Modelling of Pollutant Removal Rates in Constructed Wetlands under Varying Hydraulic Loading Rates

Udukumburage RS, Ariyasena MADN, Rupasinghe GGMBMB and * Karunarathne S

Department of Earth Resources Engineering, University of Moratuwa

*Corresponding author - Shiromi27@yahoo.co.uk

Abstract: A subsurface horizontal flow constructed wetland located at University of Moratuwa was observed from January 2012 to November 2012 in order to derive empirical equations for the treatment efficiencies of BOD, COD, Nitrate-N, Nitrite-N and Total Phosphorous with varying hydraulic loading rates. Source of polluted water was the grey water effluent from the Staff canteen which is located near the constructed wetland. BOD, COD, Nitrate-N, Nitrite-N and Total Phosphorous, turbidity and conductivity measurements were taken to ascertain the water quality. Overall treatment efficiency of the wetland cell is above 75% for all parameters. Regression technique was used to derive the empirical equations. IBM SPSS statistics -20 software was used in analysing the experimental data. The derived equations exhibit a high level of accuracy since predicted data and actual data shared a strong correlation of 79.1% for COD, 93.2% for BOD, 85.1% for Nitrate-N, 84.1% for Nitrite-N and 86.2% for Total Phosphorous. Constructed wetlands in tropic environments are capable of using these equations with relevant adjustments to the original.

Keywords: BOD, COD, Nitrate-N, Nitrite-N, Total phosphate

1.Introduction

Fresh water has become a scarce resource as a result of unmanaged exploitation and man-made pollution. Waste water is basically two types, black and grey, categorized according to the consisting impurities. Black water consists of human excreta while grey water consists of other nutrients, heavy metals and micro-organisms. Effluents from industries, domestic and agriculture are majorly grey water. Discharging these to water ways create a bad impact on human health and aquatic environment (Mayo and Bigambo,2005).

Grey water can be treated by means of physical, chemical, and biological treatment techniques. Activated sludge, trickling filtration, neutralization, chlorination, filtration and sedimentation are some of such waste water treatment methods. Also waste water is treated to a certain degree by natural

Karunarathne S, B.Sc.Eng.(Hons) (Moratuwa), M.Sc.(Saitama), Ph.D.(Saitama), MASCE(USA), C.Eng., M.I.E.(S.L.) Head of the Department Earth Resources Engineering, University of Moratuwa

Udukumburage RS, Ariyasena MADN and Rupasinghe GGMBMB, Final year Undergraduate students in the Department of Earth Resources Engineering, University of Moratuwa.

mechanisms. Bogs, swamps, mashes and fens are different types of natural wetlands which are considered as the kidneys of nature as they remove pollutants through natural processes. Some of these principles are applied in constructing artificial wetlands as well. These constructed wetlands (CW) incur low cost and low maintenance but effective in removing pollutants, due to simple and reliable operation (Economopoulou and Tsihrintzis, 2003). Vegetation, soils, types of substrate, organic and hydraulic loading and hydraulic retention time are the most important design and operational parameters of constructed wetlands. These CWs are engineered designs (Vymazal, 2011). Therefore the design parameters can be varied for the required efficiency and for localized climatic conditions. Hydraulic loading rate of constructed wetland is an important parameter that determines the pollutant removal efficiency of the same. Only a few studies have been done to investigate the impacts of varying hydraulic loading rates on the treatment efficiencies and they are also limited to temperate climatic regions and therefore the results cannot be translated to the Sri Lankan conditions directly. Hence the objective of the present study is to investigate the validity of empirical equations of removal rates for various parameters, derived from the experimental analysis.

2.Material and Methods

The horizontal flow sub surface constructed wetland at the University of Moratuwa has been used for the testing purposes throughout the project.

2.1 Experimental Setting

The grey water discharged from a university staff canteen was fed through the wetland system. Pre-treatment comprised of the removal of suspended solids and a grease trap to separate and remove the oil and grease which are not treated by the wetland itself.

Table 1 - Characteristics of the pilot scale constructed wetland

Parameter	Value
Q - flow rate	1.428 m^3/day
Φ - porosity	0.435
d - depth	0.75 m
L - length	4.00 m
W – width	2.16 m
V_e - effective volume	2.643 m^3
A - surface area	8.64 m^2

The original design flow rate of 1.428 m^3/day, was determined using the rule of thumb. The removal efficiencies for certain parameters at this hydraulic loading rate were lower than 60%. Hence the upper limit of the varying hydraulic loading rate was maintained below 1.6 m^3/day and the lower limit was maintained above 0.5 m^3/day.

2.2 Experimental Procedure

The water flow measurements were taken from the inlet and the outlet of the constructed wetland in weekly basis from February to November 2012. A plastic barrel of a known volume was used in collection of the water while the time taken was measured to fill it to measure the hydraulic loading rate.

The samples were collected in weekly basis for a particular flow rate from the inlet and outlet of the constructed wetland. The standard methods were implemented when collecting the water samples from both inlet and outlet of the wetland system. The departmental analytical laboratory was used in order to analyse BOD, COD, Total Nitrate Nitrogen, Total Nitrite Nitrogen, Total Phosphate (TP), pH, conductivity etc.

3. Results and Discussions

3.1 Experimental analysis of the effect of hydraulic loading rate on pollutant removal efficiency

Increasing hydraulic loading rates from 0.56 m^3/day to 1.6 m^3/day have caused the BOD_5, COD, Nitrite-N, Nitrate-N and Total Phosphate treatment efficiencies to drop down by significant proportions. Figure 1 shows the variation of the treatment efficiencies of BOD - 16%, COD - 12%, Total Nitrate Nitrogen - 11%, Total Nitrite Nitrogen - 13% and Total Phosphate (TP) - 27% due to varying hydraulic loads. Within the hydraulic loadings ranging from 0.56 m^3/day to 0.90 m^3/day, the treatment efficiencies of BOD and COD do not produce significant differences. Hence, it can be said that the wetland still manage to operates effectively in spite of the increased hydraulic loadings with respect to BOD and COD removal.

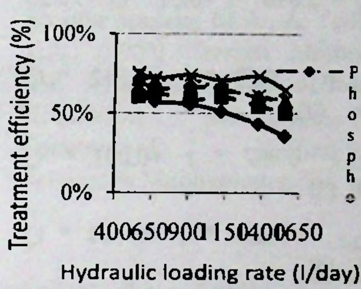

Figure 1- Variation of the treatment efficiencies for varying hydraulic loading rates of the subsurface flow constructed wetland

3.2 Mathematical modelling of the hydraulic loading rate on pollutant removal efficiency

Derivation of the regression equations for each parameter and the addition of the effect of the rain as an independent variable to the already derived equations were the primary concerns. Hence multiple regression method was employed in order to come up with formulas for each parameter. A best fit comparison was carried out to determine the best suited relationship with and without of rainfall effects for each parameter by using the amount of data explained by the regression method (Pearson's correlation coefficient R-squared value).

The statistical data collected were analysed using '**IBM SPSS statistics -20**' software. The regression equations obtained and verified for COD , BOD , Nitrate-N , Nitrite-N , TP removal with respect to varying hydraulic loading rates as given in equations from 1-5.

$E_{COD,(Q,r)} = 0.696 * r - 0.01 * Q + 79.23$ ....(1)

$E_{BOD,(Q,r)} = - 0.23 * r - 0.012 * Q + 94.039$.....(2)

$E_{Nitrate,(Q,r)} = 0.987 * r + 0.001 * Q + 59.573$...(3)

$E_{Nitrite,(Q,r)} = 0.238 * r + 0.014 * Q + 51.075$...(4)

$E_{TP,(Q,r)} = - 0.315 * r - 0.012 * Q + 58.862$.....(5)

Whereas,

$E_{(Q,r)}$= Treatment Efficiency

Q = Hydraulic Loading Rate (l/day)

R = Rainfall data (mm)

Derived regression equations were verified using a separate data set obtained from the experimental analysis and statistically tested for the correlation coefficient. According to the Table 2, almost all the parameters consist of 'R value' more than 0.75 and hence the relationships in between the 'Predicted Data' and 'Test Data' are strong.

Table 2 - Validation of the regression equations

Parameter	R^2 value of tested and predicted efficiencies
COD	.791
BOD	.932
Nitrate-N	.851
Nitrite-N	.841
TP	.862

4.Conclusions

The equations derived, for each of the above mentioned parameters are 'empirical' and can be used for other horizontal flow subsurface constructed wetlands with similar parameters after further verification and proper adjustments are incorporated to the original equations. Verification process has shown that all the five parameters hold a strong relationship with 'loading rate' and 'rainfall'.

Incorporation of the 'Rainfall' data has shown a critical improvement on each of those equations whereas percentage of the data explained has risen up in significant proportions. Higher standardized coefficients have proven the degree of importance of the loading rate and rainfall data on treatment efficiency of each parameter. An effective loading rate, which provides the necessary overall pollutant removal condition, can be determined by the derived equations.

The experimental analysis suggests the design surface area can be reduced by more than 25% and hence the constructed wetlands can be popularized among the Sri Lankan domestic environments

Acknowledgement

The authors are sincerely thankful to Dr. A.M.K.B. Abeysinghe, Mrs. P.T.N. Pathiraja, Mrs. M.W.P. Sandamali and all who helped in many ways for the success of the project.

References

Economopoulo, M.A., & Tsihrintzis, V.A., (2003). Design Methodology and Area Sensitivity Analysis of Horizontal Subsurface Flow Constructed Wetlands,Water Resources Management, 17, pp. 147-162,

Kadlec, R.H., Knight, R.L., (1996), Treatment wetlands, Boca Raton, FL: CRC Press, pp. 893,

Langergraber, G., (2008). Modeling of Processes in Subsurface Flow Constructed Wetlands, Vadose Zone Journal, 7, pp.830-842,

Vymazal, J., (2011).Constructed Wetlands for Wastewater Treatment, Environ. Sci. Technol, 45,pp. 61-69,