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Effect of Seasonal Variation on Performance of Conventional Wastewater Treatment System

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Abstract Many studies have focused on wastewater treatment however, little attention has been given to effect of seasonal variation to wastewater treatment. The purpose of this study was to determine the seasonal differences of wastewater treatment that employs screens, trickling filters and oxidation ponds. This was achieved by sampling and analyses of water samples from four different points during the dry and wet seasons of the year 2013. Water samples were taken from influent point, primary pond effluent, trickling filter effluent and final effluent. Gravimetric method was used in determining Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). The BOD_5 technique and the COD digestion method were used for determination of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) respectively while the temperature, pH and conductivity were measured using respective meters. Analysis of Variance showed that there was significant difference ($p < 0.05$) in all the parameters quantified at all the points of treatment during the two seasons. The results showed that BOD and COD both reduced from one point to the next during the two seasons of study. The TSS levels increased after primary pond effluent undergoing treatment at the trickling filter and the temperature also increased after the trickling filter effluent undergoing treatment at oxidation ponds. The levels of conductivity and TDS decreased from one treatment stage to the next during dry season but during the wet season the levels of these parameters increased from one stage to the next except that the levels reduced after the primary pond effluent underwent treatment at the trickling filter. The various stages of wastewater treatment plant under study were effective during the two seasons however, wet season recorded lower figures for most of the parameters.

Keywords: *effluent, physicochemical parameters, points, wastewater treatment, seasonal variation*

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1. Introduction

Wastewater often contains high levels of organic matter from industrial, agricultural and human wastes. It is necessary to remove the organic matter by the process of wastewater treatment. Wastewater treatment can involve physical removal of solids, biological decomposition of organic compounds, chemical, physical or biological removal of the other constituents such as heavy metals, nitrogen and phosphates and disinfection to remove potentially pathogenic micro organisms [1].

The fundamental reasons of treating wastewater are the prevention of pollution of portable water and protection of public health by safeguarding water supplies against the spread of waterborne disease [2]. In Africa, wastewater is insufficiently treated because of rise in urbanization and population which does not equate to increase in wastewater treatment facilities [3]. Release of insufficiently treated effluent containing huge amounts of nutrients to the waterways might allow benthic microbes and algal growth on rocks and wood becoming slippery, posing treat to human safety [4]. In addition Communities living downstream are at high risk of contracting diseases due to increased microbial pathogens and deteriorating physico-chemical parameters [4]. However, sufficiently treated effluent can be discharged into bay, streams, rivers wetland or lagoon or it can be used for irrigation of a golf course, landscaping or ground water recharge [5].

Prevention of river which is always the recipient of treated, partially treated of sufficiently treated wastewater require effective monitoring of physicochemical and microbiological parameters [6]. Monitoring of phycicochemical parameters during wastewater treatment aids in assessing the safety of the final effluent before being released to the river where we have aquatic life as well as human beings using the same water down stream for a range of purposes. Many studies have been documented on conventional waste water treatment processes however, comparative study in terms of wastewater treatment during dry and wet season is still lagging and that is the gap by which this study has ventured into.

2. Materials and Methods

The study was carried out at the Boundary Sewage Treatment Plant in Eldoret municipality, Uasin - Gishu

County, Kenya. The plant relies almost entirely on microbial treatment of waste. It employs screens, trickling filters and oxidation ponds. In addition it has flow chamber B where the water in the sedimentation pond effluent are pumped back to mix with the primary pond effluent The study was carried out in the months of February and March to represent the dry and wet seasons respectively. The samples were taken at exactly 9 am East Africa time from various points of wastewater treatment after varying periods of retention namely; influent wastewater. Primary pond effluent was sampled after four days of retention. Trickling filter effluent after two minutes and final effluent nine days after the trickling filter effluent underwent treatment at the two oxidation ponds. All the parameters were analysed in triplicates; Temperature and pH were tested in situ while BOD, COD, TSS, TDS and conductivity were analysed at the Eldoret Water and Sanitation Company (ELDOWAS) laboratory.

2.1. Biological Oxygen Demand (BOD)

The procedure on the BOD track manual was used. Nitrification inhibitor powder was dispensed into the empty sterile BOD bottle. Collected samples of 0.32-1.1 litres were homogenised in a blender. The pH of the sample was adjusted to a range of 6.5 and 7.5 with sulphuric acid or sodium hydroxide. The wastewater samples were measured and poured into BOD bottles. A 3.8 cm magnetic stir bar was placed in each sample bottle and stopcock grease was applied to the seal lip of each bottle and to the cap of each seal cap. One gram Lithium hydroxide powder pillow was added to each seal cap. The bottles were incubated for five days in a BOD incubator at 20°C.

2.2. Chemical Oxygen Demand (COD)

Chemical oxygen demand was determined as described in chemical oxygen demand manual where 100 ml of the samples collected were first homogenized in a blender. Two millilitres of the homogenised samples collected from the influent and primary pond effluent were pipetted into the high range reagents. The same volume was pipetted from trickling filter effluent and final effluents were added to low range reagents. Two millilitres of deionised water was added to each of the two reagents to produce a blank, then the vials were inverted gently several times and placed in a COD reactor digestor which had already been heated to a temperature of 150°C and left to heat for two hours. After this duration the vials containing the samples were cooled to room temperature and finally a programmed spectrophotometer machine was used to read the COD results.

2.3. Total Suspended Solids (TSS)

The TSS was obtained by the procedure described by [7]. A glass filter was dried by placing it in an oven with a temperature of 103°C for 60 minutes, removed and put in a dessicator to cool for 60 minutes and weighed. A 100 ml of the homogenised sample was filtered through the glass filter. The weight of the sample was obtained by using the formula;

$$\text{Total Suspended Solids } (\text{mg})/\text{L} = (\text{A} - \text{B}) \times 1000 \div \text{Sample volume}$$

Where A = weight of filter plus dried residue in mg
B = weight of filter in mg.

2.4. Total Dissolved Solids (TDS)

The filtrate obtained from the testing for total suspended solids described in above was utilized for testing for TDS by transferring it to weighed evaporating dish and evaporated to dryness on a steam bath. This was followed by drying for one hour at 180°C then cooling for one hour in a dessicator [7].

Weight of TDS was obtained using the formulae by [7]

$$\text{Total Dissolved Solids } (\text{mg})/\text{L} = (\text{A} - \text{B}) \times 1000 \div \text{Sample volume}$$

Where A = weight of dried residue plus dish in mg
B = weight of dish in mg

2.5. Conductivity (Cond)

Was measured using conductivity meter

2.6. pH

pH meter was used to determine the pH in situ.

2.7. Temperature (Temp)

Thermometer was used to measure the temperature.

2.8. Statistical Analysis

The data collected during the two seasons at the influent, primary pond effluent, trickling filter effluent and final effluent were analysed using Analysis of Variance (ANOVA) procedure using SAS 9.2 software. This was done for seven parameters; BOD, COD, TSS, TDS, conductivity, pH and temperature. Confidence level of 95% was used then the findings presented using bar graphs.

3. Results

Analysis of variance (ANOVA) was used to analyze the parameters collected from influent, primary pond effluent, trickling filter and final effluent at the Boundary sewage treatment plant during the two seasons of study as shown in Table 1 and Table 2. Figure 1 and Figure 2 demonstrates the trends of the parameters studied during the wastewater treatment process.

The parameters BOD, COD, COND, pH, TDS, TEMP and TSS were significantly (< 0.05) different in all the stages of treatment; screen and primary pond, trickling filter and oxidation ponds.

All the parameters; BOD, COD, COND, pH, TDS, TEMP, TSS and TC were significantly different ($p<0.05$) at the various treatment points; screen, primary pond, trickling filter and oxidation ponds.

Table 1. Analysis of variance (ANOVA) of the parameters during dry season at the various stages of wastewater treatment

Source	DF	ANOVA SS	Mean Square	P- value
BOD	3	482302.25	160767.42	<.0001
COD	3	3977272.25	1325757.42	<.0001
COND	3	1317072.91	439024.31	<.0001
PH	3	2.02	0.67	<.0001
TDS	3	645164.25	215054.75	<.0001
TEMP	3	83.18	27.73	<.0001
TSS	3	33030.67	11010.22	<.0001

Table 2. Analysis of variance (ANOVA) of the parameters during wet seasons at the various stages of treatment

Source	DF	ANOVA SS	Mean Square	P- value
BOD	3	466812.00	155604.0000	<.0001
COD	3	3054283.67	1018094.556	<.0001
COND	3	24252.67	8084.22222	0.0014
Ph	3	2.90	0.97	<.0001
TDS	3	6357.67	2119.22	0.03
TEMP	3	82.87	27.62	<.0001
TSS	3	67809.00	22603.00	<.0001

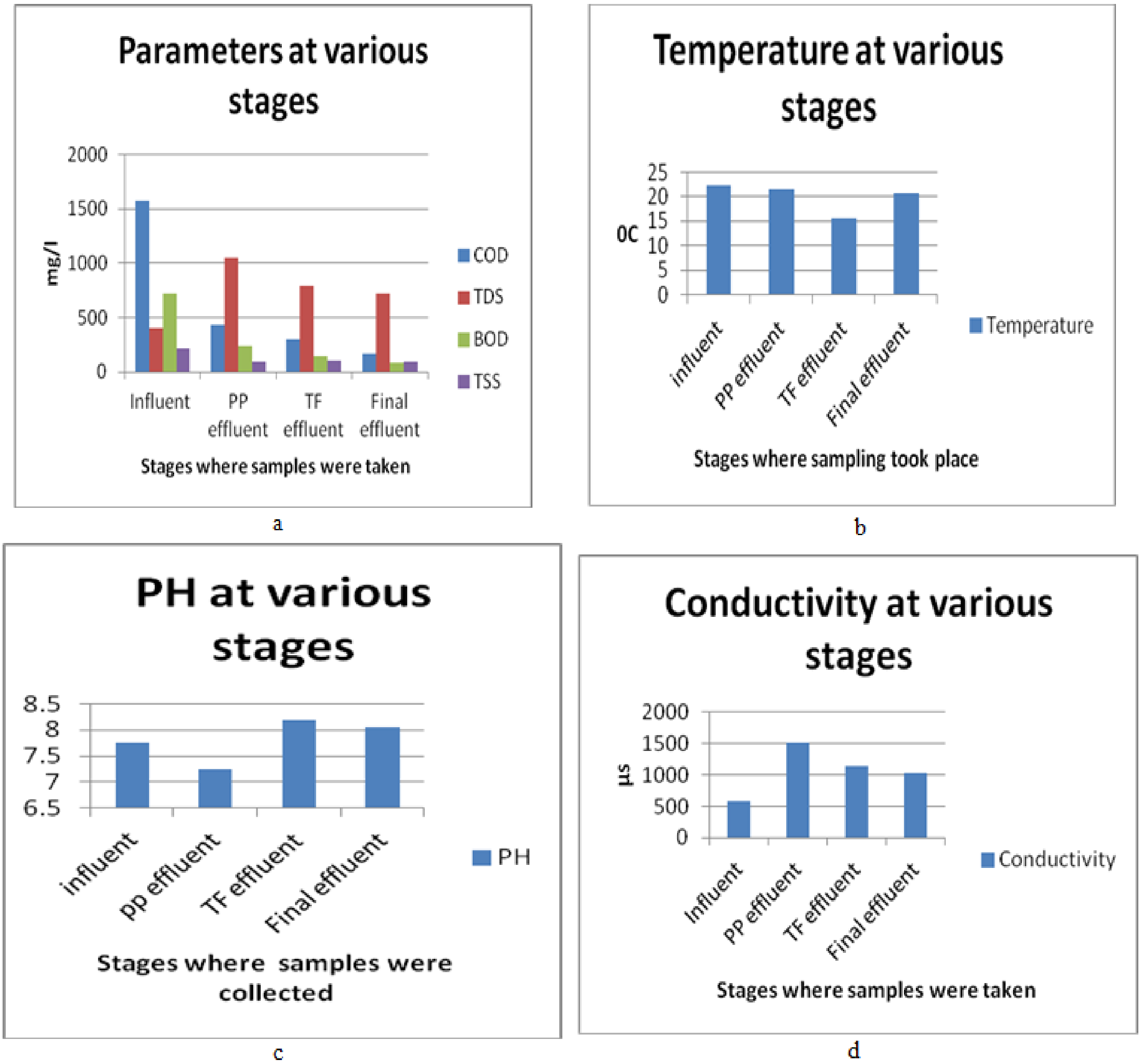

Figure 1. Physicochemical parameters at the various points where sampling took place at the Boundary sewage treatment plant during dry season

Chemical oxygen demand, biological oxygen demand reduced consistently as the wastewater underwent treatment at the various points of treatment however, TDS, conductivity, temperature and pH were inconsistent in their reduction down from one point to another during the treatment process (Figure 1a, b, c and d).

The COD and BOD reduced consistently as the wastewater underwent treatment at the various stages of treatment but, TDS, conductivity, temperature and pH were inconsistent in their reduction from one point to the next (Figure 2a, b, c and d).

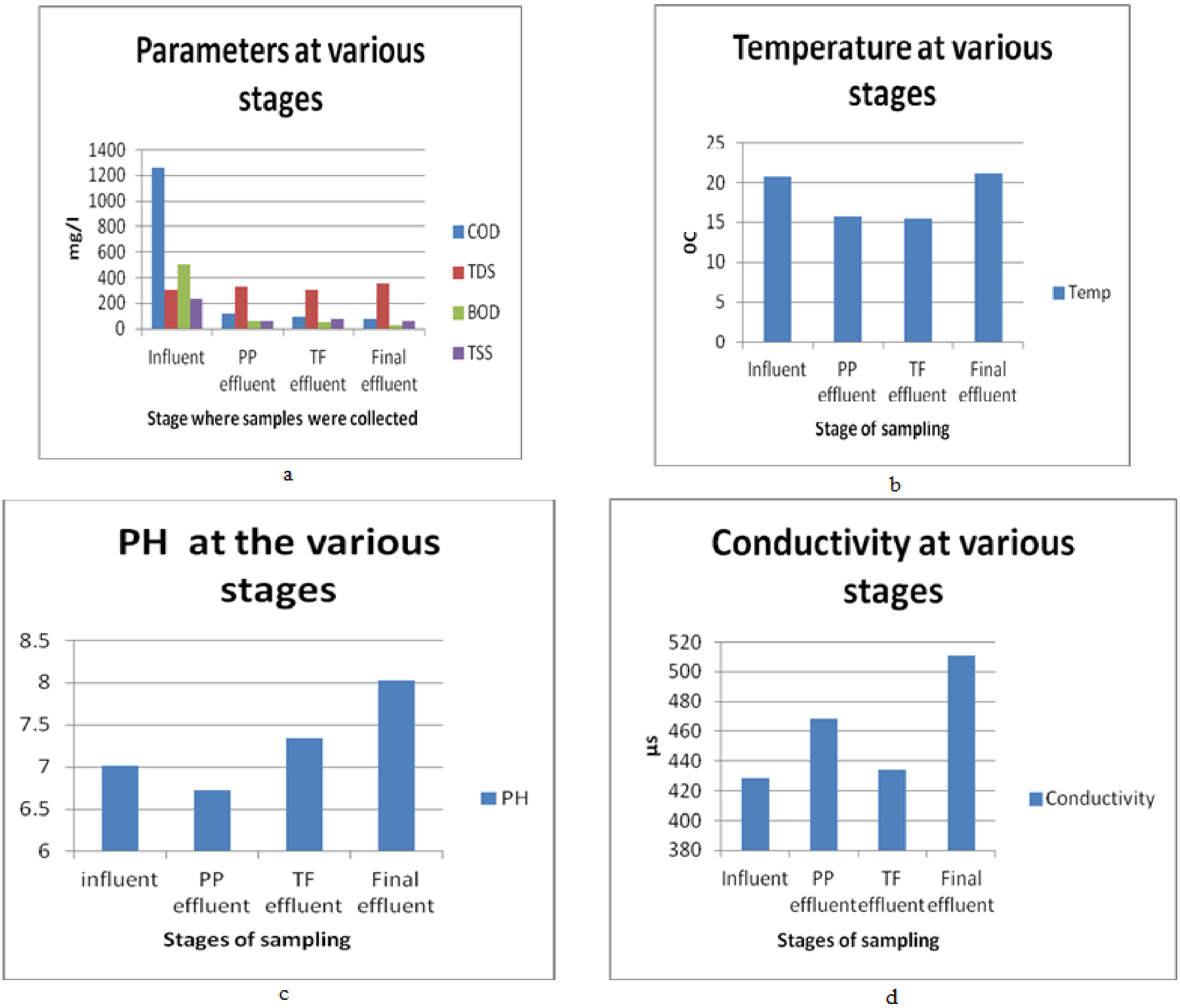

Figure 2. Physicochemical parameters at the various points where sampling took place at the Boundary sewage treatment plant during wet season

3.1. Raw Data

Table 3: Raw data collected from Boundary Sewage Treatment Plant during dry season

Table 3.1. Influent data (Raw data)

Param	Rep1	Rep 2	Rep 3
COD (mg/l)	1570	1570	1569
TDS (mg /l)	386	410	415
BOD (mg / l)	602	599	605
TSS (mg/l)	210	240	200
pH	7.77	7.72	7.78
Tem (°C)	22.3	22.3	22.3
Cond (µs)	551	585	593

Table 3.2. Primary pond data

Param	Rep 1	Rep 2	Rep 3
COD (mg / l)	447	429	430
TDS (mg / l)	1085	1096	982
BOD (mg /l)	241	241	234
TSS (mg /l)	100	90	90
pH	7.33	7.22	7.21
Temp (°C)	21.6	21.6	21.5
Cond(µs)	1550	1565	1403

Table 3.3. Trickling filter data

Param	Rep 1	Rep 2	Rep 3
COD (mg / l)	247	326	323
TDS (mg / l)	794	802	785
BOD (mg / l)	122	165	162
TSS (mg / l)	110	100	106
pH	8.04	8.21	8.3
Temp (°C)	15.6	15.6	15.6
Cond(µs)	1134	1145	1122

Table 3.4. Final effluent data

Param	Rep 1	Rep 2	Rep 3
COD(mg /l)	169	169	169
TDS (mg /l)	741	712	715
BOD (mg /l)	83	75	90
TSS (mg /l)	90	90	90
pH	8.01	8.03	8.1
Temp (°C)	20.8	20.8	20.8
Cond (µs)	1059	1017	1021

Table 4: Raw data collected from Boundary Sewage Treatment Plant during wet season

Table 4.1. Influent data

Param	Rep1	Rep 2	Rep 3
COD (mg / l)	1262	1260	1256
TDS (mg /l)	283	314	302
BOD(mg l)	499	505	502
TSS (mg / l)	240	240	240
pH	7.06	6.99	7.00
Temp(°C)	20.8	20.7	20.7
Cond (µs)	404	449	432

Table 4.2. Primary pond data

Param	Rep 1	Rep 2	Rep 3
COD (mg l)	115	116	115
TDS (mg / l)	328	326	330
BOD (mg /l)	58	58	58
TSS (mg /l)	60	60	60
pH	6.82	6.67	6.66
Temp (°C)	15.7	15.7	15.7
Cond (µs)	471	466	468

Table 4.3. Trickling filter data

Param	Rep 1	Rep 2	Rep 3
COD (mg / l)	92	92	92
TDS (mg / l)	340	304	267
BOD (mg /)	54	56	54
TSS (mg /l)	80	80	80
pH	7.22	7.38	7.42
Temp(°C)	15.2	15.6	15.6
Cond(µs)	486	382	434

Table 4.4. Final effluent data

Param	Rep 1	Rep 2	Rep 3
COD (mg / l)	77	76	77
TDS (mg / l)	361	350	361
BOD (mg / l)	28	28	28
TSS (mg / l)	63	63	60
pH	8.00	8.10	8.00
Temp (°C)	21	21.1	21.1
Cond (µs)	516	500	516

4. Discussion

All the physico chemical parameters in this study were significantly different ($p<0.05$) in all the stages of treatment at Boundary Sewage Treatment Plant during both dry and wet seasons. This can be attributed to the treatment processes at the sewage treatment plant namely; screen, primary pond, trickling filter, sedimentation pond, secondary pond and tertiary pond.

In the primary sedimentation pond the BOD could have been reduced by settlement and anaerobic digestion of organic matter at this pond as suggested by [8]. This author reported that that the BOD and solid concentration in the raw wastewater were reduced by sedimentation and anaerobic digestion. Anaerobic treatment has been found to be more suited to wastewater with high BOD [9] and therefore useful at reducing high concentrations of BOD and suspended solids for agriculture and food industries. Furthermore, the four days in which the wastewater spent at this pond exacerbated the reduction of BOD by prolonging the contact time of the wastewater and the anaerobic microorganisms to digest the organic matter to the peak hence reducing the amount of BOD. This is further supported by [8] who found out that a properly designed anaerobic pond can achieve around 60% of BOD removal in one day retention time. The reduction of BOD could also be attributed to the settling of organic matter to form sludge at primary pond and the availability of two large primary sedimentation ponds of each 21,800 m^2 surface area at Boundary Sewage Treatment Plant that probably, allowed the large organic load to be degraded allowing the anaerobic microbes to digest them adequately. Primary treatment can physically remove 20 to 30% of the BOD that is present in particulate form [10] In wastewater treatment that employs oxidation ponds and trickling filters, particulate material is usually removed by screening and precipitation and settling of small particulates and settling in basins and tanks [10].

Flow chamber B may have enhanced the reduction of BOD at the succeeding stage by acting as a stage where primary pond effluent is diluted, aerobic organisms and dissolved oxygen are introduced.

The trickling filter (TF) further reduced the BOD in the wastewater under treatment. The TF is an aerobic treatment system that utilizes microorganisms attached to a media to remove organic matter from wastewater that passes over, around, through or by the media [11]. With TF the organic material is completely mineralised to carbon dioxide, ammonia, nitrate, sulphate and phosphate in the extensive biofilm hence reducing the BOD [12]. This is because the microbial community in the filter absorbs and mineralizes the dissolved organic nutrients in the sewage thus reducing the BOD [1]. The treated wastewater and solids from the trickling filters are piped to a settling tank where the solids are separated [13]. Usually part of the liquid from the settling chamber is re-circulated to improve wetting and flushing of the filter medium, optimising the process and increasing the removal rate [13]. The Sedimentation tank at Boundary Sewage Treatment Plant with a diameter of 34 m, surface area of 900 m^2 and volume of 2,350 m^3 could have further reduced BOD. The sedimentation stage where suspended matter including death dead organisms from the preceding stages of wastewater treatment settle down, hence reducing the organic load that would have proceeded to the next stage of treatment. Some organic materials from the trickling filter could have been adsorbed onto the algae on the ridges of this pond hence giving ample time to the microorganisms present a chance to act on the matter thereby reducing the load.

The anaerobic and facultatively anaerobic processes in oxidation ponds removes organic matter leading to reduction of BOD [14]. The algae, at the edges of these ponds could also have assisted in degradation of organic matter, hence reducing BOD. [15] demonstrated that the presence of algae in the aerobic and facultative zones was essential for the efficient performance of these ponds, therefore supporting this attribution. In aerobic treatment ponds, aerobic microorganisms use dissolved oxygen to degrade the organic matter into CO_2, water and cell biomass. Passive or naturally aerated ponds rely on oxygen produced by phytoplankton during photosynthesis and to a lesser extent, diffusion of oxygen from the air into surface layers [16]. The birds at these ponds in Boundary Sewage Treatment plant may have also contributed to aeration of the ponds as well as reduction of BOD by consuming organic matter in the wastewater. The nine days of retention of wastewater in these two ponds at Boundary Sewage Treatment Plant exacerbated the reduction of BOD. This is consistent with the observations by [17] which indicated that the size and number of maturation ponds needed in a system is normally determined by the required retention time to achieve a specified pathogen concentration and organic matter.

Chemical oxygen demand is believed to be reduced partly by the same mechanisms responsible for reduction of BOD. However, this study could not account for the degredation of non-metabolic matter contributing to the COD, since Boundary Sewage Treatment Plant does not use chemicals to treat the wastewater. [1] defined COD as the amount of oxygen required for the chemical oxidation of the organic matter with the help of strong chemical oxidants. The oxygen demand associated with the microbial cells is only partially exerted during a BOD test; also some of the organic compounds measured by COD may not be metabolized by the microorganisms in either the BOD bottle or the biological treatment process [1].

The raw sewage had neutral pH during the two seasons but, the neutrality reduced to near acidic state during dry season and to acidic state during wet season after screen and primary pond stage of wastewater treatment. This reduction of pH could be attributed to the anaerobic degradation of organic matter at the primary pond that produced organic acids and gases like CO_2 and hydrogen ions that when dissolved produce mild acids like organic acid, reducing the pH. This is consistent with the argument by [9] that anaerobic digestion occurs in the sludge at the bottom of the pond which results in conversion of organic load to methane and CO_2 and releasing some soluble by –products into the water column (e.g. organic acids and ammonia).

After the primary pond effluent passed through the flow chamber B and the trickling filter the pH increased to alkaline during dry season and to neutral during wet season. This increase could be attributed to increase or introduction of hydroxyl ions to the wastewater at the trickling filter. The algae at the periphery of Boundary Sewage Treatment Plant TF and at the ridges in the sedimentation tank could be responsible for introduction of hydroxyl ions into the wastewater thereby, increasing the pH. This argument is supported by [18] that the position of oxypause similarly changes, as does the pH since at peak algal activity carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, leaving an excess of hydroxyl ions with the result that the pH can rise to above 9.

The results also portrayed that the pH increased during the two seasons after the trickling filter effluent passed the oxidation ponds. This increase in pH could be attributed to more hydroxyl ions being released into the wastewater under treatment, by the algae at the edges of the ponds. This could also be due to denitrification processes in the secondary pond that is associated with facultative anaerobic processes at the boundary sewage treatment plant. Fact supported by [11]. These authors demonstrated that denitrification occurs where oxygen levels are depleted and nitrate became the primary oxygen source of microorganisms. The authors further indicated that denitrification is an alkalinity producing process. Nitrogen present in wastewater is a reduced form of ammonia and is removed during conventional wastewater treatment by two sequential biological processes; nitrification and denitrification [19,20,21,22].

The temperature reduced after the influent passed through the screen and the primary pond during the two seasons. The temperature in the trickling filter effluent further reduced during dry season while it remained low temperature during wet season. This could be due to the fact that in the filter, sunshine cannot pass through the media to the cemented floor to heat the under drain wastewater. The rotating sprinklers at the trickling filters could also have brought about the cooling effect to the wastewater under treatment.

After treatment in the ponds, the temperature of the treated effluents increased during the two study seasons. During the dry season of study, the increase of the temperature could have been due to heat from sun that heated these ponds directly because they are open.

Total dissolved solids and conductivity increased after the influent underwent treatment at the screen and primary pond. This could be attributed to the anaerobic breakdown of the organic and inorganic materials leading to the release of dissolved solids and hence the increase in the conductivity and TDS. After the flow chamber B and trickling filter the TDS and conductivity reduced. This could be attributed to removal of nitrates in the wastewater through denitrification process. [11] showed that nitrate passing through the process of denitrification is reduced to nitrous oxide, and in turn, nitrogen gas and since nitrogen gas has low water solubility, it escapes into the atmosphere as gas bubbles.

Total suspended solids reduced after the raw sewage passed through the screen and the primary pond. This could be due to removal of solids at the screen i.e. rags, sticks that could have been having suspended solids adsorbed to them [23]. The screen could have also removed the suspended solids therefore reducing the TSS in the wastewater [23]. The primary pond is normally associated with settling of suspended solids hence reducing the TSS. Further, primary sewage treatment follows the preliminary stage of treatment where more solid matter settles and about 40 -60% of suspended solids are removed from sewage by settling [24]. The wastewater under treatment was retained for 4 days at the primary pond before sampling. This duration could have also led to further reduction of TSS because it allowed the solids to settle adequately. These findings are consistent with findings by [25] who observed that with typical retention times (weeks to months) settling is responsible for the removal of the majority of suspended solids and organic nutrients entering anaerobic ponds. The TSS increased after the primary pond effluent passed through flow chamber B and the trickling filter. The increase in the TSS could be due to death flocs from the trickling filter, solids of the media and this construction itself might have peeled out and hence contributed to this increase. Increase of TSS at this stage could also be due to the presence of algae at the floor of the trickling filter especially at the periphery that could have found their way into the treated wastewater. The TSS in samples from the trickling filter reduced after passing through the oxidation ponds due to further settlement of solids, death of microbes and decomposition of organic matter. This is consistent with the observations by [26] that the bacterial and algal cells formed during the decomposition of the sewage settle at the bottom. And eventually the pond is filled.

The graphs showed the difference between the amounts of the parameters during dry and wet seasons. The influent samples recorded higher amounts of the parameters during dry season than wet season and subsequently at the various stages of wastewater treatment. This disparity in the mounts of parameters could be explained by the dilution effect by the rain during wet season. Similarly to studies by [18], they demonstrated that the design parameters such as BOD and COD in oxidation ponds attain maximum values in the hot season and minimum values in the wet/cold season.

The significant reduction of TSS during wet season than dry could be as a result of the high rates of evaporation that occur during the dry season leading to increased concentration of solids that are suspended in less volumes of water. Since evaporation rates are bound to be lower during the wet season, more volumes of wastewater are likely to carry less amounts of suspended solids. These findings are consistent to those of [27] who found that TSS means were higher during dry season than wet and attributed these findings to dilution effect of rainfall.

However, the study would not attribute the reduction of parameters during wet season than dry season to temperature because the temperature difference between the two seasons was not huge, considering the place of study is Kenya in East Africa.

5. Conclusion

From the results of this study, it was concluded that seasonal variation does not affect the performance of conventional wastewater treatment plant. However, the wastewater treatment plant registered lower values of the parameters during wet season than during dry season.

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Statement of Competing Interests

The authors have no competing interests.

References

[1] Ramesh, KJ. Environmental microbiology. Chania: MJP publishers (2004).

[2] Akpor OB, Muchie B. Environmental and public health implications of wastewater quality. African Journal of Biotechnology. 2011 Mar 28; 10(13): 2379-87.

[3] UNEP, Green Hills, Blue Cities: *An Ecosystems Approach to Water Resources Management for African Cities. A Rapid Response Assessment*, UNEP, Nairobi 2011

[4] Wakelin, S.A.; Colloff, M.J.; Kookanal, R.S. Effect of wastewater treatment plant effluent on microbial function and community structure in the sediment of a freshwater stream with variable seasonal flow. *Appl*. *Environ*. *Microbiol*. 2008, *74*, 2659-2668.

[5] Fatta, D., Anayiotou, S. and, I. An overview of the Water and Wastewater Management Practices in Cyprus, In: IWA Specialty Conference,Wastewater reclamation and reuse for sustainability, 2005 Jeju, Korea.

[6] Chandra R, Singh S, Raj A. Seasonal bacteriological analysis of Gola river water contaminated with pulp paper mill waste in Uttaranchal, India. Environmental monitoring and assessment. 2006 Jul 1;118(1-3):393-406.

[7] Eaton, Andreio D., Lenore S. Clesceri, and A. E. Greenburg. "*Standard methods for the examination of water and wastewater*. Baltimore, Maryland, American Public Health Association." (1995).

[8] Mara, D, and International Water Association. *Design manual for waste stabilization ponds in India*. IWA, 2003.

[9] IETC – UNEP. Environmentally sound technologies for wastewater and storm water management: 2002.

[10] Prescott, LM.; Herley, JP.; and Klein, DA. Fifth edition *Microbiology*. McGraw – Hill (2002).

[11] Mackne, C., Lake, A., Casey, P., and Solomon, C. *Trickling filters achieving filtration factsheet*; 1998

[12] Martinko, M., and D. Clark. *Biology of Microorganisms: Pearson International Edition*. Pearson Publishers, 2009.

[13] Environmental Protection Agency (EPA). *Wastewater technology fact sheet trickling filters*. EPA 832 – F – 00 – 014; 2000.

[14] Pena, MVand Mara, D.*Waste stabilization ponds*. University of Leeds, Leeds, UK; 2004.

[15] USEPA., Wastewater technology factsheet: facultative lagoons, US Environmental Protection Agency; 2002 b.

[16] Shilton, Andy, ed. *Pond treatment technology*. IWA publishing, 2005.

[17] The water treatment. Maturation ponds, viewed online 02-02-2012 Http:thewater/treatments.com/wastewater-sewage-treatment/maturation-ponds; 2012.

[18] Mara DD, Pearson HW. Design manual for waste stabilization ponds in Mediterranean countries. *Lagoon Technology International* Ltda; 1998.

[19] Osada T, Kuroda K, Yonaga M. Reducing nitrous oxide gas emissions from fill-and-draw type activated sludge process. *Water Research*. 1995 Jun 30; 29(6): 1607-8.

[20] Wicht H, Beier M. N2O-Emissionen aus nitrifizierenden und denitrifizierenden Kläranlagen. *Korrespondenz Abwasser*. 1995 Mar; 42(3): 404-6.

[21] Tallec, G., Garnier, J., Billen, G., Gousailles, M. Nitrous oxide emissions from secondary activated sludge in nitrifying conditions of urban wastewater treatment plants: effect of oxygenation level. *Wat Res*, 2006 a 40 (15), 2972-2980.

[22] Kampschreur MJ, van der Star WR, Wielders HA, Mulder JW, Jetten MS, van Loosdrecht MC. Dynamics of nitric oxide and nitrous oxide emission during full-scale reject water treatment. *Water Research*. 2008 Feb 29; 42(3): 812-26.

[23] Environmental Protection Agency (EPA). *Guidelines for wastewater reuse*. September EPA / 625 / R – 04 / 08; 2004.

[24] Tortora, G., Funke, B., Case C. *Microbiology: An introduction*. San Francisco: Benjamin Cummings; 2010.

[25] Reed SC, Crites RW, Middlebrooks EJ. *Natural systems for waste management and treatment*. McGraw-Hill, Inc.; 1995.

[26] Atlas RM. *Microorganisms in our world*. Mosby-Year Book, Inc.; 1995.

[27] Monney, I., Odai, S. N., Buamah, R., Awuah, E., and Nyenje, P.M. Environmental impacts of wastewater from urban slums: Case study – old Fadama, Accra. International Journal ofdevelopment and sustainability. 2013. vol. 2 (2): 711-728.