REDUCTION OF BACTERIA AND OTHER POLLUTANTS IN SEWAGE STABILIZATION PONDS

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ABSTRACT

Management of water resources is one of the biggest the problems facing developing countries today where sewage water treatment plants only serve the urban population. The rural areas and informal settings often lack mechanisms of sewage water treatment thereby posing potential harm to the environment. Different sewage water treatment options must therefore be developed to protect the environment. Sewage Stabilization Ponds (SSPs) are artificially constructed ponds that use biological treatment mechanisms to purify sewage water. They are simple to construct and maintain, have low capital investment and annual running costs, and also require less skilled personnel. This study evaluated performance of SSPs to determine whether they can efficiently treat sewage. It was conducted at the University of Eldoret sewage treatment plant which has 4 SSPs. Performance of these SSPs was achieved by determination of numbers of bacteria and levels of physicochemical pollutants in the sewage water at 5 different points (raw sewage influent, pond 1 effluent, pond 2 effluent, pond 3 effluent and pond 4 effluent) for10 months. Results indicated that levels of all physicochemical parameters, except pH, temperature and total suspended solids reduced significantly ($p<0.05$) from one station to the next and the least values were recorded for station 5. The numbers of bacteria, except for total bacteria counts, reduced significantly ($p<0.05$) from one station to the next and the least values were recorded in station 5. Thus, SSPs are effective in sewage water treatment and can be adopted in small communities to protect aquatic environments and alleviate contamination of drinking water sources.

Key words: *Environmental sustainability, Sewage treatment, Water resources*

INTRODUCTION

Surface water bodies in developing countries are highly polluted as a result of indiscriminate discharge of wastewaters from industrial, agricultural, and domestic/sewage activities (Kambole, 2003; Hodgson, 2007*).* In developing countries only, a small proportion of the wastewater produced by sewered communities is treated. Only 10- 15% of the urban population in Africa is connected into the sewer network (WUP, 2003). There is a great need to wastewater treatment systems to avoid the health risk problems in these communities (Mara 2003).

A stabilization pond is a large shallow excavation that receives sewage from a sewer system, detains the sewage so that biological process can destroy most of the disease-causing organisms, and discharges the effluent as treated sewage (Kayombo *et al*, 2001; USDOD, 2004). Sewage stabilization pond systems provide reliable, low-cost, and relatively low-maintenance treatment for domestic discharges especially in areas that may be out of reach of Municipal sewage treatment plants such as refugee camps, schools and hospitals in rural areas. Operation and maintenance involves starting up the pond, managing pond surface conditions, maintaining the pond site, draining the pond and removing sludge.

In Kenya today where economic problems are complex, the sewage stabilization ponds should be popularized to let Public Health Engineers use them with confidence as a simple and reliable means of treatment of sewage and certain industrial sewages, at a fraction of the cost of conventional sewage treatment plants. Adopting as low a level of treatment as possible is especially desirable in developing countries, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably.

Sunlight is an important factor in the significant inactivation or removal of pollution indicator organisms in sewage stabilization ponds (Ainon and Chuan, 2002; Sinton *et al*., 2002). The ultraviolet portion of solar radiation from sunlight is bactericidal, causing direct deoxyribonucleic acid damage. At high intensities, photo-oxidation becomes more important acting through photosensitizers to damage organelles principally the cytoplasmic membrane (Davies-Colley *et al*., 1999).

The general objective of this study was to evaluate the performance of the sewage stabilization ponds at University of Eldoret in removing organic matter, nutrients and pathogens and to assess the physicochemical characteristics of the resulting effluents. The specific objective of this study was to evaluate pollutant removal efficiency of the SSPs for the selected physicochemical and bacteriological parameters and to identify the characteristics of pond influents and effluents.

METHODOLOGY

University of Eldoret has four oxidation ponds that are arranged in series with wide dykes separating them. They were constructed in 1967 but became operational in 1968. They are located in the Southwestern part of the University and drain sewage water and sewage from the students' hostels, academic area and staff residence (population: about 40,000). Each of the ponds is 150 × 32 × 1.5 m and only one of these receives sewage water influent at a time. The sewage water and sludge are retained in the pond for about two weeks during which algae, bacteria and other organisms act on them by mineralizing the organic matter content. The effluents are conveyed through sewers made of concrete pipes from one pond to the next until the effluent gets to the last pond from where it is channeled into a nearby river.

Experimental design and sampling

Water samples were collected from five sites: raw sewage in-flow to the first oxidation pond, the oxidation pond itself, inflow into the second pond and the second pond itself, inflow into the third pond and the third pond itself, inflow into the fourth pond and the effluent from the fourth pond and the effluent receiving stream (Marura river) and the pond effluent/ stream mixture, over a 10 month period (February 2013 to October 2013). Sampling was done twice every month for the months that have been mentioned. Samples was collected by filling 500 ml sterile brown bottles, iced and processed within 12 hours of collection. Figure 1 gives an illustration of the study area.

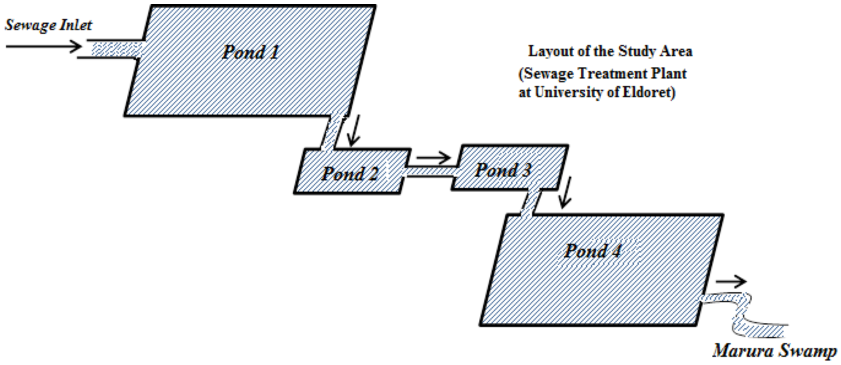

Figure 1: Illustration of the University of Eldoret Sewage Stabilization Ponds

The sampling stations and their descriptions are further described in Table 1 below.

Table 1: Sampling stations and descriptions for the study

Station number	Description of station
1	Point of entry of raw sewage into pond 1
2	Point of entry of pond 1 effluent into pond 2
3	Point of entry of pond 2 effluent into pond 3
4	Point of entry of pond 3 effluent into pond 4
5	Point of exit of pond 4 effluent into Marura river.

Examination of water samples for bacteriological indices of water quality

Analyses of water samples for total bacterial counts (TBCs), Total Coliform counts (TCs), Faecal Coliform counts (FCs), Faecal Enterococci counts (FECs) and *Clostridium perfringens* counts (CPCs) were performed using standard pour plate techniques on differential and selective bacteriological media. The colonies growing on the specific media was enumerated and identified based on morphological characteristics, staining reactions, and biochemical tests.The API 20E kit was used for rapid biochemical characterization of bacterial isolates. Table 2 illustrates the isolation critera for *C. perfingens*, total bacteria, total coliforms and Faecal streptococci and faecal coliforms.

Table 2: The isolation criteria for *Clostridium perfringens (CP)*, Total coliforms (TC), Faecal coliforms (FC), Faecal Enterococci (FE) and Total bacteria (TB) in water samples

Isolation medium	Incubation temperature °C	Incubation period (hours)	Bacteria isolated
PCA	37	48	TB
MAC	37	48	TC
MAC	44.5	48	FC
CPAB	37	48	CP
BA	37	48	FE

PCA-Plate Count Agar, MAC- MacConkey Agar, CPAB – Clostridium Perfringens Agar Base

Determination of the physicochemical parameters of sampled water

Temperature was measured with a thermometer while the pH was measured with a portable pH meter (E.I.L., Model 30C, Gallenkamp) insitu. Dissolved Oxygen (DO), turbidity, total dissolved solids (TDS), nitrites, nitrates, phosphates, chlorides and sulfates in water samples were determined using a multiparameter analyzer (HACH company) using methods described in the Manufacture's manual. The biochemical oxygen demand (BOD_5) of water samples was determined by getting the difference between DO of samples on day 1 and day 5. The total suspended solids (TSS) of water samples was determined by filtering water samples on pre-weighed filter papers, drying overnight in the oven and getting the difference in weight between the initial weight and final weight of the filter paper. The electrical conductance of water samples was determined using a conductivity probe/meter.

Data Analysis

The data from this research was analyzed using spreadsheets such as Ms Excel and SPSS programs. Analysis of variance was done to determine the significance differences in parameters of pond influents and effluents.

RESULTS

Table 3: Means of physicochemical parameters per station

Station	BOD_5	Cl^-	Cond.	DO	NO_3^{2-}	NO_2^-	pH	PO_3^{2-}	SO_4^{2-}	TDS	temp	TSS	Turb.
1	4.85	16.6	582	2.37	15.42	0.094	7.65	23.6	0.375	0.562	21.83	0.423	315
2	2.16	16.6	551	4.66	6.07	0.057	7.95	18.63	0.377	0.442	21.83	0.338	73
3	2.21	16.1	481	6.35	4.28	0.056	8.2	17.72	0.317	0.373	22.17	0.307	65
4	3.04	15.9	459	7.31	3.78	0.066	8.22	16.48	0.303	0.322	22.67	0.34	62
5	1.16	15.6	441	9.79	1.35	0.025	8.23	15.4	0.23	0.273	22.5	0.225	55
e.s.e.	1.667	1.076	32.5	1.663	1.864	0.0823	0.239	1.504	0.0559	0.0543	0.453	0.0806	28.9
l.s.d.	4.918	3.176	95.7	4.905	5.498	0.0279	0.706	4.436	0.165	0.1602	1.337	0.2378	85.3
P value	,0.009	0.049	0.025	0.053	<.0.01	0.042	0.381	0.01	0.004	0.011	0.599	0.682	<0.01

NB: All the parameters are in mg/l or ppm except for conductivity (µS/cm), pH, Turbidity (NTU) and temperature (°C)

The means of all the physiochemical parameters under study are shown in Table 3 above. The levels of all except pH were found to reduce from one station to the next with most parameter recording the most values in station 1 and the least values in station 5. Reduction of all except for pH, temperature and TSS was found to be significant at $p<0.05$. The reduction of nitrates and turbidity across the stations was highly significant even at $p<0.001$.

The pH levels in fact tended to increase slightly from one station to the next with station 1 recording the least pH (7.65) and station 5 recording the most pH (8.23). The means of temperature for the 5 stations were found not to differ significantly from one another. Although the means of TSS reduced from one station to the next, this reduction was not significant. Unlike the rest of the physicochemical parameters, DO increased from one station to the next with station 1 recording the least DO (2.37 mg/l) and station 5 recording the most DO (9.79 mg/l).

The means of bacteriological indices in this study are provided in Table 3 below. The levels of all these parameters were found to reduce from one station to the next with most parameter recording the most values in station 1 and the least values in station 5. Reduction of all except for TBC was found to be significant at $p<0.05$. The reduction of FC across the stations was highly significant even at $p<0.001$.

Table 4: Means of bacteriological indices in colony forming units (CFUs) per station

Station	TBC	CPC	FC	FE	TC
1	210692	68167	19867	90613	28717
2	103223	46840	14000	22295	27133
3	45517	25680	12317	24922	22367
4	30383	23050	5117	18067	11450
5	26067	21470	3550	11747	9100
e.s.e.	73298	18294.9	2586.2	32894.4	4635.5
l.s.d.	216229.1	53969.9	7629.3	97038.4	13674.7
P value	0.004	0.035	0.001	0.049	0.019

DISCUSSION

The principal objective of sewage treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment thus enhancing environmental sustainability. Water bodies when polluted with untreated sewage constitute health hazards to users and to aquatic life. Sewage pollution forms a greater part of the man's activity and it is the immediate need of every community of today to combat sewage pollution. It is needless to stress that if an economic balance of the many varied services which a stream or a body of water is called upon to render is balanced and taken into consideration one could think of ending up in a wise management programme. In order to eliminate the existing water pollution levels of the natural water one has to think of preventive and treatment methods. The design of sewage treatment plants is usually based on the need to reduce organic and suspended solids loads to limit pollution of the environment (Mara, 2003).

The use of SSPs has therefore been considered as the ideal way of improving effluent quality by means of natural processes (Mtethiwa et al., 2007). The SSPS are one of the lower cost methods for treating the sewage emanating from small communities and this is achieved at minimum maintenance and operational requirements (Arar, 1988). Microorganisms constitute essential agents of the sewage purification system due to their metabolic activities (Imhoff and Fair, 1956). The organic matter is broken down by aerobic bacteria into simple inorganic materials such as carbon dioxide and water. Algae utilize these compounds to produce complex organic materials that make up algal cells. During this process algal cells generate oxygen which is utilized by bacteria (Bian and Li, 1992). In essence all these lead to the efficient mineralization of organic matter, that is, lower Biochemical Oxygen Demand (BOD) and inactivation of pathogenic bacteria, yeasts and viruses (Taber and Taber, 1976).

According to the results obtained, we concluded that the natural lagoon acts via biological process of purification allowing the organic matter elimination and physical process of settling allowing the evacuation of the suspended particles towards the sediment on which the various germs are adsorbed. The University of Eldoret Sewage SSPs appears to be very efficient in wastewater treatment. It generates a nearly complete removal of organic matter and a satisfactory reduction of germs of fecal contamination and pathogens by the germicidal action of sunlight.

In this study, the bacterial load showed a maximum mean at the entrance to the first pond (station 1) and decreased with the minimum means being recorded at the point of release of the treated effluents into the receiveing water body (Station 5). At the entrance, the average number of bacteria per 100 ml is 140×108 and at exit, this number decreased to a value of 3.5×106 with an average yield purification of 99.9%. Most of the work on pathogen removal in SSPs has concentrated on the removal of the bacterial indicator organisms (*E. coli* and FC). The reduction in numbers of bacteriological indices in the consecutive ponds could be attributed to the damage to the cytoplasmic membranes of bacteria caused by sunlight (Masters et al., 2011). The processes that may remove pathogens in stabilization ponds include natural die-off, sedimentation, filtration, ultra-violet light ionization, unfavorable water chemistry, temperature effects, and predation by other organisms and pH (Kadlec and knight 1996). These authors showed that vegetated stabilization ponds seemed more effective in pathogen removal since they allow a variety of microorganisms which may be predators to pathogens to grow.

Results on the levels of the physicochemical parameters in the SSPs revealed similar results as the bacteriological indices. pH in the initial ponds tended to be acidic but as the wastewaters moved to the 3rd and 4th stabilization ponds, the pH tended to rise slightly to become basic although even the rise was not statistically significant. The reason for the acidic nature in the initial ponds could be attributed to the acidogenic phase in the inflow waters (Kayombo et al. 2002) and higher photosynthesis due to prolific algal growth in ponds (Veeresh *et al*. 2009). The basic nature of the effluents in the last 2 ponds (Stations 3 and 4) could be attributed to heavy algal growth observed in these stations. The high pH values are attributed to higher photosynthetic rates of algae, drawing more dissolved CO_2 from the waters and thereby causing high bicarbonate and carbonate concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals, leaving sodium as the dominant ion in solution (Craggs *et al*., 2012).

There was a marked increase in levels of DO in sewage effluents leaving the treatment plant (Station 5; 9.79 mg/l) than there was in the effluents coming into the treatment plant (Station 1; 2.37 mg/l). The increase in levels of DO could be attributed to the fact that the more and more organic matter was being degraded in the effluents as they were channeled from one pond to the next thereby decreeing the BOD and allowing for levels of DO to go up. The means of DO across the stations were inversely proportional to the means of BOD. The raw incoming sewage effluents (station 1) had high BOD (4.85 mg/l), while the effluents leaving the treatment plant into the receiving water body had lower BOD (1.16 mg/l). The high BOD in inflows could be contributed by the high levels of organic matter in the raw sewage that required high levels of oxygen to be oxidized. The decrease of BOD in the outflows illustrates the functioning of anaerobic zone of the ponds. Anaerobic bacteria convert organic carbon into methane and in the process, remove up to 60% of the BOD (Mara, 2003; Hodgson, 2007; Navaraj, 2005). The aerobic and anaerobic organisms work together to achieve BOD reductions of up to 75%. The heavy solids settle to the bottom where they are decomposed by bacteria. The lighter, suspended material is broken down by bacteria in suspension.

The suspended and dissolved solids in the sewage effluents also reduced significantly from one station 1 to 5.The means of TDS and TSS at the sewage inflows (Station 1) were 0.652 mg/l and 0.423 mg/l respectively while these levels in sewage outflows were 0.273 mg/l and 0.225 mg/l respectively. Higher levels of these solids at inlets could be due to semi decomposed and decomposed solids arising from organic matter. The removal of TDS and TSS followed the same trend as removal of turbidity. This could be because turbidity is often associated proportionally with the quantity of solids in water (Tadesse *et al*. 2004). The physical processes responsible for removing suspended solids include sedimentation, filtration, adsorption onto biofilm and flocculation/precipitation. Wetland plants increase the area of substrate available for development of the biofilm.

The reduction of conductivity in the sewage effluents also followed the same trend as the suspended and dissolved solids. These means were high in sewage inflows (Station1; 582) and reduced significantly in sewage outflows (Station5; 441). Conductivity of electric currents is usually effected by the suspended and dissolved solids in water and it followed that as these solids were being eliminated from the effluents then the electric conductance of the effluents reduced at the same rate.

Turbidity level in sewage inflow (Station 1) was recorded at 315 NTU and this value reduced to 55 NTU in sewage outflow (Station 5). Turbidity is influenced by several factors among them the levels of suspended and dissolved solids. It followed that as the suspended and dissolved solids were eliminated from the sewage effluents, then turbidity was also reduced at more or less the same rate.

Nitrogenous compounds (NO_2^- and NO_3^-) were also found to reduce substantially in effluents leaving the stabilization ponds. The raw influent sewage has NO_3^-N of 15.42 mg/l. while the NO_3^-N level in the sewage outfow (Sation 5) was 1.35 mg/l. The raw influent sewage (station 1) had NO_3^-N of 0.094 mg/l. NO_3^-N in the effluent of maturation pond (Station 5) was 0.025 mg/l. Removal of nitrogenous compounds in the SSPs could be attributed to the hydrolysis of organic nitrogen to ammonia. Nitrogenous compounds are utilized by algae to make more algal cells (Mara, 2003). Higher values of nitrates and nitrites at the inflows could be due to their high levels in raw effluents (Mahapatra *et al*. 2011). Nitrate nitrogen (NO_3^-N) is a necessary primary macronutrient for the biota in aerated treatment systems and therefore was consumed in the ponds by the available microorganisms. Earlier studies have reported nitrate concentrations >10 mg/l at higher organic loads with competitive algal activities (Faleschini *et al*. 2012). The trend shows that there is a drop in nitrogenous compounds present in the pond outflows. This could also be due to settling of particulate organic matter and consequent higher microbial activities, which is similar to an earlier report (Faleschini *et al*. 2012).

Phosphorous levels in sewage inflows (station 1) and the sewage outflows (station 5) were also found to be significantly different. Phosphorus removal in wetlands is based on the phosphorous cycle, and can involve a number of processes. Primary phosphorus removal mechanisms include adsorption, filtration and sedimentation. Other processes include precipitation and assimilation/uptake. Particulate phosphorus is removed by sedimentation, along with suspended solids. Means of phosphates were higher at the inflow (station1; 23.6 mg/l) indicating active mineralization with higher algal biomass and the lowest values of phosphates were recorded in the pond outflows and final effluents (Station 5; 15.4 mg/l). This could be attributed to the high organic matter in the raw effluents and therefore higher organic phosphorous.

The elimination of chlorides and sulfates in sewage effluents also followed the same trend as removal of phosphorous and nitrogenous compounds. The reason for this could be because chlorides and sulfates are also nutrients that are necessary for growth of microbial biomass and just like the phosphates and nitrogenous compounds were consumed or metabolized by these microbes for growth thereby eliminating them in the effluents.

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CONCLUSION AND RECCOMMENDATION

Efficient sewage treatment before disposal is necessary in order to avoid problems that are related to eutrophication of receiving water bodies and degradation of the environment at large. From this study, it was concluded that SSPs can be efficient and simple methods of treating sewage water before releasing them into the environment. They can become handy in areas where households or institutions are not connected to municipal sewers and therefore require alternative means of sewage treatment. The University of Eldoret SSPs were found to be efficient in reduction of numbers of bacteria as well as most of the physicochemical pollutants. The physicochemical pollutants that were not reduced significantly include pH, TSS and temperature. Dissolved oxygen was found to increase in the final effluents leaving the treatment plant showing that the SSPs were quite efficient in reduction of organic content of the sewage water. This study recommends the construction and use of these ponds in places that are out of reach of the conventional treatment plants so as to protect the environment from untreated discharges.

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