Performance of Lagoons in Sewage Treatment in Fort Portal Municipality, Western Uganda

Richard Rubongoya[1], Clement Nyakoojo[2,*], Aliyu Abubakar Shehu[3]

[1]Department of Environmental Sciences, College of Agricultural and Environmental Sciences, Makerere University, P.O Box 7062, Kampala, Uganda.
[2]Department of Plant Sciences, Microbiology & Biotechnology, Makerere University, P.O Box 7062, Kampala, Uganda.
[3]Save the Nature Foundation, Sokoto, Nigeria.
[*]Corresponding author: cnyakoojo@cns.mak.ac.ug

Abstract

In January - April 2018, a study was conducted to assess the efficiency of the waste stabilization ponds at the Kabundaire Sewage Treatment Plant located in Fort Portal Municipality, Western Uganda. Physico-chemical and microbiological parameters were measured in the influent and effluent of the lagoons using standard limno-microbiological procedures. At the influent site, the mean values (mgl^{-1}) of TSS, TDS, BOD, DO, NH_4-N, NO_3-N, TN and TP were 1097.9, 920.0, 891.4, 2.40, 150.0, 0.25, 703.2 and 24.3 respectively. The mean values of turbidity, temperature, EC, pH and TFC were 69.6 NTU, 22.4°C, 3139.6 μScm^{-1}, 7.8 and 1.19×10^7 CFU/100 ml respectively. At the effluent site, the mean values (mgl^{-1}) of TSS, TDS, BOD, DO, NH_4-N, NO_3-N, TN and TP were 389.0, 465.8, 120.8, 0.34, 49.9, 0.08, 48.7 and 15.4 respectively. The mean values of turbidity, temperature, EC, pH and TFC were 12.2 NTU, 20.9°C, 1364.7 μScm^{-1}, 8.17 and 4.51×10^5 CFU/100 ml respectively. Most of the parameters were above permissible limits for discharge of effluent proposed by the National Environment Management Authority (NEMA). The poor performance of the facility was attributed to population growth and lack of maintenance.

Keywords—Efficiency, Fort Portal, NEMA standards, Kabundaire, Lagoons

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1 Introduction

Sewage is a complex mixture of natural organic and inorganic materials in addition to anthropogenic compounds [1]. Most of the carbon compounds in sewage are carbohydrates, fats, proteins, amino acids and volatile acids. Proteins and carbohydrates are biodegradable contaminants which constitute 90% of the organic matter in domestic sewage. The sources of these biodegradable contaminants include excreta and urine from humans; food wastes from sinks; soil dirt from bathing, washing and laundering; plus various soaps, detergents and other cleansing products [2]. The inorganic components include sodium, calcium, potassium, magnesium, chlorine, sulphur, phosphate, bicarbonate, nitrogen species and phosphorus species [3]. The presence of heavy metals in sewage has also been confirmed [4]. Because of their polluting effects, the components of sewage should be reduced by treatment before it is released to the environment [5]. Most sewage treatment systems depend on aerobic and facultative anaerobic microorganisms (mainly bacteria and algae) that utilize the raw organic material as a carbon and energy source during their growth and reproduction [6]. As a result, these microorganisms decompose the organic fraction into simpler, less-toxic compounds and destroy pathogenic microorganisms. The most common and convenient method for treating sewage at wastewater stabilization plants in developing countries is based on the use of waste lagoons systems [7]. Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes that remove solids, organic matter and, sometimes, nutrients from wastewater [8]. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary and tertiary and/or advanced wastewater treatment [9]. The assessment of the performance of lagoons in the management of wastewater has been a focus of investigations by

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several authors [10][11][12]. In Uganda, no assessments are made on their efficiency although most towns in the country rely on lagoons for sewage treatment. Such lagoons suffer setbacks like poor maintenance due to inadequate funding and mixing of industrial sewage with domestic sewage [13].

The population of Fort Portal Municipality is increasing without corresponding expansion of the Kabundaire sewage treatment plant that was designed more than twenty years ago for the population at that time. The effluent from the facility is discharged into the Mpanga River System thus posing a potential problem of contamination. Numerous large buildings have sprung up resulting in increased wastewater discharge. This can cause overloading of the sewage treatment plant, which ultimately might result in decrease in its treatment efficiency. The aim of the study was to evaluate the performance of the ponds at the facility in sewage treatment.

2 Material & Methods

The study was carried at the Kabundaire National Water and Sewerage Corporation sewage treatment facility in Fort Portal, a town located in Kabarole District, Western Uganda (Figure 1). Fort Portal, the main town in the district, lies approximately 320 kilometres, by road, west of Kampala. Fort Portal has registered a steady population increase. According to the 2002 national census, the population of Fort Portal was about 41,000. The population was estimated at 54,275 in 2015 by the Uganda Bureau of Statistics. The sewage plant relies on the wastewater stabilization system that consists of aerobic, anaerobic/facultative ponds and maturation ponds that are arranged in series (Figuer 2). Sampling was done monthly for 4 months (January - April 2018) in the influent siteand effluent site. Samples for laboratory analyses were drawn from the two sites using sterile plastic bottles and 250 ml BOD glass bottles. To avoid changes in concentration and composition, the samples were capped tightly and placed in cool boxes. All measurements were made in triplicates and the mean values recorded. The effluent characteristics were compared with the maximum permissible values set by the National Environment Management Authority [14].

Total suspended solids were determined by filtering100 ml of the sample through a dry, pre-weighed filter. The residue retained on the filter was dried in an oven at 105o C until the weight of the filter no longer changed. The increase in weight of the filter was the amount of the total suspended solids [15]. Turbidity, temperature, electrical conductivity, pH and dissolved oxygen were measured in-situ with appropriate meters [16]. Total dissolved solids were determined by filtering 100 ml of the sample through a dry, pre-weighed filter. The filtrate was dried on a pre-weighed evaporating dish in an oven at 1800°C, until the weight of the dish no longer changed. The increase in weight of the dish was the amount of the total dissolved solids [15]. The biological oxygen demand was analyzed at the National Water and Sewerage Corporation laboratory, Fort Portal. Water was siphoned into 250 ml bottles and fixed by using manganese sulphate and sodium azide solutions. Initial dissolved oxygen concentration was determined by using the Winkler method [17]. The samples were incubated in the dark for five days at 20°C. BOD was calculated as the difference between the initial oxygen concentration and the final oxygen concentration [18]. Samples for the determination of ammonia-nitrogen, nitrate-nitrogen, total nitrogen and total phosphorus were poured into 100 ml glass bottles containing 4.5M sulphuric acid, fixed by adding a few drops of 6M hydrochloric acid and kept in cool boxes. The concentrations of nitrogen and phosphorus were determined at the NWSC laboratory, Fort Portal following the procedures of [16]. The membrane filtration technique (MFT) was used in the quantification of faecal coliforms [19]. The analysis was carried out at the NWSC laboratory, Fort Portal. Thet-test was used to analyze the differences between the means of the parameters in the two sites at the 95% confidence level.

3 Results

Comparative characterization of the influent and effluent of the Kabundaire sewage treatment plant is summarized in Table 1. The removal efficiency was high for turbidity, BOD, TN and TFC. It was low for TSS, EC, TDS and TP (Figure 2). The concentration of TSS was significantly higher in the influent ($t = 2.871, p = 0.05$) with an average value of 1097.9 mgl^{-1} while the corresponding value for the effluent was 389.0 mgl^{-1}. The turbidity for the influent and effluent was 69.6 NTU and 12.2 NTU respectively. The two values did not differ significantly ($t = 1.384, p = 0.05$). The difference between influent and effluent temperatures was not significant ($t = 1.428, p = 0.05$). The conductivity was high in the raw sewage with an average of 3139.6 $\mu S\,cm^{-1}$. In the treated wastewater the conductivity was 1364.7 $\mu S\,cm^{-1}$. The difference was not significant ($t = 0.768, p = 0.05$). The total dissolved solids in the influent varied between 788.1 mgl^{-1} and 1155.1 mgl^{-1} with an average of 920.0 mgl^{-1}. The total dissolved solids in the effluent ranged between

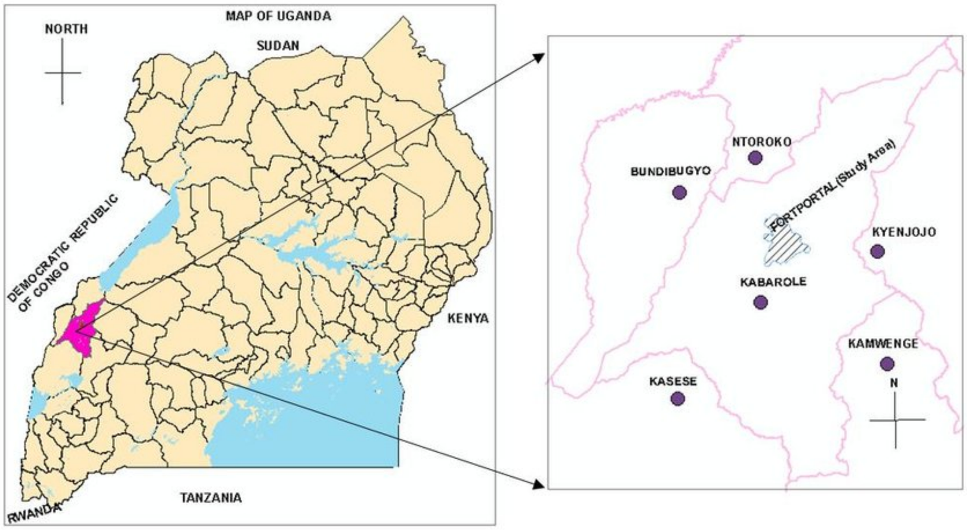

Fig. 1: Map showing the location of the study area

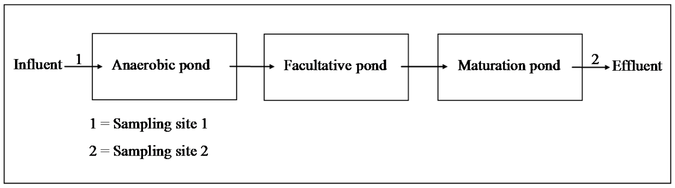

Fig. 2: Arrangement of ponds at the Kabundaire wastewater treatment facility.

Parameter	**Influent**	**Effluent**	**Maximum Permissible Level**
TSS (mgl^{-1})	1097.9	389	100
Turbidity (NTU)	69.6	12.2	30
Temperature (°C)	22.4	20.9	20-35
EC (μScm^{-1})	3139.6	1364.7	<500
TDS (mgl^{-1})	920	465.8	1200
pH	7.8	8.17	9-Jun
BOD (mgl^{-1})	891.4	120.8	30
DO (mgl^{-1})	2.4	0.34	-
$NH_4 - N$ (mgl^{-1})	150	49.9	5
$NO_3 - N$ (mgl^{-1})	0.25	0.08	5
TN (mgl^{-1})	703.2	48.7	10
TP (mgl^{-1})	24.3	15.4	5
TFC (CFU/100 ml)	1.19×10^7	4.51×10^5	<400

TABLE 1: Comparison of influent and effluent characteristics of the Kabundaire sewage treatment plant

$397.3\,mgl^{-1}$ and $561.3\,mgl^{-1}$. The solids differed significantly ($t = 2.954, p = 0.05$). The higher effluent pH value was not significant ($t = 1.127, p = 0.05$). It fluctuated between 7.5 and 8.2 with an average of 7.8 in the influent. It fluctuated between 8.1 and 8.3 with an average of 8.17 in the effluent. The average concentrations of BOD for the sites were $891.4\,mgl^{-1}$ and $120.8\,mgl^{-1}$ respectively. The influent dissolved oxygen was comparatively higher than the effluent dissolved oxygen. However, the difference was not significant ($t = 1.373, p = 0.05$).

The concentration of ammonia-nitrogen was higher in the influent ranging from 128.2 mgl^{-1} to 208.4 mgl^{-1} with an average of 150 mgl^{-1}. The difference between the concentrations in the two sites was significant (t = 3.102, p = 0.05). Variations of $NO_3 - N$ showed similarity to those of dissolved oxygen. Nitrate-nitrogen concentrations were not detectable in several samples. The influent had a higher concentration compared to the effluent. The difference was statistically significant ($t = 3.654, p = 0.05$). Total nitrogen was higher in the influent site with an average value of $703.2\,mgl^{-1}$. The corresponding value for the effluent site was $48.7\,mgl^{-1}$ indicating a reduction of about 93.1%. TP was higher in the raw sewage with an average of $24.3\,mgl^{-1}$. In the treated wastewater the TP was $15.4\,mgl^{-1}$ representing a 36.6% reduction (Figure 3). Faecal coliforms were higher in the influent. The minimum concentration in the influent was 3.84×10^6 CFU/100 ml, while the maximum concentration was 1.20×10^7 with an average of 1.19×10^7 CFU/100 ml. Despite the evidence of a high percentage reduction in the faecal coliforms, their density was above the maximum permissible level set by the NEMA.

4 Discussion

Because of the reduced flow rate suspended solids are removed by sedimentation [20]. The process is

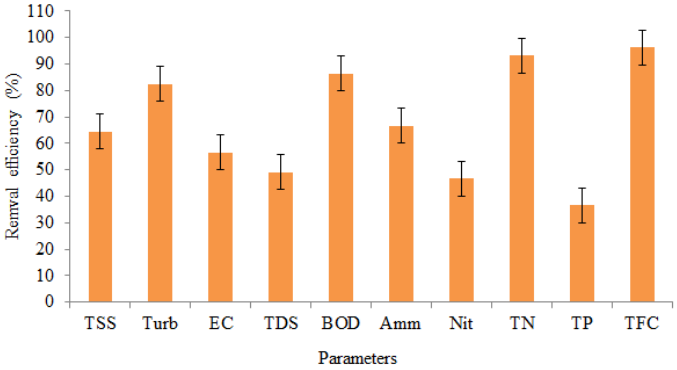

Fig. 3: Removal efficiency of the Kabundaire sewage treatment plant

facilitated by the action of the gravitational force on the particulates. The high TSS concentrations of the effluents can be attributed to the high TSS levels in sewage that resulted in the inability of the system to remove all the suspended solids [21]. Removal of total suspended solids might have lead to decreased turbidity in the effluent. The high efficiency of turbidity removal from sewage was also observed by [12].The small range of temperature between the influent and effluent is characteristic of aquatic systems in the equatorial region [22]. However the temperatures of the two sites are in a range that is ideal for bacterial growth as noted by [23].

Reduction in the effluent conductivity may be a result of uptake of the essential elements by microalgae. Evidences of reduction of ions in wastewater due to accumulation by algae have been provided by several investigators [24][25][26]. However, the high conductivity value above the maximum permissible level suggests that the concentrations of major ions wasstill high and that tertiary treatment is necessary in order to reduce the ion load in the effluent [12]. Reduction of total dissolved solids in the effluent may be attributed to uptake of essential ions by algae and adsorption [27]. Although a certain level of these ions in water is necessary for aquatic life, the high values are harmful because the osmotic flow of water into and out of the cells of aquatic organisms can be interrupted [28].

The pH showed little variation although it was slightly higher in the effluent. The photosynthetic activity of the microalgae might have assimilated large quantities of carbon dioxide leading to a slight increase in pH of the effluent [29]. The microorganisms using oxygen produced by microalgal photosynthesis degraded the organic matter into gaseous products like carbon dioxidethereby reducing the BOD in the effluent [20].The high BOD removal percentage is consistent with investigations by [7][8]. However, the high BOD in the effluent above the maximum permissible level is an indicator of organic loading [30]. Most of the reduction in BOD of the final effluent from the lagoons is attributed to algal uptake in the facultative ponds [20].

Very low dissolved oxygen in wastewater might be attributed to the utilization of the gas by bacteria in the decomposition of organic matter in the wastewater [31]. The higher the organic matter loading, the greater the oxygen deficit [32] because of the high oxygen demand. Reduction of dissolved oxygen by microbial-mediated organic matter degradation is a common biological phenomenon [23]. The low amount of ammonia in the effluent is attributed to uptake by the microalgae [33]. It is the most preferred form of nitrogen by algae especially blue green algae [17]. However, the presence of ammonia above the permissible limits in the effluent is an indicator of contamination. The implication is that effective nitrification has not occurred during the wastewater treatment process. Low oxygen conditions in the system could not favour nitrification.

Heavy organic matter loading from raw sewage is the primary cause of increased oxygen demand that initiates an anoxic or low oxygen environment [33]. Following deoxygenation (due to rapid uptake of oxygen by sewage-degrading bacteria), many facultative anaerobic bacteria like Pseudomonas, Archromobacter, Bacillus and Micrococcus use nitrate-nitrogen as an exogenous hydrogen acceptor in the oxidation of organic matter and denitrification occurs [34]. This process depletes a significant proportion of nitrate-nitrogen and might have contributed to low nitrate levels in the effluent. The influent had a higher concentration of nitrate-nitrogen because denitrification is less efficient in the presence of some oxygen. Denitrification as a consequence of oxygen depletion in aquatic systems has been documented by other authors [35], [36]. Nitrate removal by algal uptake has also been suggested [29].

Assimilation into algal biomass might have led to lower total nitrogen levels in the effluent. An investigation by [37] revealed the robustness of algae in removing N from sewage thus improving its quality. High nitrogen removal efficiency due to assimilation in algal biomass has also been reported by other authors like [38]. Other mechanisms of nitrogen removal from wastewater include sludge deposition, adsorption by bottom sediments, denitrification and loss of ammonia as a gas to the atmosphere [8]. Despite lower phosphorus levels in the effluent, TP was above the recommended levels. A secondary effluent loaded with phosphorus concurs with the results of a research carried out by [9]. Some authors have attributed high phosphorus levels in effluents from sewage treatment plants in Africa to insufficient treatment because of increased urbanization and population which does not equate to increase in wastewater treatment facilities [12][39]. High effluent coliform numbers in the range of those revealed by this study have been documented [40]. The efficiency of disinfection of the stabilization ponds was high (about 92.2%). This observation is consistent with the results of an investigation by [20].

5 Conclusion

The study revealed that the Kabundaire STP is not efficient in adjusting a number of parameters thus releasing a low quality effluent to the environment. This is depicted by the fact that most of the parameters analyzed were abovethe maximum permissible limits of the NEMA standards.

The town has expanded thus increasing wastewater discharge. This has probably caused overloading of the sewage treatment plant, which ultimately resulted in decrease in its treatment efficiency. Discharge of the secondary effluent into the Mpanga River catchment area is likely to exacerbate the problem of pollution and increase public health hazards.

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