Integrated Constructed Wetland for Nitrogen elimination from Domestic Sewage: The case study of Soba rural area in Khartoum South, Sudan

John Leju CELESTINO LADU[1, 2]; Martin Kajokare LOBOKA[3]; Yatta S. LUKAW[4]

1. School of Energy and Environment, Department of Environmental Science and Engineering, Southeast University, Nanjing 210096, P. R. China
2. College of Natural Resources and Environmental Studies, Department of Environmental Studies, University of Juba, Republic of South Sudan
3. School of Environmental Science, China University of Geo-sciences, Wuhan, China
4. College of Natural Resources and Environmental Studies, Department of Basic of Sciences, University of Juba, Republic of South Sudan

John.leju6@gmail.com

Abstract: This research paper tried to assess the efficiency of integrated constructed wetland in eliminating Nitrogen from domestic sewage of Soba rural area in Khartoum South, Sudan. The integrated constructed wetland is about 8.89 acres and consists of two sludge puddle and five shallow vegetated wetland units. The assessment of this study was base on influent and effluent concentrations of ammonia – nitrogen (NH3), nitrate-nitrogen (NO3-N) and wetland hydrology. The influent sewage classically contained 40 mg L^{-1} NH_3-N and 5 mg L^{-1} NO_3-N. The average concentration of Nitrogen in the integrated constructed wetland effluent was less than 1.0 mg L^{-1} for both forms. Generally, a total load of 2802 kg NH_3-N and 441 kg NO_3-N was received by the integrated constructed wetland and an elimination rate of 98.0 % and 96.9 % respectively. Average a real N loading rate (245 mg m^{-2} d^{-1} NH_3-N and 38 mg m^{-2} d^{-1} NO_3-N) had a significant linear relationship with a real N elimination rate (240 mg m^{-2} d^{-1} and 35 mg m^{-2} d^{-1}, correspondingly) for both forms. The a real first-order N elimination rate constants in the integrated constructed wetland averaged 14 m yr^{-1} for NH_3-N and 11 m yr^{-1} for NO_3-N respectively. Temperature coefficients (θ) for N lessening in the integrated constructed wetland was low and recommended that the variability in N elimination by the integrated constructed wetland was temperature independent.

[John Leju CELESTINO LADU, Martin K. LOBOKA, Yatta S. LUKAW. **Integrated Constructed Wetland for Nitrogen elimination from Domestic Sewage. The case study of Soba rural area in Khartoum South, Sudan.** Nat Sci 2012;10(8):30-36]. (ISSN: 1545-0740). http://www.sciencepub.net/nature. 6

Keywords: integrated constructed wetland; domestic wastewater, Nitrogen, sludge puddle; Wetland hydrology.

1. Introduction

Most wastewaters, such as domestic sewage, industrial and agricultural wastewater, urban drainage and landfill leachate, contain nitrogenous compounds that have given rise to various negative phenomena in water environments.

Nitrogen elimination from domestic sewage by constructed wetlands is considered as one of the most famed scheme for small communities in rural areas. The main elimination mechanisms of nitrogen in Constructed wetlands are nitrification and denitrification (R.H. Kadlecet al, 1996).

Constructed wetlands have now been successfully used in the treatment of several wastewaters such as domestic sewage, urban runoff and storm water, industrial and agricultural wastewater and leachate (M. Scholz et al, 2005). Nitrogen elimination in sewage treatment is imperative because of the potential hazard it causes to both living things and the ecosystem. However, the principal impact of nitrogen is due to its role as a limiting nutrient in many aquatic environments. Nitrogen is the limiting nutrient in most aquatic environments. Elevated nitrogen inputs into water bodies can result in increased plant growth and eutrophication. Eutrophication due to nitrogen inputs have been implicated in loss of species diversity (Preston et al. 2003) and increased occurrence of harmful algal blooms such as red tide, which threaten both human and ecosystem health (Anderson et al. 2002, Huang et al. 2003). Excessive nutrients in aquatic ecosystems cause eutrophication, which can lead to decreased dissolved oxygen levels and fish kills (Cook, 2001).

1.1 Chemistry of Nitrogen

Nitrogen can exist in nine various forms in the environment due to seven possible oxidation states (WEF, 1998)

Table (1) Principal forms of nitrogen

Nitrogen Compound	Formula	Oxidation State
Organic nitrogen	Organic-N	-3
Ammonia	NH_3	-3
Ammonium ion	NH_4	-3
Nitrogen gas	N_2	0
Nitrous oxide	N_2O	+1
Nitric oxide	NO	+2
Nitrite ion	NO_2	+3
Nitrogen dioxide	NO_2	+4
Nitrate ion	NO_3	+5

The principal forms of nitrogen of concern in onsite wastewater treatment and soil-groundwater interactions are Organic-N, NH3/NH4+, N2, NO2-, and NO3-(Rittman & McCarty, 2001; Sawyer et al., 1994; US EPA, 1993). Because these forms still represent four possible oxidation states that can change in the environment, it is customary to express the various forms of nitrogen in terms of nitrogen rather than the specific chemical compound: Organic-N, NH3-N, NH4+-N, N2-N, NO2--N, and NO3--N. Thus, for example, 10 mg/L of NO3--N is equivalent to 45 mg/L of NO3- ion.

1.2 Nitrogen Transformations in wetlands

The elimination mechanisms for nitrogen in constructed wetlands include utilization, ammonification, nitrification/denitrication, and plant uptake and matrix adsorption. Numerous studies have proved that the major elimination mechanism in most constructed wetlands is microbial nitrification/denitrification (Vymazal et al., 1998). Untreated ammonia can exert a significant oxygen demand through biological nitrification and it may cause eutrophication in receiving waters, and can be toxic to aquatic organisms. Therefore, the need for nitrogen control in sewage effluents has generally been recognized and many treatment processes have been developed to remove nitrogen from the sewage stream.

A “constructed wetland” is a wetland purposely constructed for pollution control and wastewater management, at a location other than existing natural wetlands. It is a multifaceted biological system that resembles natural self cleansing processes. Wetlands provide services of immense value to society. They control floods, protect coastal zones, control water qualities and they host a great diversity of species. The cultural and economical importance of wetlands to native communities is beyond description.

Pollutants removal in ICW systems can be accomplished through a combination of physical, chemical and biological processes that naturally occur in wetlands and are associated with the vegetation, sediments and their microbial communities. The N biogeochemical cycle within wetland ecosystems is multifarious and involves several transformation and translocation processes. These include ammonia volatilization, ammonification, N fixation, and burial of organic N, ammonia sorption to sediments, nitrification, denitrification, anammox, and assimilation. Usually, N elimination through bacterial transformations involves a chronological process of ammonification, nitrification and denitrification. Denitrification is thought to be the major N elimination pathway, and characteristically accounts for more than 60 % of the total N elimination in constructed wastewater wetlands. This microbial process consists of the reduction of oxidised forms of N, mainly nitrate and nitrite, to the gaseous compounds nitrous oxide and dinitrogen. Anaerobic conditions are a prerequisite for the occurrence of denitrification. While nitrate availability often regulates denitrification, organic carbon content, pH and temperature also play important roles. Temperature affects denitrification by controlling rates of diffusion at the sediment-water interface in wetlands. Denitrification rates in CWs have been shown to increase dramatically with temperature, within a lower and upper bounds of around 5 ^{o}C and 70 ^{o}C, respectively. The microbial activities related to nitrification and denitrification can decrease considerably at water temperatures below 15 ^{o}C or above 30 ^{o}C and most microbial communities for nitrogen elimination function at temperatures greater than 15 ^{o}C. Nitrification involves the sequential biochemical oxidation of reduced N species such as ammonia (NH_3) to nitrite (NO_2^-) and nitrate (NO_3^-) under strict aerobic conditions, which may be present in the sediment-water interface of FWS CWs. The nitrification process requires high oxygen concentrations and is highly sensitive to DO levels. Being an anaerobic process, denitrification is also sensitive to DO levels. Hydraulic characteristics such as water depth, hydraulic loading rate (HLR), and hydraulic retention time (HRT) are important factors for determining the treatment performance of CWs. At lower HLR and longer HRT, higher nutrient removal efficiencies are usually obtained.

There are limited studies to quantify N removal in full-scale industry-sized CWs based on wetland hydrology and corresponding pollutant concentration profiles. This paper appraises the N removal efficiency of a full-scale ICW applied as the main unit treating domestic wastewater in Sudan. Removal of NH_3-N and NO_3-N were analysed, with the aim of comparing the annual and seasonal N removal efficiencies, estimate the areal N removal rates and determine areal first-order kinetic coefficients for N removal, and assess the influence of water temperature on the N removal performance.

2. MATERIALS AND METHODS

2.1 Study Site Description

The sanitary sewage system in Sudan began since early fiftieth of the twenty century. Thus the service covered an area of 8.89 acres. As Khartoum Capital expanding vertically and horizontally, more interest was put on sanitary sewage water and projects were executed to dispose the effluent and reuse it safety specially in growing greenbelt south Khartoum City since early sixty, irrigated by the effluent which disposed from the Soba Sewage Water Treatment Plant (SSWTP).

The treated sewage plant (TSP) located 15km south Khartoum City (Treatment Sewage Plant in Soba). The area investigated consists of Soba Agricultural project and the Shigilab / Elkrmuta mixed farms.

The ICW comprises a small pumping station, two sludge units, and five shallow vegetated cells. The design capacity of the ICW system is 1,750 p.e. and covers a total area of 16.64 acres. The total surface area of the constructed wetland unit is 5.56 acres. Untreated influent sewage from the village is pumped directly into a receiving sludge unit. The wetland units were originally planted with *Carex riparia* Curtis, *Phragmites australis*, *Typha latifolia* L., *Iris pseudacorus* L., and *Glyceria maxima*.

2.2 Data Analysis and Modelling

The elimination rates for NH_3-N and NO_3-N, based on a one-year data set (May, 2011–May, 2012) were quantified using three common approaches for CWs. The first approach estimated the mass removal efficiency (%) as follows:

Removal efficiency

$$= \frac{Q_o C_o - Q_e C_e}{Q_o C_o} \times 100 \qquad (1)$$

The second approach estimated the areal removal rate (mg-N m^{-2} d^{-1}) as follows:

$$\text{Removal rate} = q \times \left(C_o - C_e\right) \qquad (2)$$

The third approach estimated the areal-based first-order removal rate constants for ammonia (K_A) and nitrate (K_N) using the K–C* model, assuming plug flow conditions:

$$\ln\left(\frac{C_e - C^*}{C_o - C^*}\right) = -\frac{K}{q} \qquad (3)$$

Where Q_o and Q_e are the daily volumetric water inflow and outflow rates (m^3 d^{-1}), C_o and C_e are influent and effluent concentrations, respectively, of NH_3-N or NO_3-N (mg N L^{-1}), C^* is the background concentration (mg N L^{-1}) and K is the areal first-order removal rate constant (m yr^{-1}). The K values were normalised to 20 ^oC (K_{20}) based on Eq. (4) using values estimated from Eq. (5). A C^* of 0 mg L^{-1}, recommended by Kadlec was used to calibrate the model.

The effect of temperature on the areal first-order removal rate constants for the N species was modelled using the modified Arrhenius relationship:

$$K_{(t)} = K_{(20)} \theta^{(t-20)} \qquad (4)$$

Where $K_{(t)}$ and $K_{(20)}$ are the first-order removal rate constants (m yr^{-1}), t is temperature (^oC), and θ is an empirical temperature coefficient . A linear form of Eq. (4) was used to estimate parameters of the model from the data set:

$$\log(K_{(t)}) = \log\theta(t-20) + \log(K_{(20)}) \qquad (5)$$

Values of $\log(K_{(t)})$ versus (t-20) were plotted and fit with a linear regression. The resulting slope and intercept were equal to $\log\theta$ and $\log(K_{(20)})$ respectively.

The hydraulic loading rate, q (m yr^{-1}) was calculated as:

$$q = \frac{Q}{A} \qquad (6)$$

Where Q is the total water inflow rate (m^3 d^{-1}), and A is the total surface area for five wetland units (m^2).

The overall dynamic wetland water budget was calculated with Eq. (7).

$$Q_o - Q_e + Q_c + (P - ET - I)A = \frac{dV}{dt} \qquad (7)$$

Where Q_c is catchment runoff rate (m^3 d^{-1}), P is the daily precipitation rate (m d^{-1}), ET is the daily evapotranspiration rate (m d^{-1}), I is the daily infiltration rate (m d^{-1}), and $\frac{dV}{dt}$ is the net change in volume (m^3 d^{-1}).

2.3 Statistical Analysis

Data distributions were tested for normality. Data presentation uses means of actual measured values. Statistically significant differences were determined at α = 0.01, unless otherwise stated. Comparisons of means were by paired student t-tests and analysis of variance (ANOVA). Regression analysis used the standard least squares fit.

3.1 Results

3.1 Wetland Hydrology

Generally, surface flows from the sludge unit and precipitation were considered as the inflow sources to the ICW system, whereas evapotranspiration and water infiltration were assumed to be lost water. Precipitation and evapotranspiration were calculated as the amount of water falling on, or evaporating from the wetland unit surface, respectively. The HLR, HRT, and mean dimensions of each ICW unit are shown in Table 2.

Table (2) Size and hydraulic characteristics of ICW system

ICW section	Area (m^2)	Depth (m)	Volume (m^3)	HRT (d)	HLR (mm day^{-1})
Puddle 1	4664	0.42	1958.9	18	24.4
Puddle 2	4500	0.38	1710.0	16	26.8
Puddle 3	12660	0.32	4051.2	32	10.7
Puddle 4	9170	0.36	3301.2	23	16.1
Puddle 5	1460	0.29	423.4	3	100.3
Total wetland	32454	-	11444.7	92	7.3

3.2 Influent and Effluent Nitrogen Concentrations

Overall, NH_3-N was recorded as the dominant form of N contained in the influent sewage received by the ICW. Annual influent concentrations (average ± SD) of 40 ± 13.6 mg L^{-1} and 5 ± 3.8 mg L^{-1} were recorded correspondingly for NH_3-N and NO_3-N, demonstrating a high variability of the influent domestic sewage (Table 3). Average concentrations of N in the ICW effluent were consistently less than 1.0 mg L^{-1} and recorded an average of 0.8 ± 1.6 mg L^{-1} for NH_3-N and 0.3 ± 0.2 mg L^{-1} for NO_3-N.

Table (3) Concentrations of nitrogen in Influent and effluent at ICW between May 2011 and May 2012

Parameter	Unit	Influent		*n*	Effluent		*n*
		Mean	SD		Mean	SD	
Ammonia	mg N L^{-1}	40	13.6	120	0.8	1.6	120
Nitrate	mg N L^{-1}	5	3.8	101	0.3	0.2	101

n = sample number, SD = standard deviation

Table (4) Comparison of seasonal nitrogen concentrations at ICW influent and effluent points between 2011 and 2012

Season	Months	NH_3-N (mg L^{-1})					NO_3-N (mg L^{-1})				
		n	Influent		Effluent		*n*	Influent		Effluent	
			Mean	SD	Mean	SD		Mean	SD	Mean	SD
Summer	1 May - 31 Jul	47	42	10.1	0.3	0.2	45	5	2.1	0.3	0.2
Winter	1 Nov - 31 Jan	17	31	11.5	3	3.1	15	2	1.6	0.3	0.1

n = sample number, SD = standard deviation

3.3 Nitrogen Loading and Removal Rates

Generally, the average (± SD) areal NH_3-N loading rate (245 ± 321.9 mg m^{-2} d^{-1}) was higher compared to that of NO_3-N (38 ± 58.3 mg m^{-2} d^{-1}). Nevertheless, the areal elimination rates for the two N forms were consistently high, with average (± SD) of 240 ± 317.8 mg m^{-2} d^{-1} for NH_3-N and 35 ± 54.9 mg m^{-2} d^{-1} for NO_3-N. Hence, nitrogen was efficiently eliminated from the influent sewage throughout the study period, except during winter as shown in Table 5 and6.

Table (5) Ammonia loading and elimination rates in ICW between 2011 and 2012 at different season

Season	Months	*n*	Total inputs (mg m^{-2} d^{-1})		Total outputs (mg m^{-2} d^{-1})		Removal rate	
			Mean	SD	Mean	SD	(mg m^{-2} d^{-1})	%
Summer	1 May - 31 Jul	47	278	347.7	0.5	0.79	275	99.5
Winter	1 Nov - 31 Jan	17	204	108.4	25.2	33.60	187	57.6

n = sample number, SD = standard deviation

Table (6) Nitrate loading and elimination rates in ICW between 2011and 2012 at different season

Season	Months	*n*	Total inputs (mg m^{-2} d^{-1})		Total outputs (mg m^{-2} d^{-1})		Removal rate	
			Mean	SD	Mean	SD	(mg m^{-2} d^{-1})	%
Summer	1 May - 31 Jul	45	44	70.3	0.5	0.55	41	96.2
Winter	1 Nov - 31 Jan	15	19	16.1	2.5	2.24	16	60.8

n = sample number, SD = standard deviation

4. Discussion

Domestic sewage inflow to the ICW varied monthly, with individual system values ranging between 1.4 - 613 m^3 d^{-1}. The average inflow rate (± SD) was 104 ± 106.1 m^3 d^{-1}, yielding average hydraulic loading of 7 ± 10.5 mm d^{-1}, whereas the associated discharge at the effluent point ranged from 0 - 492 m^3 d^{-1} with an average (± SD) of 131 ± 179.4 m^3 d^{-1}. The average daily outflow volumes recorded for the ICW were higher than the average daily inflow volumes, possibly due to precipitation inputs.

The net change in volume recorded throughout the study period (average ± SD) was 62 ± 371.3 m^3 d^{-1}. Likewise, a strong linear correlation ($R^2 = 0.97$, $P < 0.01$, $n = 708$) was observed between precipitation and wetland volumetric flow rate, and suggested that precipitation probably had a considerable influence on the hydraulic loading rate. Evapotranspiration and infiltration amount to about 25 % and 5 % correspondingly, of water outflows from the ICW system, whereas the effluent accounted for nearly 50 %.

The effluent concentrations of both N form were considerably lower ($P < 0.01$, $n = 120$) than the influent. Furthermore, influent concentrations of the two N forms showed some seasonal variations (Table 4). Nevertheless, whereas the variations in concentrations of the influent NO_3-N was significant ($P < 0.01$, $n = 18$), variations of the influent NH_3-N was not. The highest (average ± SD) seasonal influent concentration of NH_3-N (42 ± 10.1 mg L^{-1}) and NO_3-N (8 ± 6.3 mg L^{-1}) were recorded in summer and in fact the highest elimination rate occurred also in the same season. The effluent NH_3-N concentrations were slightly higher in the winter (3 ± 3.1 mg L^{-1}) compared to that in summer. No seasonal variations in the effluent NO_3-N was observed, and was typically in the section of 0.3 mg L^{-1}. There was a significant linear relationship between the areal loading and elimination rates for NH_3-N ($R^2 = 0.99$, $P < 0.01$, $n = 120$) and NO_3-N ($R^2 = 0.99$, $P < 0.01$, $n = 101$), demonstrating a near complete areal elimination rate. The close fit of the points to the regression line also indicate a remarkably constant areal elimination rate for both N class. On the whole, average annual mass elimination efficiencies were relatively high for the ICW. About 92.7 % elimination was recorded for NH_3-N and 84.4 % for NO_3-N. Over the one-year study period, surface inflows carried a total load of 2802 kg NH3-N into the ICW system and 98.0 % were retained. Similarly, a total load of 441 kg NO_3-N had been received by the ICW and 96.9 % retention had been recorded. Areal-based first-order N removal rate constants (K) calculated for NH_3-N and NO_3-N reduction in the ICW were 14 ± 16.5 m yr^{-1} and 11 ± 12.5 m yr^{-1}, respectively. Average water temperatures ranged between 16 -24 ^{o}C. The average effects of temperature (θ) on N elimination rate constants were estimated to be 1.005 for NH_3-N and 0.984 for NO_3-N. There was no correlation observed between water temperature and the kinetic rate constants for both NH_3-N and NO_3-N. Nevertheless, relatively high N elimination rates have been recorded at all times of the year, where the water temperature within the studied ICW ranged only between 16 ^{o}C and 24 ^{o}C, further confirming the low influence of temperature on N elimination in the ICW. Nevertheless, N elimination by the ICW was influenced by seasonality, with slightly higher elimination recorded during the warmer months. It is possible that this seasonality may have been influenced by plant nutrient uptake. This suggests that N elimination by the ICW may be largely due to physical processes. Physical treatment processes are less influenced by temperature. A significant linear relationship was observed between the kinetic rate constants and the loading rates for both NH_3-N and NO_3-N, indicating that physical processes in fact may have played an important function in the N removal performance of the ICW.

5. Conclusion

From the comprehensive assessment of a one-year (May 2011–May 2012) data set comprising influent and effluent loadings of ammonia-nitrogen (NH_3-N) and nitrate-nitrogen (NO_3-N), together with total water budgets, ICW can be efficient at eliminating N pollution from domestic sewage, with relatively high areal elimination rates at all times of the year. Annual mass elimination efficiencies were consistently high for the two N forms with average of 92.7 % elimination for NH_3-N and 84.4 % for NO_3-N. Overall, during the one-year operation, the ICW received a total load of 2802 kg NH_3-N and 441 kg NO_3-N and recorded 98.0 % and 96.9 % elimination respectively. Average areal elimination rates for NH_3-N and NO_3-N were 240 ± 317.8 mg m^{-2} d^{-1} and 35 ± 54.9 mg m^{-2} d^{-1}, respectively and showed significant linear correlations with areal loading rates. Nitrogen elimination showed some seasonal trends. Elimination rates in the summer months were slightly higher. Lowest rates were observed in winter. Areal first-order N removal rate constants in the ICW averaged 14 m yr^{-1} for NH_3-N and 11 m yr^{-1} for NO_3-N. The normalised areal elimination rate constants suggested that N elimination in the ICW were slightly affected by temperature. The temperature coefficients (θ), approximated using the modified Arrhenius equation, were low and further validated the low influence of temperature on N elimination in the ICW.

Acknowledgements

Acknowledgments is extended to School of energy and environment, department of environmental science and engineering, Southeast University and to the college of Natural Resources and Environmental Studies, department of environmental studies, University of Juba for providing academic support.

Corresponding Author:
John Leju CELESTINO LADU.
College of Natural Resources and Environmental Studies, Department of Environmental Studies, University of Juba - Juba, Republic of South Sudan
E-mail: john.leju6@gmail.com

REFERENCES

1. Black and Veatch Corporation (2010). White's Handbook of Chlorination and Alternative Disinfectants (5th. Ed.). John Wiley and Sons, Inc., New Jersey.
2. Sayed Hag Elnur, (2006). The resue of effluent in agriculture South Khartoum city.
3. R.H. Kadlec and R.L. Knight, (1996). Treatment Wetlands. Lewis Publisher, Florida, USA,.
4. Taha et al (2001). Impact of treated sewage water on soil characteristics, forage production and the surrounding inhabitants. PhD thesis. Faculty of agriculture, University of Khartoum.
5. Beutel, M. W, (2006. Inhibition of Ammonia Release from Anoxic Profundal Sediments in Lakes using Hypolimnetic Oxygenation. Ecological Engineering, *28*(3), 271-279.
6. USEPA, (2002). Drinking Water from Household Wells. EPA 816-K-02-003. United States Environmental Protection Agency, Washington, DC.
7. Machate, T., Noll, B. H. H., Kettrup, A. (1997) Degradation of Phenanthrene and Hydraulic Characteristics in a Constructed Wetland. Water Research, *31*(3), 554-560.
8. Moshiri, G. A. (1993. Constructed Wetlands for Water Quality Improvement. CRC Press, Boca Raton, Florida, USA.
9. Kadlec, R. H., Knight, L. R., Vymazal, J., Brix, H., Cooper, P., Haberl, R, (2000). Constructed Wetlands for Pollution Control: Processes, Performance, Design and Operation. International Water Association (IWA) Specialist Group on Use of Macrophytes in Water Pollution Control. Scientific and Technical Report No. 8. IWA Publishing, London.
10. Scholz, M., Xu, J. (2002). Performance Comparison of Experimental Constructed Wetlands with Different Filter Media and Macrophytes Treating Industrial Wastewater Contaminated with Lead and Copper. Bioresource Technology, *83*(2): 71-79.
11. Scholz, M. (2004). Treatment of Gully Pot Effluent Containing Nickel and Copper with Constructed Wetlands in a Cold Climate. Journal of Chemical Technology and Biotechnology, *79*(2): 153-162.
12. Zhao, Y. Q., Sun, G., Allen, S. J. (2004). Anti-sized Reed Bed System for Animal Wastewater Treatment: A Comparative Study. Water Research, *38*(12): 2907-2917.
13. Scholz, M., Lee, B. H. (2005). Constructed Wetlands: A Review. International Journal of Environmental Studies, *62*(4): 421-447.
14. US EPA. (1995). Handbook of Constructed Wetlands: A Guide to Creating Wetlands for Agricultural Wastewater, Domestic Wastewater, Coal Mine Drainage, and Stormwater in the Mid-

Atlantic Region. Volume 2: Domestic Wastewater. Environment Protection Agency, Washington, DC.

15. Verhoeven, J. T. A., Meuleman, A. F. M. (1999). Wetlands for Wastewater Treatment: Opportunities and Limitations. Ecological Engineering, *12*, 5-12.
16. Harrington, R., Carroll, P., Carty, A., Keohane, J., Ryder, C. (2007). Integrated Constructed Wetlands: Concept, Design, Site Evaluation and Performance. International Journal of Water, *3*(3), 243–256.
17. Scholz, M., Harrington, R., Carroll, P., Mustafa, A. (2007). The Integrated Constructed Wetlands (ICW) Concept. Wetlands, *27*(2): 337-354.
18. Nygaard, B., Ejrnæs, R. (2009). The Impact of Hydrology and Nutrients on Species Composition and Richness: Evidence from a Microcosm Experiment. Wetlands, *29*(1):187-195.
19. Jurdo, G. B., Johnson, J., Feeley, H., Harrington, R., Kelly-Quinn, M. (2010. The Potential of Integrated Constructed Wetlands (ICWs) to Enhance Macroinvertebrate Diversity in Agricultural Landscapes. Wetlands, *30*(3): 393-404.
20. Carty, A., Scholz, M., Heal, K., Gouriveau, F., Mustafa, A. (2008). The Universal Design, Operation and Maintenance Guidelines for Farm Constructed Wetlands (FCW) in Temperate Climates. Bioresource Technology., *99*, 6780-6792.
21. Mustafa, A., Scholz, M., Harrington, R., Carroll, P. (2009). Long-term Performance of a Representative Integrated Constructed Wetland Treating Farmyard Runoff. Ecological Engineering, *35*(5), 779-790.
22. Dunne, E. J., Culleton, N., O'Donovan, G., Harrington, R., Olsen, A. E. (2005). An Integrated Constructed Wetland to Treat Contaminants and Nutrients from Dairy Farmyard Dirty Water. Ecological Engineering, *24*(3), 221-234.
23. Harrington, R., McInnes, R. (2009) Integrated Constructed Wetlands (ICW) for Livestock Wastewater Management. Bioresource Technology, *100*, 5498-5505.
24. Spieles, D. J., Mitsch, W. J. (2000). The Effects of Season and Hydrologic and Chemical Loading on Nitrate Retention in Constructed Wetlands: A Comparison of Low- and High Nutrient Riverine Systems. Ecological Engineering, *14*, 77-91.
25. Crumpton, W. G., Phipps, R. (1992). Fate of Nitrogen Loads in Experimental Wetlands. In: The Des Plaines River Wetlands Demonstration Project. Wetlands Research, Inc., Chicago, IL.
26. Lee, C., Fletcher, T. D., Sun, G. (2009). Nitrogen Removal in Constructed Wetland Systems. Engineering Life Science, *9*(1), 11-22.
27. Horizontal Subsurface Treatment Wetlands. Ecological Engineering, *35*, 159-174.
28. Boutilier, L., Jamieson, R., Gordon, R., Lake, C., Hart, W. (2010). Performance of Surface-flow Domestic Wastewater Treatment Wetlands. Wetlands, *30*, 795-804.
29. Ran, N., Agami, M., Oron, G. (2004). A Pilot Study of Constructed Wetlands using Duckweed (*Lemna gibba* L.) for Treatment of Domestic Primary Effluent in Israel. Water Research, *38*(9), 2241-2248.
30. Kadlec, R. H. (2003). Pond and Wetland Treatment. Water Science and Technology, *48*(5), 1-8
31. Tanner, C. C., Clayton, J. S., Upsdell, M. P. (1995). Effect of Loading Rate and Planting on Treatment of Dairy Farm Wastewaters in Constructed Wetland–II. Removal of Nitrogen and Phosphorus. Water Research, *29*(1), 27-34.
32. Huang, J., Reneau Jr., R. B., Hagedorn, C. (2000). Nitrogen Removal in Constructed Wetlands Employed to Treat Domestic Wastewater. Water Research, *34*(9), 2582-2588.
33. Chung, A. K. C., Wu, Y., Tam, N. F. Y., Wong, M. H. (2008). Nitrogen and Phosphate Mass Balance in a Sub-Surface Flow Constructed Wetland for Treating Municipal Wastewater. Ecological Engineering, *32*(1), 81-89.
34. Kadlec, R. H., Reddy, K. R. (2001). Temperature Effects in Treatment Wetlands. Water Environment Research, *73*(5), 543-557.
35. Hammer, D. A., Knight, R. L. (1994). Designing Constructed Wetlands for Nitrogen Removal. Water Science and Technology, *29*(4), 15-27.
36. Mitsch, W. J., Horne, A. J., Narin, W. R. (2000). Nitrogen and Phosphorus Retention in Wetlands–Ecological Approaches to Solving Excess Nutrient Problems. Ecological Engineering, *14*, 1-7.
37. Anderson, D. M., P. M. Gilbert, et al. (2002). "Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences." Estuaries 25(4B): 704-726.
38. Adam and Adeeb (2000). Reuse and develop irrigation system in irrigated schemes. Annual forum No.37. Ministry of agriculture
39. M. Scholz, B. H. Lee, (2005). Constructed wetlands: A review, Int. J. Environ. Stud., 62, 421–447.

5/16/2012