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Performance Analysis of Anaerobic Baffled Reactor and Constructed Wetland for Community Based Wastewater in Dar Es Salam, Tanzania

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***Abstract*— *The treatment performance of community based (decentralized) wastewater treatment systems are not monitored by municipalities in Tanzania and therefore these systems pose pollution threat to receiving water bodies. The aim of this research is to assess and compare the treatment performance of existing community based technologies which are affordable, manageable and climate compatible in Tanzania. The selected existing decentralized technologies for this study were Anaerobic Baffled Reactor (ABR) found in Kigamboni, Dar es Salaam and Constructed Wetland (CW) found in Mbagala, Dar es Salaam. Wastewater samples in and out of these systems were collected and analyzed for physical, chemical and biological parameters. The observed average effluent concentration of BOD_5 (67.5, 90 mg/L), NH_3-N (276.6, 115.7 mg/L), PO_4-P (13.2, 17.7 mg/L) and FC (9 $x10^6$, $4.2x10^6$ counts/100mL) in ABR and CW, respectively testified to an inferior standard of treatment caused by mismanaged operation and maintenance. Both ABR and CW with slight adjustment were found to be effective in removal of all physical, chemical and biological parameters.*
***Keywords*— Community, wastewater, treatment, baffled reactor, Constructed wetland.**

I. INTRODUCTION

Selection of a proper wastewater technology and infrastructure is a daunting challenge and continue to be a priority issues in developing countries especially in Tanzania. The wastewater management proposed for the new city of Kigamboni is the centralized model by using Membrane BioReactor (MBR) technology for wastewater treatment (Hakiardhi, 2012; URT, 2010). The proposed technology is widely used in developed countries but not in Africa. In Africa, MBR is only available in cape Town, South Africa and in Casablanca, Morocco (Judd, 2015; Singhirunnusorn, 2009). However, research shows that, for developing countries centralized, mechanical wastewater treatment options like MBR are not highly recommended, in some places many such plants have been neglected. As an example in Mexico more than 90% of the centralized systems were not functional (Flores *et al*., 2009). The reasons behind neglect the treatment plants were related to failure of government to provide necessary operation and maintenance requirement. The selected technologies were not sustainable, sustainability in this context is not only that, the technology should be economical but also, should be socially acceptable, feasible in term of technology and institutions, and be environmental acceptable (Singhirunnusorn, 2009).

For the proposed eco-city of Kigamboni, there is a risk that, most operational cost, maintenance cost (material and equipment), energy cost will not be effectively expensed. Its common in developing countries that, decision makers tries to select expensive technologies, with a belief that, because technologies work better in developed countries, it will do it anywhere else. This is can be true, but most of such choices are not usually feasible in developing countries (Hophmayer-Tokich, 2006; Weichgrebe *et al*, 2008). The impacts of selecting a non-sustainable wastewater treatment technology spreads beyond its immediate time of operations, it affects the future generation as well (Massoud *et al*., 2009). Lack of expertise, and government support could result into ineffectiveness of the MBR technology for this new eco-city.

The aim of this research was to assess and compare the treatment performance of existing technologies which are affordable, manageable and climate compatible in Tanzania. The selected existing technologies for this study were Anaerobic Baffled Reactor (ABR) and Constructed Wetland (CW) found in Kigamboni and Mbagala, respectively. The study was conducted in years 2015-2016. These technologies are simple in design, construction, operation and maintenance, have low capital, operation and maintenance costs and they have high efficiency in wastewater treatment (Mbwette *et al*., 2001; Hoffmann *et al*., 2011; UN-HABITAT, 2008; Zhang *et al*., 2014).

II. MATERIALS AND METHODS

2.1 Site location

Wastewater sources for this study were collected from two sites. The first site is the Sludge Treatment Plant (STP) which is an anaerobic Decentralized wastewater treatment (DEWAT) plant run by UMAWA, the local community in Kigamboni area. The second site was the Constructed Wetland treatment at St. Anthony High school in Temeke district.

2.2. Experimental Methods

The Kigamboni Anaerobic Sludge Treatment Plant (STP - DEWATs system) found in Kigamboni comprise of biogas digester, Anaerobic Baffled Reactor (ABR) and it treats sewage collected from Pit Latrines and Septic Tanks (Figure 1 and Figure 2). It was designed to serves about 5500 people. Before the plant had been constructed, the sewage had to be transported to municipal waste stabilization ponds for treatment. This plant also produces biogas energy which is used for cooking (Krzeminski *et al*., 2012). The project was constructed by the German organization called Bremen Overseas Research and Development Association (BORDA), and commissioned the plant to UMAWA, a community-based organization from Kigamboni. The sizing of the plant is as follows, biogas digester (settling tank 50m^3, Anaerobic Baffled Reactors 12 m^3, Sludge drying bed 50m^3, and the French drain 8m^3. As detailed in table 1, the plant is designed to treat 4.8m^3/day, this is the sum total the black water and grey water amounting into 1.4 and 3.4 m^3/day respectively. The designed BOD, Total Nitrogen and Total Phosphorus is 97, 19 and 3 mg/L, respectively. The designed flow rate is 0.7m^3/h. Wastewater from pit latrines are poured into biogas settler to settle big particles and trapping the biogas produced (BORDA, 2016). Currently the system is hydraulically overloaded and there is uncontrolled infiltration of storm water into sewer manhole that leads to under performance of the system in treatment of wastewater.

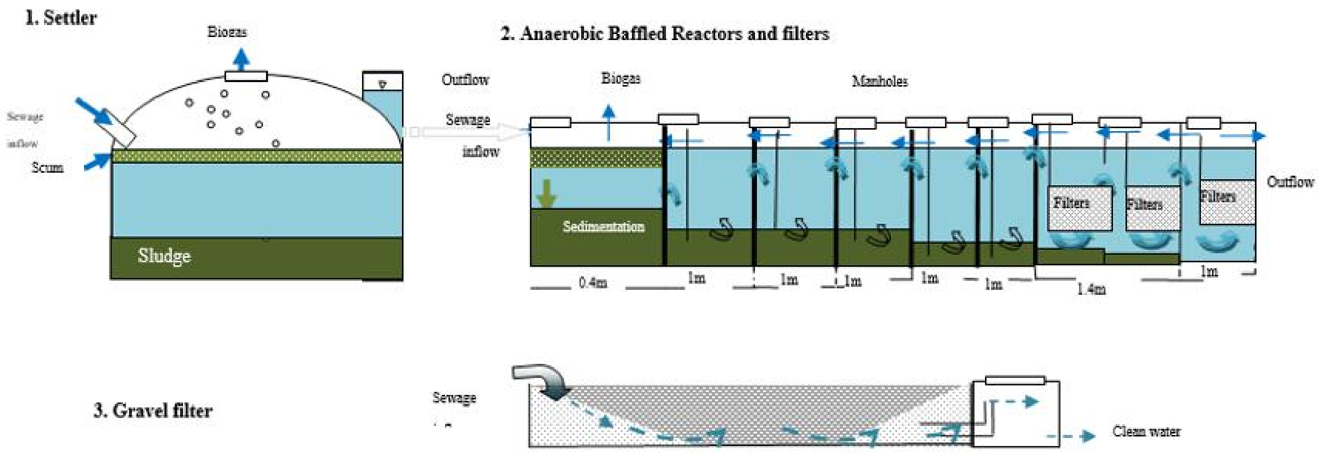

Fig.1: Schematic diagram of the sludge treatment plant operating in Kigamboni area

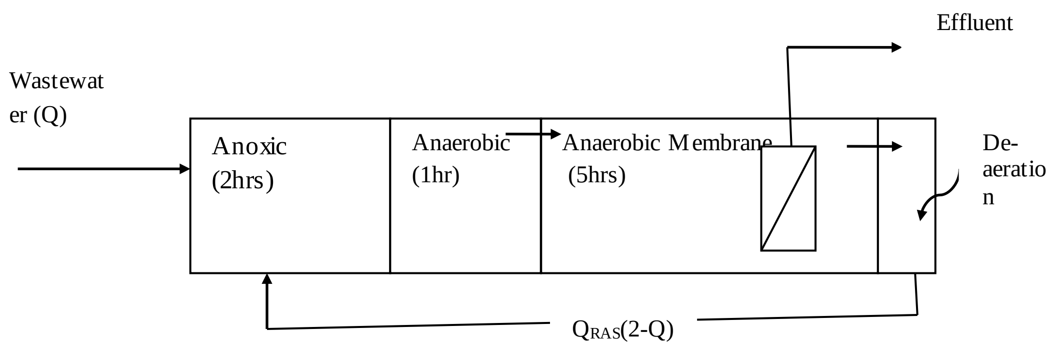

Fig.2: schematic process diagram of Hyundai Advanced Nutrient Treatment (HANT) Process according (Yoon et al., 2004)

Table.1: Design parameters

Wastewater parameter	**Flow (m^3 /day)**	**Suspended solid –load (TSS) (kg/day)**	**BOD (mg/L)**	**COD (mg/L)**	**Total-N (mg/L)**	**Total –P (mg/L)**
Black water	1.4	0.2	265	559	59	3
Gray water	3.4	0.0425	25	51	3	3
Kigamboni STP inflow	4.8	0.3	97	204	19	3
Kigamboni STP effluent	4.8	0.01	40	80	16	3

Another wastewater treatment technology found in the study area is the constructed wetlands (CWs). There are four (4) CWs that are constructed in parallel at the St. Anthony High school in Mbagala (about 10 kilometres, outside of Kigamboni project area). The CWs serve about 2000 people (High school student). The dimension of each wetland cell is 15m x 5m x 0.6m. They receive wastewater from septic tank at a flow rate of 11 m^3/day. The system is still new; it had an age of less than a year by November, 2015 a time of sample collection.

2.3 Sampling and Analysis of Parameters

The influent and effluent wastewater samples were collected from the anaerobic Sludge Treatment Plant (STP) located in Kigamboni area for a period of four months. Other influent and effluent wastewater samples were collected from the Subsurface Flow Constructed Wetland System (SFCWS) for the same period. Wastewater samples were collected from influent and effluent of ABR and CW for the laboratory analysis twice per month for four months from November, 2015 to February, 2016 and the average values for each month were used in data analysis.

Wastewater parameters analysed were physical (pH and temperature) Biological and Biochemical (Faecal coliforms (FC) and Biological Oxygen Demand (BOD_5)) and chemical (Nitrate Nitrogen (NO_3-N), Ammonia Nitrogen (NH_3-N), and Phosphate Phosphorus (PO_4-P)). Physical parameters were analysed in situ using pH and conductivity meters. Chemical and biological parameters were analysed in Ardhi University Laboratory according to standard methods (APHA, 2012).

III. RESULTS AND DISCUSSION

3.1 Performance of Decentralized Wastewater Treatment (DEWAT), A BORDA based anaerobic baffled reactor Sludge Treatment Plant (STP) found in Kigamboni

The results of pH in the influent of this ABR plant ranged from 7.45 -7.66 with an average of 7.55 while in the effluent ranged from 7.51 - 8.18, with an average of 7.86 (Table 2). Generally the performance of this plant met the required national wastewater discharge standards which require that pH of effluent treated wastewater to be between 6.5 and 8.5 (TBS, 2005). The temperature in the influent and effluent ranged from 22 – 28 with an average of 25. The temperature and pH for the this plant is conducive for the microbial activities, they are within the accepted average of 25 ºC and 6.5 to 9 for pH according to (Balthazar, 2014; Metcalf & Eddy, 2004; Elyasi, 2015; Hann, 2015)

The influent BOD concentration varied between 364 and 384mg/L with average of 374 mg/L. The average effluent BOD was 67.3mg/L which is above the designed effluent BOD for this DEWATS plant (40mg/L).

Table.2: Mean Effluents Performance of Different Physical, Chemical and Biological Parameters for (DEWAT)

Parameters	Mean (Avg) Influent	Mean (Avg) Effluent	Tanzania Wastewater Discharge Standards
pH	7.55	7.86	6.5-8.5
Temperature, ºC	22	28	20 - 35
Phosphate (mg/L)	19.67	13.18	6
Nitrate-nitrogen (mg/L)	1.95	4.58	20
Biological Oxygen Demand(mg/L)	371	67.5	30
Total Suspended Solids(mg/L)	1784.8	1009	100
Ammonia -Nitrogen	231.8	276.6	7.5
Feacal Coliform(Count/100mL)*10^6	20.25	9	0.01

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These values will affect the plant uptake. On other hand, effluent results of NO_3-N levers ranged from 1.4 to 1.95mg/L. This is a good result as it complies with the Tanzanian standards and even FAO recommend standard of a range 5-30mg/L. In theory, nitrification process is the one that, lead to higher values of NO_3-N. However, values of Ammonia-Nitrogen recoded was higher in the effluent, this could be due to anaerobic nature of ABR, does not allow oxidation of NH_4 to nitrite, and then to NO_3, this could be the reason of low NO_3 in this plant (Hann, 2015; Yoon *et al*., 2004; Ahamed *et al*., 2015; Krishna *et al*., 2009; Li *et al*., 2015; Xu-Sadri *et al.*, 2015). Values for phosphates concentration in the influent of this constructed ABR plant ranged from 17.5-21.5mg/L with an average of 19.6mg/L. Meanwhile, phosphates values in the effluent ranged from 11.3-15.5mg/L, with an average of 13.18mg/L (Table 2). This amount of the phosphate will be suitable for the users of treated wastewater, especially for the irrigation of landscape and urban farms.

Values for (FC) count in the influent of this ABR 22.5 x 10^6 -18 x 10^6 count/100mL with an average of 22.5 x 10^6 Count/100mL. Meanwhile, (FC) count values in the effluent ranged from 10 to 8 x 10^6 Count/100mL, with an average of 9 x 10^6 Count/100mL. The effluent values of FC are not in an acceptable range for the release in the environment (TBS, 2005), however if an additional chlorination is added to this water, the result will lead to the good water that could be even allowed for other domestic uses (Mwegoha *et al*., 2013).

3.2 Performance of constructed wetland at St. Anthony High school, Tanzania

Values for pH in the influent of this constructed wetland ranged from 7.18 -7.46 with an average of 7.3 (Figure 3). While pH values in the effluent ranged from 7.15 -7.63, with an average of 7.4, these average pH results indicates that the variation in the influent and effluent is not significantly different. In terms of performance, this plant met the required national wastewater discharge standards which require that pH of treated wastewater effluent to be between 6.5 and 8.5 (TBS, 2005). The temperature in the influent and effluent ranged from 22.5 – 27.5 with an average of 25 (Figure 3). The temperature and pH for the this plant is conducive for the microbial activities, they are within the accepted range of 20-30 ºC and 6.5 to 9 for pH according to (Balthazar, 2014; Metcalf & Eddy, 2004; Kihila *et al*., 2014).

Values for BOD concentration in the influent of this constructed wetland ranged from 76-420 mg/L with an average of 156.8mg/L. Meanwhile, BOD values in the effluent ranged from 42-260mg/L, with an average of 90mg/L. The removal efficiency is 42.6%. The BOD values for effluent and influent for this wetland is shown in Figure 4. The effluent BOD is supposed to be 30mg/L or below, to meet the allowable discharge standards (TBS, 2005). The higher BOD values in the effluents could be due to reason that the wetland is recently started to be operated and the wetland plants were still at early stage of growth during the time of the sample collection. This could mean that, there was no enough roots system for diffusing the oxygen from the plants to the wastewater (Sim, 2003). To improve the performance, close monitoring and compliance to the operation and maintenance requirement as stated in the operation manual, is required (Njau *et al*., 2010).

The (NO_3-N) values for effluent and influent for this wetland is shown in Figure 5. Values for (NO_3-N) concentration in the influent of this constructed wetland ranged from 1.9 -25 mg/L with an average of 7.72mg/L. Meanwhile, (NO_3-N) values in the effluent ranged from 1.5 -21.5mg/L, with an average of 6.3mg/L. The removal efficiency is 18.4%. The effluent Nitrate values for this plant are lower than the required standard which is 20 mg/L (TBS, 2005). This could be due to low influent Nitrate values (Senzia, 2003; Bigambo, 2003).

The (NH_3-N) values for effluent and influent for this wetland is shown in Figure 6. Values for (NH_3-N) concentration in the influent of this constructed wetland ranged from 48 - 136.05 mg/L with an average of 123.1mg/L. Meanwhile, (NH_3-N) values in the effluent ranged from 35 - 134.2mg/L, with an average of 115.7mg/L. The removal efficiency is 6%. Effluent Ammonia-Nitrogen values for this plant are bigger than the required discharge standard which is 25 mg/L (TBS, 2005).

Values for phosphates concentration in the influent of this constructed wetland ranged from 16.4 -18.51 mg/L with an average of 17.7mg/L. Meanwhile, phosphates values in the effluent ranged from 12.34 -16.1mg/L, with an average of 14.7mg/L. The removal efficiency is 16.9%. The effluent values of phosphate are relatively high than the allowable discharge a standard which is 6mg/L (TBS, 2005).

The Fecal coliform (FC) values for effluent and influent for this wetland are shown in Figure 7. Values for (FC) count in the influent of this constructed wetland ranged from 5 x 10^6 -18 x 10^6 count/100mL with an average of 12.8 x 10^6 Count/100mL. Meanwhile, (FC) count values in the effluent ranged from 3 to 6 x 10^6 Count/100mL, with an average of 4.2 x 10^6 Count/100mL. The effluent values of FC are not in an acceptable range for the release in the environment (TBS, 2005), however if an additional chlorination is added to this water, the result will lead to the good water that could be even allowed for other domestic uses. One of major source of the faecal contamination in the aquatic environment is the wastewater effluents, faecal contamination lot of problems in human health and environment. When

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thinking about water reuses for sensitive functions it is important to consider the wastewater treatment that efficiently remove fecal to large extent (Mwegoha *et al.*, 2013).

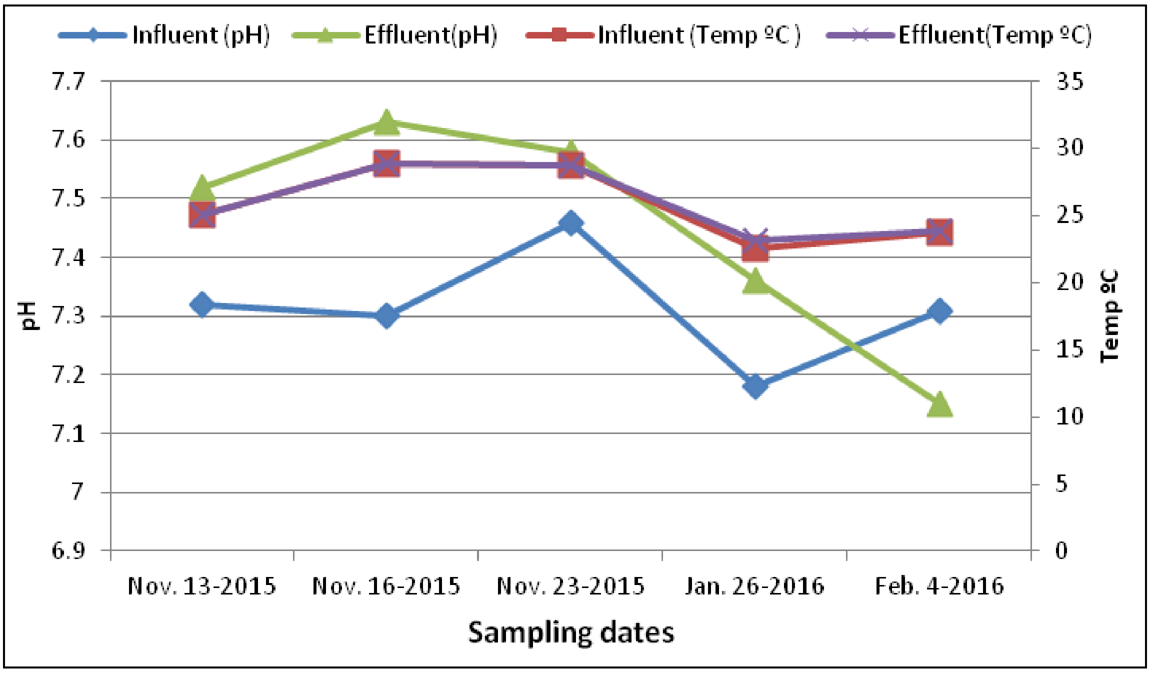

Fig.3: Variation of pH and Temperature

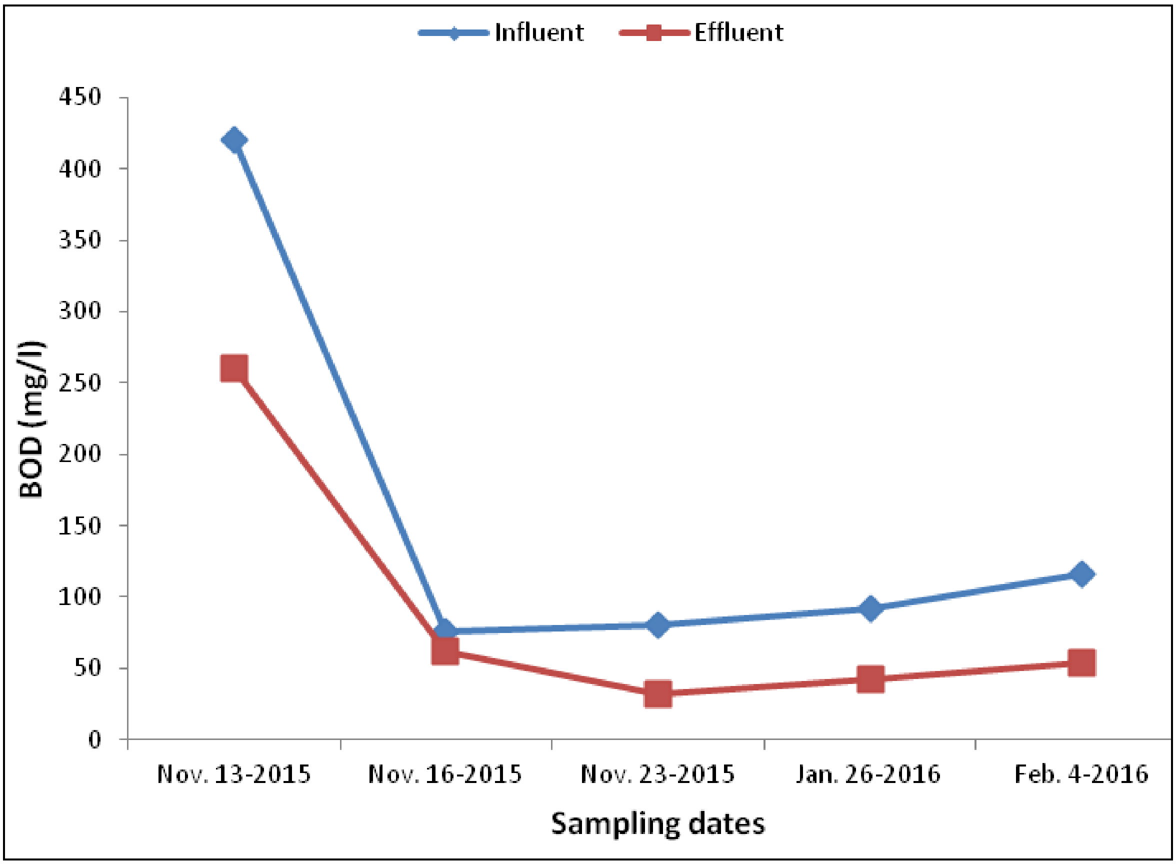

Fig.4: Variation of BOD

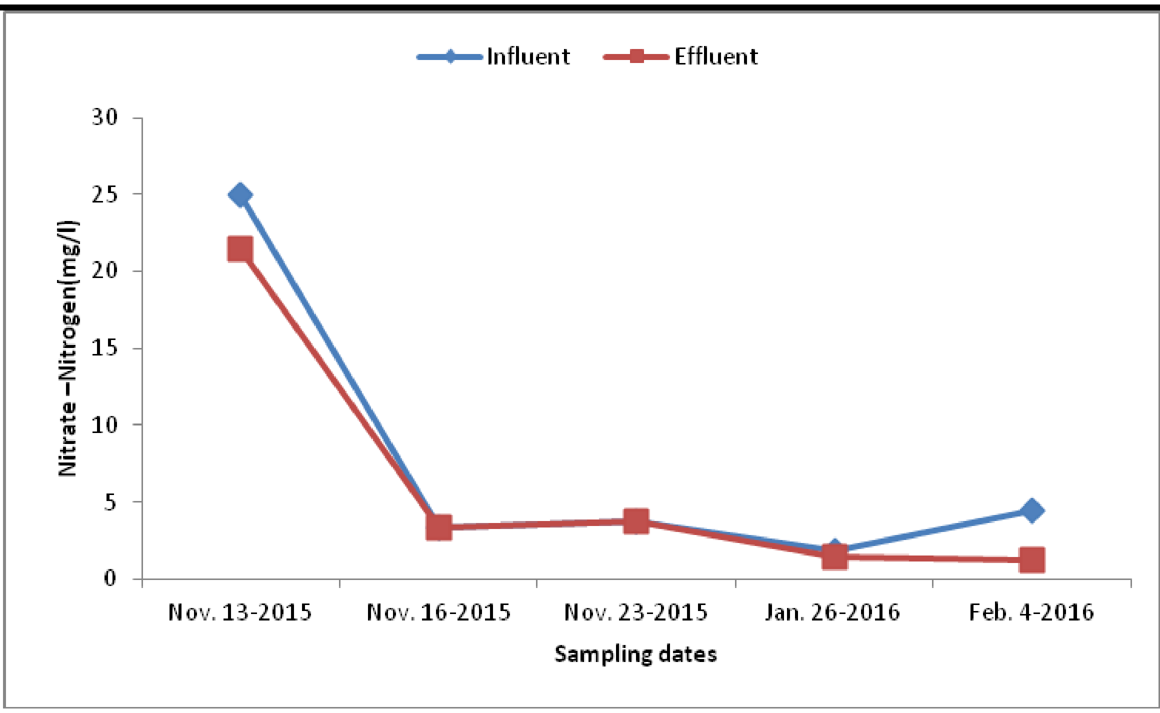

Fig.5: Variation of Nitrate Nitrogen

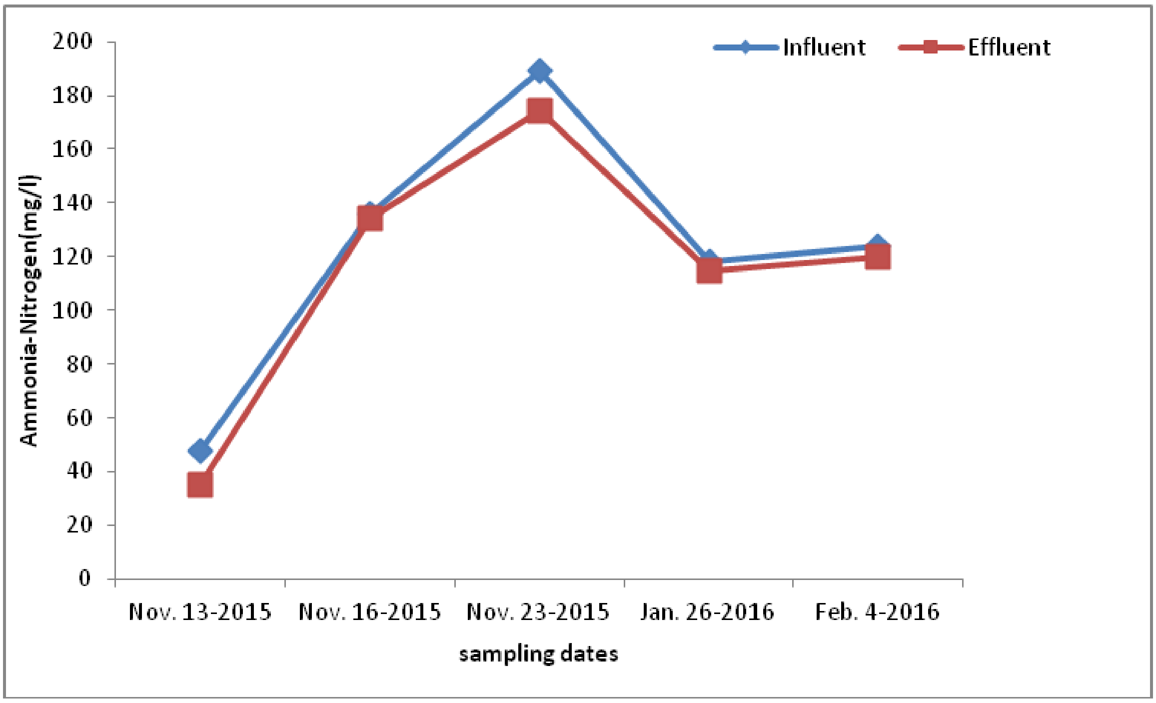

Fig.6: Variation of Ammonia Nitrogen

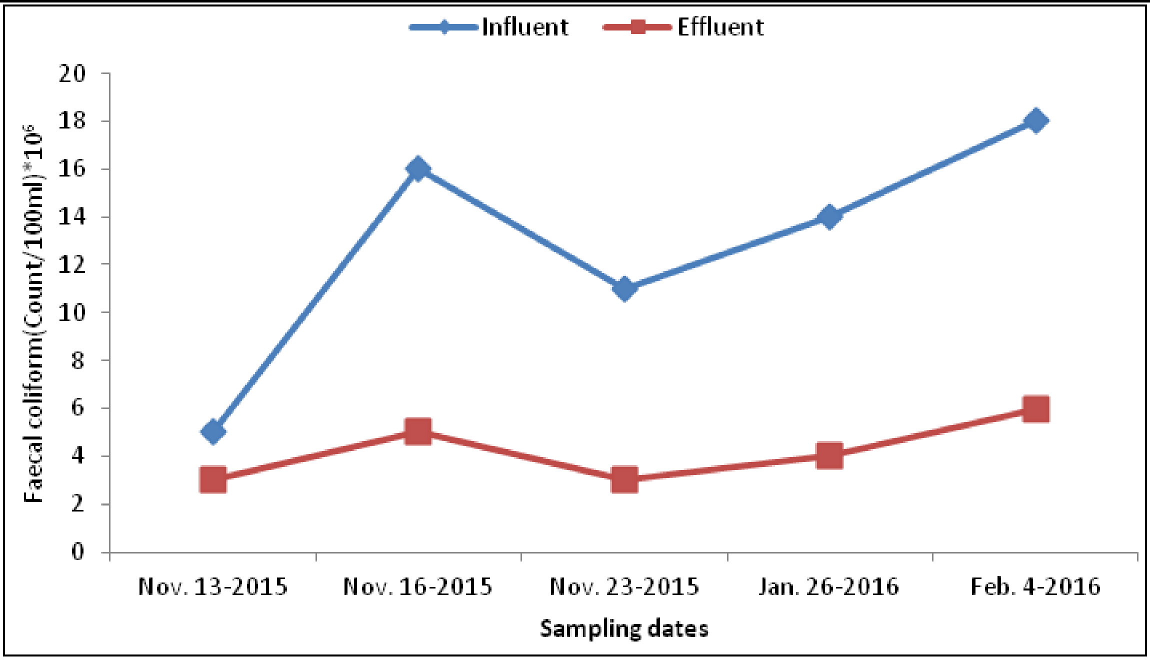

Fig.7: Variation of Faecal Coliforms

IV. CONCLUSIONS

In general, performance of this ABR plant was not producing good-quality of treated wastewater effluent. The reason for inadequate performance is that, wastewater and faecal sludge feed into the treatment plant is about 10-15 m^3/day, this is up to three times higher than designed capacity, this ABR plant is designed for 4.8m^3/day. The overloading is due to increase of number of household that, use this treatment plant, initially only 5500 people was using this but now up to 15000 people are use this plant, these people who mainly use pit latrines and septic tanks, prefer this ABR services instead of the municipal waste stabilization ponds for treatment, which is far and costly for them. Because of this, hydraulic overlaying resulted into poor removal performance of BOD and other parameters such as NH_3-N, PO_4-P, FC.

Large amount of wastewater was not properly treated. The designed flow rate emptying or releasing wastewater the plant is 7m^3/h. The operated flow rate was higher beyond its designed capacity; this is because the wastewaters are emptied at high speed from the tank to the treatment plant. Because of high speed of inflow rate at the influent chamber of the settling tank, it affects the performances of the Anaerobic Baffled Reactors (ABR), as wastewater does not settle in the active sludge and therefore not properly perform anaerobic treatment. In this plant, there are four ABR in series, so the wastewater retention time is shorter than expected. Also wastewater tends to bypass the horizontal sand filter, which is in the land chamber to polish the final effluent. To ensure discharging standards are met, this study, suggest that, wastewater and faecal sludge inputs have to be as per design. The efficiency of ABR will increase when the input of big quantities of water is loaded slowly in the digester. It is recommended that a pipe with small diameter be used to feed the digester.

The performance for these CWs in removing pollutants is relatively low 6% - 43% and this could be due to the reasons that, the wetland cell is still new (with an operation period of less than 1 year), wetland plants are still at early stage of growth and therefore there is insufficient oxygen released to the CW that lead to limited growth of aerobic bacteria who are responsible for aerobic decomposition of organic matters. However, literature concludes that, properly designed, operated and maintained constructed wetlands have high performance in removal of pollutants from wastewater, the performance in the removal of pollutants reaches up to 99.0% (Balthazar, 2014; Kimwaga *et al*., 2013).

Both ABR and CWS with slight adjustment were found to be effective in removal of all physical, chemical and biological parameters.

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