IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 4 (April. 2018), ||VIII|| PP 73-80

Performance Evaluation of Waste Stabilization Ponds in Mwanza City, Tanzania

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Abstract: - The objective of the study was to evaluate the performance of the waste stabilization ponds in treating domestic wastewater in Mwanza city. The studied parameters included BOD_5, COD, pathogen reduction, Total Suspended Solids (TSS), pH, dissolved oxygen (DO) and temperature. Data on the concentration of these parameters at the influent and effluent of the ponds were collected from MWAUWASA[1] office. Then the removal efficiencies of BOD_5, COD, TSS and pathogen reduction were calculated. Concentrations of BOD_5, COD, TSS and pathogen reduction in the influent and final effluent were 357mg/l, 652mg/l, 324mg/l and cfu5800/100 and 27mg/l, 47mg/l, 72mg/l and cfu100/100 ml respectively. This represents removal efficiency of 92.43% (BOD_5), 92.80% (COD), 77.77% (TSS), and 98.30% (pathogens) respectively. The wastewater temperature in anaerobic ponds (influent) was 27.5^0C. In maturation ponds (effluent) temperature was 23.5 ºC. pH values were 7.4 at the raw influent and 8.4 in the final effluent. Concentration of dissolved oxygen (DO) was 9.6mg/l in the influent (anaerobic pond), and 50.4 mg/L in the final effluent (maturation ponds). The effluent that is discharged from the WSP to receiving water body (this case - Lake Victoria) meets the recommended standards by Tanzanian Bureau of Standards (TBS).

Key words: Domestic wastewater, Mwanza, removal efficiency, waste stabilization ponds.

Date of Submission: 23-04-2018 Date of acceptance: 11-05-2018

I. INTRODUCTION

WSPs are regarded as the method of first choice for treatment of municipal wastewater in tropical and sub-tropical countries. Mwanza city in Tanzania experiences a tropical climate. In the city of Mwanza the collected wastewater (sewage) is treated in waste stabilization ponds (WSPs) before being discharged into receiving water body-Lake Victoria. This paper evaluates the performance efficiency of waste stabilization pond system in Mwanza. The performance of WSP ponds was judged by the removal of BOD, COD, Total Suspended Solids (TSS), and pathogen reduction. These parameters were studied at anaerobic pond influent and maturation pond effluent. They were studied since for domestic wastewater treatment, these are pollutants of most concern [1]. According to [2] these parameters are useful indicators of the performance of WSP system. Other parameters studied were pH, dissolved oxygen (DO) and temperature. These are environmental parameters that affect growth of the bacteria groups involved in waste stabilization ponds. Most bacteria grow well in the temperature range 15–40^0C. Most bacteria prefer near neutral or slightly alkaline conditions, around pH 6.5–8.5; some can tolerate pH >9. Some bacteria can only grow in the presence of oxygen (the 'obligate aerobes'); some can only grow in its absence – the ('obligate anaerobes'); and some can grow in both its presence and in its absence, although growth is better in its presence (facultative bacteria). Therefore studying the treatment performance of the wastewater stabilization ponds can provide baseline information regarding the quality of the effluent on the receiving water body/Lake Victoria which will assist in putting in place the necessary corrective measures to prevent pollution to the Lake. The final effluent quality of the studied parameters is compared with TBS standards for municipal wastewater effluent quality.

[1] MWAUWASA has overall responsibility for Mwanza urban water, providing water supply and sewerage services in Mwanza City

II. LITERATURE REVIEW

[3] describe WSP as large shallow basins enclosed by earthen embankments in which wastewater is biologically treated by natural processes involving pond algae and bacteria WSP systems comprise a single string of anaerobic, facultative and maturation ponds in series, in which there is a continuous in and out flow of wastewater.

Anaerobic ponds are commonly 2 – 5 m deep and receive wastewater with high organic loads (i.e., usually greater than 100 g BOD/m^3.day), rely totally on anaerobic digestion to achieve organic removal. The process of anaerobic digestion is more intense at temperatures above 15^{o}C [4]. The anaerobic bacteria are usually sensitive to pH <6.2. A properly-designed anaerobic pond will achieve about 40% removal of BOD at 10^o C, and more than 60% at 20^o C. A shorter retention time of 1.0 - 1.5 days is commonly used [5]

Facultative ponds are designed for BOD removal on the basis of a relatively low surface loading (100 – 400 kg BOD/ha. day), the facultative pond relies on naturally-growing algae and BOD removal by the pond bacteria is generated primarily via algal photosynthesis. According to [6] about 70 – 90% of the BOD of the final effluent from a series of well-designed WSPs is related to the algae they contain. Facultative ponds are usually 1.5-2.5 m deep. The Hydraulic Retention Time (HRT) for ponds treating anaerobic effluent varies between 5 and 30 days. Effluent BOD value ranges from 20 to 60 mg/L, while TSS levels vary from 30 to 150 mg/L [7] ; [8].

The maturation ponds (1 to 1.5 m deep) receive the effluent from the facultative ponds and are required only when stronger wastewaters (BOD_5 > 150 mg L^-1) are to be treated prior to surface water discharge [9]. The primary function of maturation ponds is the removal of excreted pathogens. Pathogens die off due to the high temperature, high pH or radiation of the sun leading to solar disinfection [10].

2.1 Arrangement of WSP

The different WSP types are arranged in a series – first an anaerobic pond, then a facultative pond, and finally one or more maturation ponds (Figure 1). At any one site there may be more than one series of WSP, each usually receiving an equal proportion of the wastewater flow. Mara [11] stated that the effluent from a series of ponds is of better quality than that from a single pond of the same size.

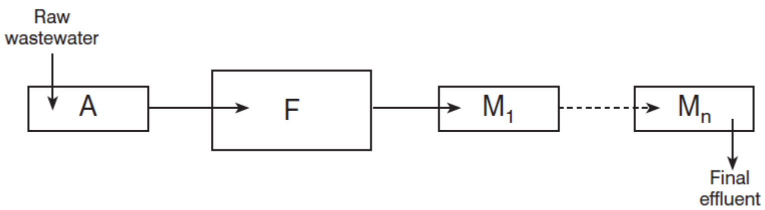


Figure 1.Typical WSP Layout: A, anaerobic pond; F, facultative pond; M_1–M_n, maturation ponds (Source, Mara D.D, 2004)

2.2 Performance of WSPs

[12] describes that for domestic wastewater treatment, the pollutants of most concern are biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), and indicators-(total Coliforms or fecal Coliforms). In the European Union, pond effluents have to meet the same BOD requirement as other effluents (<25 mg/L) but with one very important difference: filtered samples are used to determine the BOD. Furthermore in the EU pond effluents can contain up to 150 mg TSS per litre, whereas effluents from other treatment processes can contain only 35 mg TSS/L [16] . In Tanzania permissible limits for municipal wastewater discharge into receiving water bodies are: 30 mg/L for BOD, 100 mg/L for total suspended solids, 10,000counts/100m pathogen removal 20-35^{0}C for temperature and 6.5-8.5 for pH.

Table 1 presents removal efficiency, detention time and area requirement for waste stabilization pond, whereas, table 2 shows concentration and percentage of reduction values of BOD_5, COD and TSS requirements for discharges from urban wastewater treatment plants as per Tanzania Bureau of Standards (TBS) and EWURA[2] guideline [15]

[2] Energy and Water Utilities Regulatory Authority (EWURA) monitors water quality and standards of performance for the provision of water supply and sanitation services in Tanzania.

Table 1. Removal efficiency, detention time and area requirement for waste stabilization pond

Pond	BOD Removal (%)	Pathogen Removal (%)	Detention Time(days)	Area requirement (m^2)
Anaerobic	50-85		2-5	2,000-8,000
Facultative	80-95		5-30	8,000-40,000
Maturation	60-80	90	15-20	8,000-40,000

(Source: [13]

Table 2. Requirements for discharges from urban wastewater treatment plants: Concentration and percentage of reduction values of BOD_5, COD and TSS.

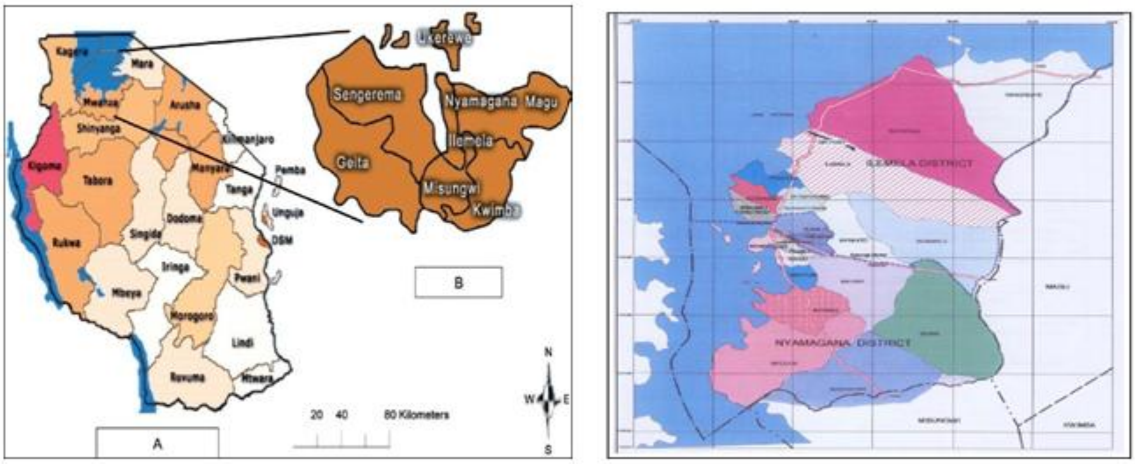
Parameter	Concentration (mg/l)	Minimum percentage of values
BOD_5	30 mg/L	**70-90**
COD	60 mg/L	**75**
Pathogen removal(cfu/100)	10,000counts/100mL	**90%**
TSS	100 mg/L	**90**

(Source: [14]; [15]

III. METHODOLOGY

3.1 Description of the study area

The present study was conducted in Mwanza city (Latitude 2° 31' 0.01"S and Longitude 32° 53' 60"E) that is located on the shores of Lake Victoria in Northern Tanzania. Mwanza City, the second largest city in Tanzania after Dar -es Salaam and is the capital of Mwanza region one of the fastest developing urban centers in Sub-Saharan Africa. It covers an area of 1,337 square km out of these 71.55 km^2 (28%) is covered by water and the remaining 184.9 km^2 (72%) is dry land. According to the 2012 Tanzanian national census Mwanza City is composed of two administrative districts namely; Nyamagana and Ilemela with a total population of 706,453. The 2012 census shows annual population growth rates of 5.5 for Nyamagana and 2.6 for Ilemela between 2002 and 2012.The City has 27 administrative wards of which 18 are from Nyamagana district and 9 are from Ilemela district. The wards are subdivided in 210 sub-wards (110 for Nyamagana and 100 Ilemela). Figure 2 shows the location of Mwanza and its districts Nyamagana and Ilemela and ward boundaries



. **Figure 2. Map of Tanzania showing the location of Mwanza and its districts Nyamagana and Ilemela and ward boundaries**

3.2 Waste Stabilization Ponds in Mwanza

The studied waste stabilization pond system is located 7 km to the East of Mwanza city in Batuja sub-ward in Ilemela district. At the time of this study the system was receiving a flow of 5000 m^3/day which was less than the expected design of 5750m^3/d. It comprises three (3) anaerobic ponds in parallel located as the first waste stabilization pond unit immediately downstream of the screen and grit chamber. Anaerobic ponds with retention time of 1 .5 day (36hrs) are followed by four (4) facultative ponds (retention time 14 days) and six (6) maturation ponds (7 days retention time) in series. The system has a total of 13 ponds. In addition there is one septage lagoon and 26 sludge drying beds each with a dimension of 26.6m x 10.2m. The schematic layout of the WSP system in Mwanza is shown in Figure 3.

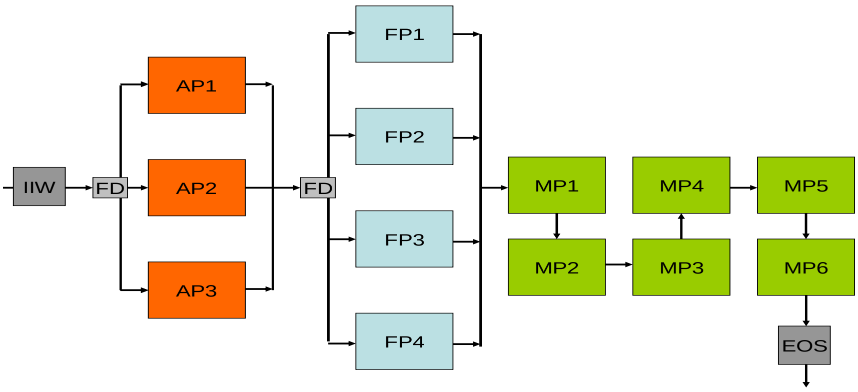


Figure 3. Schematic flow and layout of the Mwanza Waste Stabilization Ponds: AP, anaerobic pond; PF, facultative pond; MP, maturation pond; WSP, waste stabilization pond

3.3 Data Collection

Qualitative research methods of data collection were employed in gathering required data and information for this study. These methods include interviews with MWAUWASA key informants, field site visits, and archive information.

3.3.1 Interviews

Face to face semi-structured interviews were conducted with Sewerage engineer and senior technician officer from MWAUWASA. Sewerage engineer is an overall in charge of sewerage services including WSP, whereas, senior technician officer is responsible for daily operation and maintenance of the ponds. The interview with sewerage engineer was aimed at obtaining data on the concentration of performance parameters of interest (BOD_5 COD, TSS, pathogen, pH, DO and temperature) in this study at the influent raw wastewater and maturation pond effluent. From these data removal efficiencies were calculated. In addition checklist was prepared to establish information on the specifications of WSP. Interviews also provided information on collection and preliminary wastewater treatment before being discharged to WSP.

3.3.2 Field visit

Field visit was undertaken with senior technician officer with MWAUWASA during preliminary survey in the study area to observe mainly the arrangement, layout and physical features of the pond system.

3.3.3 Archive data

Secondary data were collected through review of the related documents from different sources including books, journals and reports. Some of the documents reviewed included: Tanzanian Bureau of Standards, National Environmental Compendium [14] and Water and Wastewater Quality Monitoring Guidelines for Water Utilities [15]. Archive information obtained from these reports complemented information collected from primary data.

3.3.4 Removal efficiency calculation

After knowing the inlet and outlet concentration of the studied parameters the removal efficiency for these parameters were calculated by using the following formula [16]

Efficiency (%) = $(C_{in} – C_{eff})/ C_{in} * 100$

Where;

C_{in} is the concentration of the waste material in the influent

C_{eff} is the concentration of the waste material in the effluent

IV. RESULTS AND DISCUSSIONS

4.1 Wastewater collection

Wastewater services in the districts of Nyamagana and Ilemela in Mwanza city falls under the mandate of Mwanza Urban Water Supply and Sanitation Authority (MWAUWASA). MWAUWASA was established to ensure that wastewater is treated to meet Tanzanian effluent standard before disposal into the receiving water body, and to develop and carry out proper maintenance of all infrastructures connected with water supply and sewerage service. Thus wastewater collection from all urban households in Mwanza falls under the mandate of MWAUWASA but only those connected to a cesspit, septic tank or sewerage pipe. According to MWAUWASA sewerage engineer 4100 people are connected to central sewerage system, which is located along airport road, Mwanza-Musoma road and Mwanza Shinyanga road. Areas connected to sewerage system include: Igogo, Pasiansi, Mabatini, Kirumba, Katangiri, Kilimahewa, Mwaloni, Isamilo, and city center. Wastewater from these areas ends up into WSP.

The wastewater from housing units connected to the city's sewer system flows by gravity and by pumping to the primary treatment units located at central pumping station in Nyamagana by two (2) sewers of 600mm and 560mm respectively. Wastewater from Mabatini, Kirumba, Igogo, Mwaloni, Isamilo, and city center is collected using one pipe of 600 mm and flows by pumping and gravity, while the other pipe of 560mm size conveys wastewater from Pasiansi, Nyamanoro, Kilimahewa, Kirumba, Kitangiri, and Kilimahewa.

4.2 Wastewater treatment in WSP

Prior to treatment in the WSPs, the wastewater is first subjected to physical treatment to remove coarse material and suspended solids which may otherwise clog the pumps and floating materials accumulating on the surface of waste stabilization ponds and heavy solids entering the pond sludge layer. Collected wastewater is led through a grid which retains the large particles. Such a grid consists of parallel bars with a mutual distance of about 40mm, inclined to the horizontal at 60^0. From screening stage wastewater flows into a grit removal longitudinal chamber with sloping bottom provided prior to sedimentation tank. The purpose of inclusion of grit channels in physical treatment is to differentially remove grit. These materials are removed to allow efficient pumping of effluents and to prevent clogging of pumping system.

Wastewater from the grit chamber **is** pumped in a 750mm diameter PVC pipeline to a manhole inserted at Pasiansi in Ilemela district about 4.1 km from the central pumping station. The elevation of the inlet works at this manhole is 70m. From Pasiansi wastewater flows 2 km by gravity in a diameter 750mm pipe to the inlet works of anaerobic WSP. Three anaerobic ponds are operated at a time. The septage lagoon treat wastewater from septic tanks collected from houses which are not connected to the main sewer. Wastewater is transported to the lagoons by vacuum tankers. As reported by MWAUWASA sewerage engineer about $280m^3$ of wastewater is transported weekly by vacuum trucks (two trucks with a capacity of $10m^3$ –i.e average of 28 trips weekly). Effluent from septage lagoons joins effluent from anaerobic ponds. Consequently, facultative ponds treat effluent from anaerobic ponds and septage lagoons. Effluent from facultative pond flows to maturation ponds. The final effluent from maturation ponds is discharged into Lake Victoria, which is being used as the principal source of water supply to Mwanza and other neighbouring regions. Specifications of the Mwanza WSP systems are presented in table 3**.**

Table 3. Specifications of the pond systems at Mwanza WSP

Pond	Length bottom (m)	Wide bottom (m)	Length top water level (m)	Wide top water level (m)	Depth water (m)	Water volume (m^3)
AP1	37.5	37.5	59.1	59,1	3.75	4,881
AP2	37.5	37.5	58.5	58.5	3.75	4,775
AP3	37.5	37.5	57.9	57.9	3.75	4,671
FP1	86.0	58.8	100.0	68.9	1.75	6,728
FP2	86.6	59.9	100.4	70.0	1.75	6,822
FP3	90.0	59.6	103.6	69.6	1.75	7,012
FP4	89.5	59.2	103.6	69.1	1.75	6,978
MP1	74.5	52.2	83.0	60.7	1.40	4,666
MP2	74.4	47.1	84.3	57.0	1.40	4,378
MP3	72.3	48.2	81.9	57.9	1.40	4,330

MP4	72.6	49.2	82.1	58.6	1.40	4,408
MP5	72.8	50.2	82.4	59.8	1.40	4,513
MP6	72.4	49.5	81.9	59.0	1.40	4,424
Total						68,585

4.3 Efficiency Removal of studied parameters (pollutants) in WSP

Table 4 shows the values and calculated removal percentage of Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and pathogens. BOD_5 at the influent of anaerobic pond was 357 mg/l and 27 mg/l at maturation pond effluent. This represents 92.43% removal efficiency in the maturation ponds. The satisfactory BOD removal performance can be attributed to the higher hydraulic retention time (HRT) applied. The COD at the influent was 652mg/l and 47 mg/ at the effluent. This represents 92.80% removal efficiency. When effluents with high concentrations of BOD are discharged into the natural water body, they can cause depletion of natural oxygen resources which may lead to septic conditions. A study by [17] indicates that it is uncommon to obtain better than 90% BOD removal in waste stabilization. Therefore findings in this current study suggest that the WSP system at Mwanza is very effective in the removal of BOD.

The total suspended solid (TSS) at the effluent (maturation pond) was 72 mg/l lower than that of influent or anaerobic pond of 324 mg/L. The outlet value is within the TBS standard of 30 mg/L. The high TSS concentrations of the influents of the anaerobic ponds can be attributed to the high TSS levels of the raw sewage. The reduced TSS levels at the outlet could be attributed to the removal efficiency through the sedimentation of solids. TSS removal of 77.77% observed in the study implies that the WSP is efficient in ensuring that impact of effluents at the receiving water body –Lake Victoria is reduced and that the users of Lake Victoria are safeguarded. The high TSS reduction efficiency demonstrates that the WSP systems at Mwanza are efficient in reducing TSS Discharge of effluents with high levels of suspended solids into aquatic bodies lowers water quality and depletes dissolved oxygen available for aquatic life.

The pathogen level of the raw sewage is 58000 counts/100 ml while that of the final pond effluent was 100 counts/100 ml; representing removal efficiency of 98.30%. The concentration of the pathogens of the final effluent is very low compared to the recommended guideline value of 1000 counts/100 ml. This indicates that the final pond effluent can be discharged into the natural environment without posing threat to humans and the ecosystem in general. Effluents with high concentrations of pathogens have high potential of endangering public health.

Table 4. The removal efficiencies of the studied parameters (BOD_5: Biochemical Oxygen Demand ; COD: Chemical Oxygen Demand; TSS: Total Suspended Solids and Pathogens) in the stabilization pond

Parameter	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)
BOD5	357	27	92.43
COD	652	47	92.80
TSS	324	72	77.77
Pathogens	5800	100	98.30

pH, Temperature and DO levels

Results presented in table 5 indicate values of pH, temperature and dissolved oxygen at influent and effluent of the WSP system.

Table 5. pH, temperature and dissolved oxygen levels

Parameters	Influent	Effluent
pH	8.4	7.4
Dissolved oxygen(DO) mg/l	9.6	50.4
Temperature (^{0}C)	27.5	23.5

The wastewater temperature in anaerobic ponds (influent) was 27.5^{0}C and 23.5 ºC in the last maturation ponds (effluent). The wastewater temperature decreases in maturation ponds this due to the higher evaporation rate from the surface of the ponds which accomplished with higher latent heat.

This study shows that pH values were 7.4 at the raw influent and 8.4 in the final effluent. The pH of the maturation ponds is higher than that of the anaerobic ponds. It is common to find variations in pH in WSP systems. Maturation ponds usually have high pH which aid in the pathogen die-off mechanism. [18] reports that diurnal pH changes in WSP, and indicate that increase in pH up to 11 is common in WSPs, with highest pH levels usually reached during the late afternoon. The increased pH value in maturation ponds is due to rapid photosynthesis by the pond algae, which consumes carbon dioxide (CO_2) faster than it can be replaced by bacterial respiration; as a result carbonate and bicarbonate ions dissociate. Algae fix the resulting CO_2 from the dissociation while hydroxyl ions (OH) accumulate so raising the pH value. Similar results were found by [19].

For the case of dissolved oxygen (DO) the concentration was 9.6mg/l in the influent (anaerobic pond), and 50.4 mg/L in the final effluent (maturation ponds). Low values of DO in influent(anaerobic pond) can be attributed to the fact that anaerobic ponds are usually deep(3.75m) and receive wastewater with high organic loads and rely totally on anaerobic digestion(absence of oxygen) to achieve organic removal. According to [20].anaerobic ponds normally do not contain dissolved oxygen (DO) or algae. A great enhancement in DO concentration in maturation pond can be attributed to the occurring reduction of BOD_5 load, algal oxygen production, and transformation of oxygen from air through the ponds surface.

High value in effluent (maturation pond) could be due to higher rate of photosynthesis in these ponds. During this process algal cells generate oxygen which is utilized by bacteria. These processes all lead to the efficient mineralization of organic matter translating into lowered BOD and inactivation of microorganisms. But values of the dissolved oxygen concentration in the effluent provide little useful information on pond performance, since they are altered substantially by oxygen exchange between the effluent and the atmosphere during the turbulent exit of the effluent from the pond (Mara and Pearson, 1986).

V. CONCLUSION

Some parameters (Temperature, pH, DO, BOD_5, pathogens and TSS) that play a key role in waste stabilization ponds performance were studied. Waste stabilization ponds system in Mwanza was found to be performing well regarding the studied parameters. The findings of this study were within the allowable limits by TBS, subsequently ensuring protection of receiving water body- Lake Victoria.

The average BOD_5 at inlet and outlet were 357 and 27mg/l respectively, the BOD_5 removal meet the Tanzania Standard of 30mg/l. This suggests that the pond system is working properly. The BOD_5 removal efficiency was 92.43%. Average pathogen in influent was 5800 count/100ml and effluent was 100 count/100ml respectively, the pathogen removal is within Tanzania standard. The average pathogen removal efficiency is determined to be 98.30%. The concentration of the faecal coliforms of the final effluent is very low compared to the recommended TBS guideline value of 10,000 counts/100 ml. This indicates that the final pond effluent discharged into Lake Victoria does not pose threat to humans and the ecosystem in general. TSS at inlet, and outlet were 324mg/l and 72mg/l. The calculated removal efficiency of T.S.S was 77.77%.

Other wastewater parameters (temperature, pH, and DO) of the final pond effluent compare well with their respective recommended values laid down by TBS. Hence Mwanza waste stabilization pond system provides a useful method for treating and disposing wastewater and therefore should be regarded as a method of choice for treating wastewater elsewhere in Tanzania.

ACKNOWLEDGMENT

The author extends her acknowledgement to the wastewater engineer of MWAUWASA Mr. Saidi Lusindilo and senior technician with MWAUWASA all those who participated in one way or another. Their support is highly appreciated. I thank the entire management of MWAUWASA for allowing me to use the data available to evaluate performance of WSP.

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