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PERFORMANCE EVALUATION OF A HYBRID NATURAL WASTEWATER TREATMENT POND SYSTEM IN KIGALI, RWANDA

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Abstract- This study aimed at evaluating the performance of the Nyarutarama waste stablization ponds. The study was conducted from July to October 2008 with sampling done fortnightly. The parameters monitored were temperature, pH, conductivity, total suspended solids, dissolved oxygen, five-day biochemical oxygen demand, chemical oxygen demand, total nitrogen, total phosphorus, ammonium-nitrogen, nitrate-nitrogen, nitrite-nitrogen and faecal coliforms. The samples were collected at the inflow and outflow points of each pond and analysed according to standard methods. Parshall Flume was used for flow measurement. The Nyarutarama treatment ponds received about 355 m^3/day of sewage with an estimated total hydraulic retention time of 45 days. The results showed that there is substantial reduction in pollutants in the system in terms of TSS, BOD5, COD, TN and TP, with high reductions observed in the second pond. Although there was about 96% removal of FC, the concentration in the final effluent was still very high (above 2,000 cfu/100ml) compared to WHO guidelines for irrigation water of 1,000/cfu/100ml. It was concluded that, there is scope for better results if the treatment system is properly managed in term of. This management includes optimal harvesting of macrophyte plants, control of open water zones, and protection of pond embankments.

Keywords- Faecal coliform, natural treatment systems, nutrients, ponds, water lettuce, wastewater treatment, effluent quality

Introduction

Many sewage treatment plants in sub-Saharan African countries become dysfunctional after a short period of time due to insufficient funds for operation and maintenance [1]. In Rwanda, 61% of the population had access to improved sanitation in 2011, compared to 32% in 1990 [2]. The City of Kigali is growing rapidly at about 5% per annum, dramatically affecting the city landscape, with infrastructure now failing to cope with the loads imposed upon them. About 83.3 of the households in Kigali have access to improved sanitation with the general picture as follows: flushing toilets 8.1%; pit latrines with constructed floor slab 75.2%; pit latrines without constructed floor slab 15.2%; and 1.5% with no access of any kind [3]. Only a small percentage of the residents in Kigali use conventional septic tanks, whilst less than 1% are connected to five small wastewater treatment plants, including the Nyarutarama natural wastewater treatment ponds. The configuration of the plant is innovative but its performance is not known. The plant's effluent is discharged into an agricultural area where sugarcane, beans and sweet potatoes are cultivated. The main objective of this study was to assess the performance of the individual treatment units of the Nyarutarama Wastewater Treatment Plant in terms of physico-chemical and bacteriological criteria. Specifically, the parameters monitored were temperature, pH, electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N) & faecal coliforms (FC).

Materials and Methods

Description of the Study Area

Fig-1 shows the location of the Nyarutarama Ponds in Kigali City, Rwanda. The Nyarutarama Ponds receive settled sewage from 483 houses. The plant treats settled sewage from septic tanks and consists of a primary pond which is 101 m in length, 66 m in width and 1.5 m in depth (with portions of aerobic and anaerobic zones). The second pond is covered by water lettuce (*Pistia stratiotes*) and is 73 m in length, 42 m in width and 1.2 m in depth. The third pond is a mixture of aquatic plants and free water surfaces with 67 m of length, 43 m of width and 0.9 m of depth (essentially a constructed wetland). Fig-2 shows the dimensions and layout of the ponds and how they are covered. At the inlet of the first pond, a flow measuring device (Parshall Flume) was constructed.

Sampling

The sampling points were situated at the inlet, after the first pond, at the end of the water lettuce-covered pond and outflow of the constructed wetland [Fig-2].

The sampling was done for three months, from July to September 2008. The parameters monitored are BOD_5, COD, TP, TN, NH_4-N, NO_2-N, NO_3-N, TSS, FC, DO, EC, pH, and temperature. The samples were collected and stored in 500 ml plastic bottles and placed on ice in cooler boxes. The samples were carefully preserved and analysed according to Standard Methods [4]. The DO, EC, pH, and temperature were measured *in situ using HACH field testing kits.*

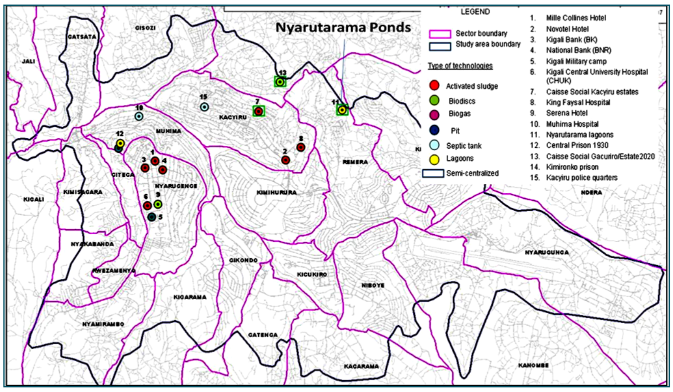

Fig. 1- Map of Kigali City showing the location of sewage treatment plants and the Nyarutarama Ponds

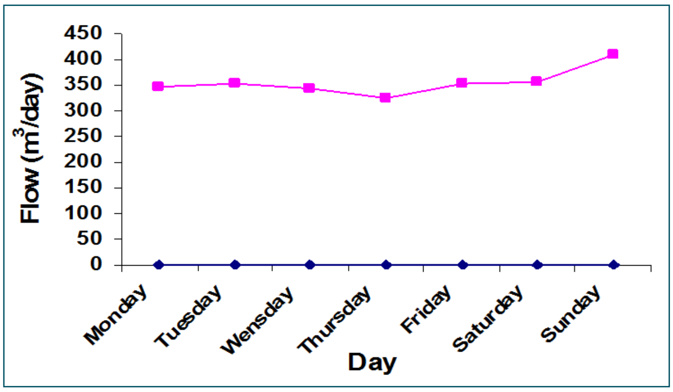

Fig. 3- Daily inflows at Nyarutarama Ponds as measured in October 2007

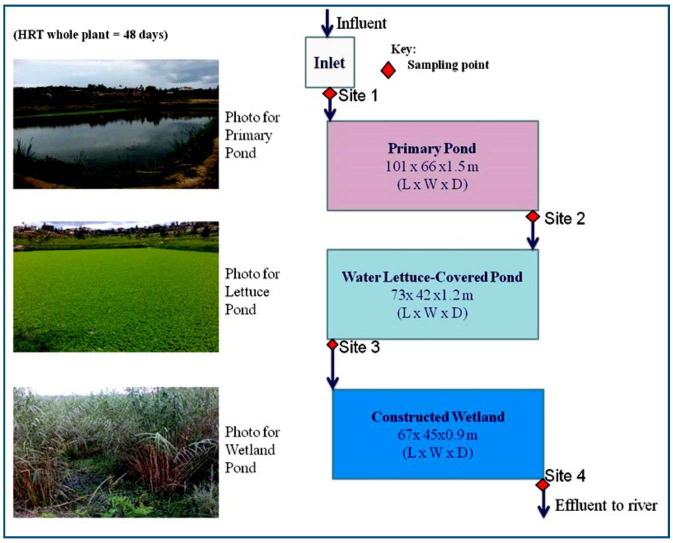

Fig. 2- Schematic diagram of the Nyarutarama Ponds, showing the layout, sampling points and some photos of the ponds.

Flow Measurement

The inflow to the ponds was determined by using a Parshall Flume. The head was measured continuously for one week at 30-minute intervals. The flow was calculated from Eq-1 for flow in a Parshall Flume as described by [5].

$$Q = Ch^n \quad (1)$$

where, Q = flow, m^3/s; C = a constant = 1.403; n = coefficient depending on shape, = 1.548; h = water head, m

Data Analysis

Data was analyzed for descriptive statistics using SPSS software in order to compare the removal efficiency of each unit. The results are presented in this paper as mean ± standard deviation. Results were compared with the Rwandan and European Union guidelines.

Result

Flow Measurement

The flow in the Nyarutarama Ponds was monitored for a week in October 2008 and the results showed a mean value of 355±6 m^3/d. Fig-3 shows the variation of flow in m^3/d during that particular week. The maximum flow was observed on Sunday and the minimum on Thursday and this was attributed to variations in household activities which peak over weekends when most people are at home.

Summary of Analytical Results

The experimental results for the physico-chemical and bacteriological analyses conducted in this study are summarised in Table-1.

Table 1- Mean values and (±) standards deviation of physico-chemical and bacteriological parameters monitored at Nyarutarama Ponds, July-October 2007

Parameter	Site1	Site 2	Site 3	Site 4
pH	7.5 ± 0.1	9.1 ± 0.7	9.7 ± 0.3	7.5 ± 0.2
Temperature (°C)	24.4 ± 0.4	25.2 ± 0.2	25 ± 0.3	24.3 ± 0.8
Conductivity (ms/cm)	919 ± 68	607 ± 44	528 ± 16	575 ± 32
BOD_5 (mg/L)	714 ± 457	140 ± 70	129 ± 43	38 ±14
COD (mg/L)	1181 ± 314	250 ± 65	231 ± 27	61 ± 12
NO_2-N (mg/L)	0.027 ± 0.007	0.035 ± 0.008	0.007 ± 0.001	0.006 ± 0.001
NO_3-N (mg/L)	15.3 ± 3.5	11.6 ± 6.2	2.9 ± 1.1	2.3 ± 0.9
NH_4-N (mg/L)	20.1 ± 6.0	11.7 ± 2.7	6.5 ± 5.9	3.0 ± 1.4
TN (mg/L)	35.4 ± 6.3	32.2 ± 9.7	36.0 ± 7.4	26.2 ± 3.7
TP (mg/L)	11.8 ± 2.3	5.6 ±1.2	7.6 ± 3.5	3.0 ± 0.9
TSS (mg/L)	526 ± 431.4	166.6 ± 120.7	207.0 ± 63.1	20.4 ± 8.9
Faecal coliforms *10^3 (cfu/100ml)	58 ± 19.4	16.8 ± 2.9	7 ± 2.3	2.3 ± 0.2

Field Measurements of pH, Temperature and Electrical Conductivity

The pH variations were observed during sampling along the pond systems, with the effluent having a pH value of more than 7. The standard deviation did not show substantial fluctuations in pH. Sites 2 and 3 had high values in comparison to Sites 1 and 4. This was expected since Ponds 2 and 3 were covered by floating aquatic plants and algae which would raise values of pH during the day due to photosynthetic activities. The mean temperature increased at Sites 2 and 3 due mainly to exposure to sunlight and decreased in the effluent with a mean of 24.3°C. The decrease was attributed to shading caused by the emergent plant species in the last pond. Electrical conductivity reduced by 85% in the final effluent. The comparison between EC results from Sites 3 and 4 showed an increase in Site 4. The unexpected increase in conductivity at Site 4 could be attributed to the concentration of wastewater after the loss of water through evapo-transpiration.

Total Suspended Solids

There were very high concentrations of TSS in raw sewage with very high fluctuations (526 ± 431) mg/L. In general, the third site showed higher concentration in TSS than in the second site and the fourth site. This is attributed to the nature of the pond which contains high levels of suspended organic matter. The results show a mean TSS removal of 95% and the mean concentration of effluent was 20±8.9 mg/L.

Organic Matter (COD and BOD_5)

The BOD_5 concentration decreased along the course of the ponds, as expected. The final effluent quality was 61±12 mg/L COD and 38±14 mg/L BOD_5. The higher standard deviations of ±314 mg/L for COD and ±456 mg/L for BOD_5 in comparison with the respective means were noticed in the settled sewage flowing into the first pond showing high variability in influent quality and the need for buffering. The overall percentage removal of BOD_5 and COD was 95%.

Nutrients

Total Nitrogen and Total Phosphorus

The total nitrogen removal followed the same pattern as that for total phosphorus. There seemed to be an increase in concentrations in the water lettuce-covered pond for both parameters, suggesting that the pond is retaining and accumulating nutrients. The mean effluent concentrations for TP and TN were 3.0 ± 0.9 mg/L and 26.2 ± 3.7 mg/L, respectively. The removal efficiencies for the same were respectively 83% and 25%, indicating poor plant performance, especially for TN. It is possible that the aquatic weeds cover could be fixing nitrogen from the air, or simply that there is not enough conditions for nitrogen removal (ammonia volatilisation and denitrification).

Ammonium, NH_4-N

Results for the mean concentration of ammonium-nitrogen show that the standard deviation was very high in the third site compared to other sites. This is attributed to changes in the environment (temperature) and ammonia volatilization and nitrification, which are related to changes in the pond coverage by the water lettuce. It was observed that there is no harvesting system for the macrophytes and sometimes the pond is completely covered whilst other times there is very little or no coverage. The overall mean percentage removal observed was 85% and the mean effluent concentration was 3.0 ± 1.4 mg/L.

Nitrate-Nitrogen (NO_3-N) and Nitrite Nitrogen (NO_2-N)

The increase in NO_2-N in the first pond shows that significant nitrification was taking place in this pond whilst in the subsequent ponds nitrification had decreased. However, this is not reflected by a corresponding increase in NO_3-N concentration in the same pond. The pond had different zones of septic areas and algae-covered open spaces. It is possible that this zonation allowed for both nitrification and denitrification to take place considering also that the hydraulic retention time in the pond was calculated at 28 days for the first pond.

Faecal Coliforms

The faecal coliforms were expressed in colony forming units per 100 ml. The coliform concentration were gradually decreasing until $5.7*10^3$, which is slightly more than 1,000 cfu/100ml recommended by WHO guidelines for restricted irrigation [6]. The mean removal efficiency for faecal coliforms was 96%.

Analysis of Characteristics of the Treatment Ponds

The details on the pollution loading of the treatment ponds including dimensions are shown in Table-2. This information is important for analysing the design and performance of the treatment systems and comparing this with other systems. The first part of the table gives general dimensions of the pond and characteristics of the flow. The second part gives, for each parameter, the nutrient loading as kg/d, the surface loading as kg/m²/d, the volumetric loading as kg/m³.d and the amount of pollution load produced by one person per day (unit load in g/cap.d. These are common design parameters in wastewater treatment [7].

Table 2- Derived design data on the dimensions and loading of the plant based on results from this study

		Primary Pond		Lettuce-covered Pond		Wetland-type Pond	
Daily flow, m³/d	355	HRT, d	28	HRT, d	10	HRT, d	7
Population, #	2800	Surface area, m²	6666	Surface area, m²	3066	Surface area, m²	2868
Unit flow, L/cap.d	127	Volume, m³	9999	Volume, m³	3679	Volume, m³	2580
		Depth, m	1.5	Depth, m	1.2	Depth, m	0.9

Parameter	Type of loading	Primary Pond	Lettuce-covered Pond	Wetland-type Pond
BOD_5	Load, kg/d	253	50	46
	Surface loading, kg/m².d	0.038	0.007	0.007
	Volumetric loading, kg/m³.d	0.025	0.005	0.005
	Unit load, g/cap.d	91		
COD	Load, kg/d	419	89	82
	Surface loading, kg/m².d	0.063	0.013	0.012
	Volumetric loading, kg/m³.d	0.042	0.009	0.008
	Unit load, g/cap.d	150		
TN	Load, kg/d	12	11	13
	Surface loading, kg/m².d	0.002	0.002	0.002
	Volumetric loading, kg/m³.d	0.001	0.001	0.001
	Unit load, g/cap.d	4.4		
TP	Load, kg/d	4	2	3
	Surface loading, kg/m².d	0.001	0	0
	Volumetric loading, kg/m³.d	0	0	0
	Unit load, g/cap.d	1.5		

Discussion

Flow Measurement

The Nyarutarama wastewater treatment system received 355 m^3/day of wastewater, resulting in an overall hydraulic retention time of 45 days. With a population of 2,800 and a surface area of 12,599 m^2, the pond area requirements are 4.5 m^2/person. Natural wastewater treatment plants normally use an HRT > 20 days and area requirements of 2–5 m^2/PE [7], indicating that the design of these ponds is within expected limits.

Performance of the Primary Pond

The removal efficiencies for the main sewage parameters from the primary pond are shown in Table-3.

Table 3- Mean values of main sewage parameters normally monitored at sewage treatment plants, showing removal efficiencies achieved in the primary pond at Nyarutarama

Parameter	Site 1	Site 2	Removal efficiency, %
Hydraulic retention time, d		28	
BOD_5 (mg/L)	714	140	80
COD (mg/L)	1181	250	79
TN (mg/L)	35	32.2	8
TP (mg/L)	11.8	5.6	53
TSS (mg/L)	526	166.6	68
Faecal coliforms $*10^3$ (cfu/100ml)	58	16.8	71

The raw wastewater contained a mean concentration of 526 mg/L TSS while the primary pond effluent was 166 mg/L with the mean percentage removal of 68 %. The BOD_5 decreased over the primary pond effluent from 714 ± 457 to 140 ± 70 mg/L. This reduction would be mainly due to anaerobic degradation and settlement in sludge formation. The COD also decreased. The mean BOD_5/COD ratio for the primary pond was 0.56 and this means that a greater portion of the COD could be removed by biological treatment. Similar studies conducted by [8] on these ponds gave the BOD_5/COD ratio of 0.45. The mean percentage removal of COD was 80%, which agrees with the design value for similar treatment units [9].

The total suspended solids removal in the primary pond showed a good removal efficiency of 68%. This could have been due to sufficient hydraulic retention time of 28 days which gives more time for settling. The phosphorus removal in the primary pond was modest, with a mean removal efficiency of 53%. Faecal coliforms were substantially reduced in the primary pond; the percentage removal was 71%. The die-off could be attributed to long hydraulic retention time which allows for enough time for pathogens to settle at the bottom of the pond and die off [8].

Performance of the Water Lettuce-covered Pond

The removal efficiencies in the water lettuce-covered pond for the main sewage parameters are shown in Table-4.

The mean pH was 9.7 ± 0.3. This was attributed to photosynthetic activities taking place during the day. Normally, in water lettuce-covered ponds; pH decreases with the retention time [10]. During the course of the study, water lettuce was harvested by municipal authorities and then left to decompose on the embankments, from where it was washed back into the pond. A dense cover of water lettuce on the water surface could be the factor inhibiting oxygen from entering the water by diffusion from the air and photosynthetic production of oxygen by phytoplankton because of the poor light penetration. The water lettuce-covered pond functions like an anaerobic digester: the reactions, which take place in the intermediate zone of the pond, produce gases. According to [10], these gases attach to the TSS and are lifted to the surface, or they are trapped by the roots. BOD_5 removal decreases in ponds covered with water lettuce because of the limited oxygen transfer into the water. It increases with the concentration of nitrogen and can be hampered by a shortage of nitrogen. According to [10], the water hyacinth growth is optimal for N/P ratio comprised between 2.3 and 5. In Nyarutarama ponds, the N/P ratio was 8.4. The negative removal efficiencies are due to the loss of water via evapotranspiration.

Table 4- Mean values of main sewage parameters normally monitored at sewage treatment plants, showing average removal efficiencies achieved in the water lettuce-covered pond at Nyarutarama

Parameter	Site 2	Site 3	Removal efficiency, %
Hydraulic retention time, d		10	
BOD_5 (mg/L)	140	129	8
COD (mg/L)	250	231	8
TN (mg/L)	32.2	36	-12
TP (mg/L)	5.6	7.6	-36
TSS (mg/L)	166.6	207	-24
Faecal coliforms $*10^3$ (cfu/100ml)	16.8	7	58

Performance of the Constructed Wetland

The removal efficiencies for the main sewage parameters for the constructed wetland are shown in Table-5.

Table 5- Mean values of main sewage parameters monitored at sewage treatment plants, showing removal efficiencies achieved in the constructed wetland at Nyarutarama

Parameter	Site 3	Site 4	Removal efficiency, %
Hydraulic retention time, d		7	
BOD_5 (mg/L)	129	38	70
COD (mg/L)	231	61	73
TN (mg/L)	36	26.2	27
TP (mg/L)	7.6	3	60
TSS (mg/L)	207	20.4	90
Faecal coliforms $*10^3$ (cfu/100ml)	7	2.3	67

The passage of wastewater through the constructed wetland resulted in considerable improvement in water quality. The high TSS, nutrients and organic matter removal achieved by the third pond was consistent with reports for other constructed wetlands in literature [11]. A high reduction of faecal coliforms is normal for constructed wetlands, and nitrogen removal in this pond was also comparable with other wetlands [11]. The results from this study are in agreement with results reported in literature for TSS and phosphorus removal [14]. Nitrogen removal efficiency is within normal range [Table-6], although it seems there is an accumulation of organic material in the pond with the bulk of the nitrogen in particulate form.

The removal of faecal coliforms in the water lettuce system and in the constructed wetland should be due to sedimentation at the bottom of the ponds and photo oxidation as explained by Bolton and Greenway [1]. The mean percentage removal of 96% agrees with information in literature e.g. [11-13].

Overall Performance of the Nyarutarama Ponds

Table-7 shows the overall removal efficiency for the main sewage parameters normally monitored at sewage treatment plants. It also compares the final effluent with guidelines for discharge into a river or for irrigation.

Table 6- Percentage reduction and expected effluent concentration for common contaminants in constructed wetland compared to Nyarutarama pond effluents.

Parameter	Literature		Nyarutarama Ponds	
	Expected Removal Efficiency	Expected effluent Concentration	Removal Efficiency at Nyarutarama	Effluent Quality at Nyarutarama
BOD_5	70-90%		95%	38 mg/L
TSS	51-98%	37-64 mg/L	90%	20.4 mg/L
Nitrogen	12-96%	6.3-30 mg/L	27%	26.2 mg/L
Phosphorus	12-91%	0.5-9.6 mg/L	83%	3 mg/L

Source: Crites, et al [14]

The overall removal efficiency for the main sewage monitoring parameters was satisfied except for the TN, which is very low (25%). Since NO_2-N and NH_4-N are low and TN is high, it is deduced that the bulk of the nitrogen is from suspended organic matter. The poor removal efficiency could also be due to the large population of ducks and other perching birds living in the constructed wetland. These could increase the organic nitrogen through their faecal droppings into the pond [8,11]. The Rwandan guidelines for effluent discharge into a river are fairly new but it is shown in Table 7 that these are all met for the parameters studied. However, it should be noted that these guideline values are very conservative than the ones used in other countries [11]. Table-8 shows a comparison of the performance of the Nyarutarama Ponds to literature figures and it indicates that, overall, the performance is within expectations.

Table 7- Overall-removal efficiency of main sewage parameters at Nyarutarama as normally monitored at sewage treatment plants, and comparison of effluent quality with relevant guidelines

Parameter	Influent Site 1	Effluent Site 4	Overall removal efficiency	Allowable limit for effluent discharge into river in Rwanda *
BOD_5 (mg/L)	714	38	95%	50
COD (mg/L)	1,181	61	95%	400
TN (mg/L)	35	26.2	25%	30
TP (mg/L)	11.8	3	83%	5
TSS (mg/L)	526	20.4	96%	50
Faecal coliforms $*10^3$ (cfu/100ml)	58	2.3	96%	400

**Source: Directives on Minimum Requirements for Liquid Waste Disposal and Treatment, 2009*

Table 8- Treatment efficiency of Constructed Wetlands for various types of wastewater and configurations

	Removal efficiencies, %				
Cases	This study	Case 1[a]	Case 2[b]	Case 3[c]	Case 4[d]
Parameter	Downstream of facultative pond	Downstream of facultative pond	Metallurgical industry effluent	Treatment of storm-water	General literature figures
NH_3-N, mg/L	77	-38.2	-49		
Org-N, mg/L		89.9			
NO_3-N + NO_2-N, mg/L		51.5	60-70	22	
TKN, mg/L		56.4		9	81
TN, mg/L	25	56.2		16	30-90
BOD_5 , mg/L	95	82.2	77		60-96
COD, mg/L	95		78		91.5
TP, mg/L	83			12	78.5
TSS, mg/L	96	91.5		9-46	89.5
FC (CFU/100ml)	67	99.96		76	79-99.93

[d]Source: Bastian & Hammer [18]; Reed and Brown [9]; Reed et al [20].

The Nyarutarama Pond system shows a greater potential as a viable system for sewage treatment. Pollutant removal could be enhanced by proper management to control optimal harvesting, maintaining macrophyte surface coverage, frequent desludging to reduce accumulation of pollutants, etc. Nitrogen removal could be improved by promoting separate zones for oxidation, ammonia volatilisation, and denitrification. A further study on nitrogen transformations in such a system is therefore greatly recommended. The treatment plant should be properly fenced and manned by an attendant. This would prevent outside interference from pedestrians, children and animal grazing. A private company or an individual could be assigned to carry out regular maintenance. At the time of the study there was hardly anyone responsible for this

Conclusions

From the results of this study, the following conclusions were drawn:

- For the following parameters: BOD_5, COD, TN, TP, TSS and Faecal coliforms the effluent met the Rwandan standards for effluent discharge into a river and the FAO effluent reuse in agriculture, despite low removal efficiency for total nitrogen which stood at 25%.
- Removal efficiency of each pond is mainly moderate for almost all parameters except total nitrogen.
- The water-lettuce coverage pond showed poor removal efficiency for total nitrogen, total phosphorus and total suspended solid.

Recommendations

To ensure a reliable and sustainable management of Nyarutarama Ponds, the following actions are recommended:

- The management of the ponds could be contracted out to ensure proper maintenance and operation of the ponds and their surroundings.
- Installation of a system of removing screening and grit at inlet from the preliminary treatment processes in order to reduce the quantity of sludge accumulated in the primary pond and to protect the Parshall Flume.
- Regular desludging and proper management of macrophytes coverage, including an optimal macrophyte harvesting regime,

is required to ensure their optimal growth and improved pollutant removal efficiency.

- Checking effluent quality regularly by routine analysis of key parameters, which are harmful to environment especially faecal coliforms, nutrients, chemical and biochemical oxygen demand.

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Conflicts of Interest: None declared.

References

[1] Cisneros B.J. (2011) *Treatise on Water Science*, 4, 147-200.

[2] WHO/UNICEF (2013) *Progress on Sanitation and Drinking-water*, WHO Press, Geneva, Switzerland.

[3] National Institute of Statistic of Rwanda (2012) *The third Integrated Household Living Conditions Survey*, Main indicators report, Kigali, Rwanda.

[4] American Public Health Association (2005) *Standard Methods for the Examination of Water and Wastewater*, 25th ed., Washington, DC, USA.

[5] USBR-US Bureau of Reclamation (2001) *Water Measurement Manual - A Guide to Effective Water Measurement Practices for Better Water Management*, United States Department of Interior, Bureau of Reclamation, 3rd ed., Denver, Colorado.

[6] Blumenthal U.J., Mara D.D., Peasey A., Ruiz-Palacios G. and Stott R. (2000) *Bulletin of the World Health Organization*, 78(9), 1104-1116.

[7] Metcalf I.N.C. (2003) *Wastewater Engineering: Treatment and Reuse*,- McGraw-Hill.

[8] Rwasana J. (2006) *Study of diagnosis, management and rehabilitation of the wastewater treatment plant at Nyarutarama (Rwanda)*, MSc Thesis, National School of Engineers of Water and Environment, Strasbourg, France.

[9] Reed S.C. and Brown D.S. (1992) *Water Environment Research*, 64(6), 776-781.

[10] Koné A. (2002) *Epuration des eaux usées par lagunage à microphytes et a macrophytes en Afrique de l'Ouest et du Centre : Etat des lieux, performances epuratoires et criteres de Dimensionnement*, École Polytechnique Fédérale de Lausanne, Thèse de Doctorat, Lausanne, Suisse.

[11] Bolton K.G.E. and Greenway M. (1999) *Water Science and Technology*, 39, 199-206.

[12] Birks R. and Hills S. (2007) *Environ. Monit. Assess*., 129, 61-69.

[13] Ghunmi L.A., Zeeman G., van Lier J. and Fayyed M. (2008) *Water Science and Technology*, 58(7), 1385-1396.

[14] Crites R.W. (2006) *Natural Wastewater Treatment Systems*, Taylor and Francis Group, UK.

[15] Senzia M., Mashauri D. and Mayo A. (2003) *Physics and Chemistry of the Earth*, 28(20), 1117-1124.

[16] Maine M., Sune N., Hadad H., Sánchez G. & Bonetto C. (2006) *Ecological Engineering*, 26(4), 341-347.

[17] Birch G.F., Matthai C., Fazeli M.S. & Suh J.Y. (2004) *Wetlands*, 24(2), 459-466.

[18] Bastian R. & Hammer D. (1993) *Constructed wetlands for water quality improvement*, CRC Press, Boca Raton, Florida, 59-65.

[19] Kemp M.C. & George D.B. (1997) *Water Environment Research*, 69(7), 1254-1262.

[20] Reed R.C., Middlebrooks E.J. & Crites R.W. (1995) *Natural Systems for Waste Management and Treatment*, McGraw-Hill, New York, USA.