; EPA/625/R-99/010; Cincinnati, Ohio
 240

241 US Army, 1998, Water Resources Assessment of Guyana.
 242 <http://uog.edu.gy/faculties/fot/repository/sites/default/files/Water%20resources,%20Guyana.pdf>
 243 (Retrieved: 2013, 09).

244 Vazquez-Montiel, O.; Horan, N.; Mara, D. (1996). Management of Domestic Wastewater for
 245 Reuse in Irrigation. Great Britain. *Water Science Technology (1996) Vol.33 (10-11) pp.355-362.*

246 Wittgren, H. and Maehlum, T. (1996) Wastewater constructed wetlands in cold climates. In: R.
247 Haberl, R. Perfler, J. Laber, and P. Cooper (eds.) *Water Science & Technology Vol 35 (5)*,
248 Wetland systems for water pollution control 1996. Oxford, UK: *Elsevier Science Ltd.*, pp.45-53.