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Performance evaluation of Kangemi Sewage Plant in nutrients and organic matter removal, Nyeri Kenya

S. Hassan, N. Kitaka & W. Muia (Kenya)

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This study estimates the efficiency of Kangemi Sewage Plant. Hence, contributing to understanding the performance of the treatment plant and its impacts on water pollution. The plant treats wastewater through conventional processes. For environmental quality assurance, its performance requires a consistent monitoring to evaluate the impact of the effluents to the receiving waters. Changes in the properties of the effluent can occur along the treatment process, but the final effluent quality is determined by the effectiveness of the treatment process. Key nutrients (Nitrogen and Phosphorus), TSS and BOD5 were determined as the water quality indicators. Kruskal-Wallis test was run at $p<0.05$ significance. Nitrogen, BOD5 and TSS indicated a significant difference among the sites. No significant difference for Phosphorus and pH. Removal efficiency for (BOD5), TSS, Ammonia and TN were 60%, 85%, 59% and 54% respectively. Consequently, the plant had a high removal efficiency for N but low for P.

Background information

Increase in human population, urbanization and enhanced surface runoff from agricultural lands has accelerated generation of wastewater into the recipient waterbodies. Municipal waste and sewage are disposed indiscriminately into water systems such as streams and rivers, posing a threat to pollution of surface water in developing countries (Solomon, 2009). Discharge of wastes due to anthropogenic activities into aquatic systems has resulted to their degradation by frequent reception of domestic and industrial wastes, therefore exposing humans and aquatic biota to multiple health hazards (Bakare et al., 2003). Consequently, this has led to pollution of these systems with excessive nutrients, organic wastes, dissolved ions and inorganic compounds. Kithiia (2012) pointed out that surface water systems in Kenya are increasingly being polluted from both point and diffuse sources as a result of rapid industrialization, urbanization, intensive farming coupled to poor planning for waste management, leading to discharge of wastes into aquatic ecosystems. Increased nutrient concentrations and suspended matter are some of the major properties of degraded river water quality particularly due to sewage input. In a sewage plant, nutrients, organic matter and other contaminants removal varies depending on level of contaminants in the influents and the methods used in the treatment, which will in turn determine the efficiency of their removal. For example, according to USEPA, (2000), removal of nitrogen depends on organic loading which affects efficiency of nitrification in the wastewater. Ineffective control of surface water pollution through poor wastewater treatment compromises water quality, increases treatment costs of drinking water and is a potential health and environmental hazard. Hosetti and Frost, (1998) have suggested that regular monitoring of chemical and biological constituents should be implemented to facilitate regulatory standards to be met before discharge of effluents. Discharging untreated or inadequately treated wastewater into surface waters, including rivers, can facilitate eutrophication due to increased nutrient levels.

Materials and methods

The study site, Kangemi Treatment Plant, lies on (0°25'S and 36°58'E) and discharges effluent into Chania River, in Nyeri County, Central Kenya. Nyeri Town has a population of 119, 273 and an area of 183.10 Km2

(KNBS, 2010). The mean annual temperature ranges from 16-18 °C, with a maximum ranging from 22-24°C (Orodho, 2001). Samples were taken at least thrice per point. The plants average discharge for the 3 months was 3500m3/day implying that the loading of parameters will not differ significantly over time. The plant has a diversion of storm flows ensuring that it doesn't enter the main treatment plant.

In-situ measurements (pH, temperature, conductivity and dissolved oxygen) were taken to determine their variability at the selected points. The sampling design comprised of five sites (1-5 stations) within the plant. Site S1 was at the primary sedimentation tank, site S2 was sampled after the trickling filters in the secondary sedimentation tank just before the maturation ponds, and site S3 and S4 were at the outlet of maturation pond 1 and 2 respectively. Site S5 was at the outlet of maturation pond 3 being the final effluent from the system (Figure 1). Water samples for nutrients (SRP, TP, NO3-N, NO2-N, NH4-N, and TN) BOD5 and TSS were collected in triplicate and analyzed using standard procedures for APHA, (2005).

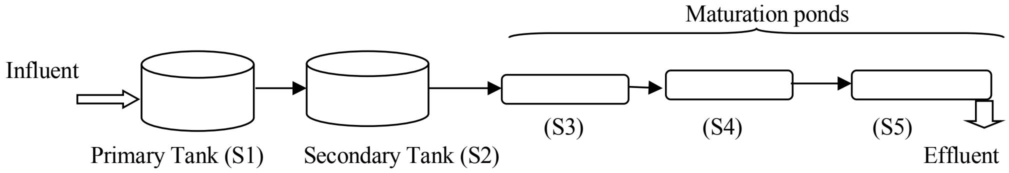

Figure 1. Schematic representation of sites S1 to S5 at Kangemi Sewage Plant

Source: author, 2018

Plant efficiency was estimated using the formula:

$$\text{Efficiency } (\%) = \frac{\text{IC (mg/L)} - \text{EC (mg/L)}}{\text{IC mg/L}} \times 100 \qquad (1)$$

Where, IC is the influent concentration, EC is effluent concentration.

Data analysis

All statistical tests were carried out at $p<0.05$ significance level and data subjected to a normality and homogeneity of variance tests The difference between concentration values of parameters at different sampling points and time in the plant was tested using the Kruskal-Wallis test (ANOVA on ranks). This nonparametric test was selected because of the skewness and heterogeneity of variances of most variables.

Results

Water temperature in the plant ranged between 22.1 ± 0.3 and 24.2 ± 0.2 °C. Temperature differed significantly between the sites (S1-S5). The highest temperature was at site S5 (24.0°C) and lowest recorded at site S1 (22.1°C). Oxygen concentration differed significantly across the sites with lowest DO concentration being at the primary sedimentation tank 0.2 mg/L) and highest at effluent of maturation pond 1 (S3) with (6.9 mg/L). There was a non-significant decline of DO in the ponds from S3 to S5. Water pH did not differ significantly among the sites (Kruskal Wallis, $p > 0.05$). However, the highest pH range of (7.8-7.9) was recorded in S5 (Maturation Pond 3 outlet) while the lowest pH range of 7.3-7.5 was recorded in S1 (Primary Tank). There was a significant difference in conductivity among the sites. Site S1 recorded the highest conductivity (1352.2 µS/cm) value that progressively decreased from S1 to S5 with the latter site having the lowest conductivity (855.9 µS/cm). Table 1 below shows the significance levels at $p<0.05$ for selected parameters of sites S1-S5.

The average value of BOD5 in all the sites was 68.7 mg/L and varied significantly (Table 1) among the sites during the monitored period. The highest mean BOD was 111.21 mg/L at the primary sedimentation tank (S1) and the lowest was 45.3 mg/L at the effluent site (S5) which is above the national environmental recommended effluent standards of 30mg/L in Kenya (Water Quality Regulations, 2016). The highest BOD removal efficiency was recorded between S2 and S3 (Table 2), with lowest removal efficiency between S3 and S4 (2.6 %).The total BOD removal efficiency of the plant based on S1-S5 was 59.2% .The mean value of total suspended solids (TSS) in all the sites of the plant was 56.9 mg/L. TSS concentration varied significantly among the sites (Table 1). The highest TSS was recorded at S1 (191.8 mg/L) and lowest (18.7 mg/L) at site S4. Mean TSS increased slightly at S5 (26.9 mg/L). The measured values did not exceed the effluent discharge standards allowable in Kenya (30 mg/L), (Water Quality Regulations, 2016). The highest removal efficiency for TSS was between S1 and S2 at 87.0% and lowest between S2 and S3 (10.6%). The overall TSS efficiency of the plant was 85.9% (Table 2).

Table 1. Kruskal-Wallis test (ANOVA on ranks) summary on measured variables along sites S1-S5

parameters	H	P=Asymptotic sig. (2 sided test)	parameters	H	P=Asymptotic sig. (2 sided test)
Temperature	36.0[a]	0.000	Ammonia	18.8[a]	0.001
Oxygen	50.4[a]	0.000	TN	80.7[a]	0.000
pH	9.11 [a,b]	0.600	SRP	2.2[a]	0.696
Conductivity	27.8[a]	0.000	TP	4.5[a,b]	0.341
Nitrites	43.0[a]	0.000	BOD	26.2[a]	0.000
Nitrates	37.6[a]	0.000	TSS	31.7[a]	0.000

a. The test statistic adjusted for ties. n=90, TN (n=100), d.f =4

b. No significant differences across samples.

Table 2. Mean ±SE and average removal efficiencies for selected nutrients for sites: n = 90, TN (n=100)

SITES	Ammonia	BOD5	TSS	TN	Organic-N
S1	4.2±0.8	111.2±7.8	191.7±9.9	41.1±1.6	36.7±1.6
S2	2.9±0.3	80.5±11.3	24.9±2.2	61.2±1.8	46.5±1.8
Effic.	*29.6*	*27.7*	*87.0*	-	-
S3	2.8±0.2	54.±9.6	22.2±2.4	60.1±1.2	40.1±1.2
Effic.	*7.1*	*33.0*	*10.6*	-	*13.8*
S4	2.6±0.3	52.6±10.3	18.7±1.4	67.9±1.8	52.7±1.7
Effic.	*7.9*	*2.6*	*15.9*	-	-
S5	1.5±0.2	45.3±7.9	26.9±3.9	18.9±0.8	4.8±0.8
Effic.	*40.2*	*13.8*	-	*72.0*	*90.9*
Overall effic.	***64.0***	***59.2***	***86.0***	***54.2***	***86.9***

*Effic. = efficiency (%)

The mean value of total nitrogen in all the sites sampled was 49.8 mg/L. TN varied significantly among the sites. The highest concentrations of TN (67.9 mg/L) and organic nitrogen (52.7 mg/L) were recorded at S4 and lowest concentration at S5 (Table 2). The overall removal efficiency of the plant for organic nitrogen and TN was 86.9% and 54.6% respectively (Table 2). The mean concentration of ammonium was highest at S1 (4.2 ± 0.8 mg/L) and lowest concentration at S2 (1.5 ± 0.2 mg/L) as shown in (Table 2). There was a significant variation of ammonium nitrogen among the sites (Table 1). The measured values do not exceed the allowable Kenyan discharge standards (Water Quality Regulations, 2016) (≤30 mg/L) at the effluent but, exceeds the recommended ammonia concentration for drinking water (≤1 mg/L), (USEPA 2011). The total efficiency of the plant for ammonium nitrogen removal was 63.9%.

Nitrite concentration varied significantly across the sites. During the sampling period, the average value of nitrite nitrogen in all the sites at the plant was 0.2 mg/L. The lowest concentrations were recorded at S1, (0.01 mg/L) and highest at S3 (0.3 mg/L). The overall removal efficiency of nitrite could not be quantified, since the results showed that there was an increased level (96%) at the effluent (S5) compared to the primary tank concentration (S1). However, the effluent concentration was within the minimum discharge standards for nitrite allowed in Kenya (3mg/L) for discharge into environment (Water Quality Regulations, 2016). The average value of nitrate nitrogen during the monitored period in all the sites at the plant was 10.6 mg/L, with lowest value at S1 (0.2 mg/L) and highest value at S3 (16.9 mg/L). The nitrates concentrations varied significantly in the sites. The overall efficiency of removal for nitrate was not computed because of an irregular pattern, where there was a progressive increase from S1 to S5 (12.1mg/L). The value of nitrates in the effluent was within the discharge limits in Kenya (10mg/L).

The average value of total phosphorus during the monitored period was 1.6 mg/L at primary tank (S1) of the plant and 1.6 mg/L at the outflow (S5). Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) showed no significant variation among the sites (Kruskal-Wallis, $p > 0.05$). Though not significant, there was an increase in SRP from S4 to S5. The highest SRP was recorded in S3 (1.3 mg/L) and lowest value at S1 (1.2 mg/L). Overall efficiency for SRP removal could not be determined due to inconsistent fluctuation among the sites. TP indicated highest value at S1 with 1.67 mg/L and lowest value of 1.48mg/L at S2. The mean ratio of TN: TP ratio was 31:1, which might imply P is the limiting nutrient in the site. The overall efficiency of the plant for TP was very low (2.0%).

Discussion

Physico-chemical parameters such as temperature, dissolved oxygen, conductivity and pH are known to have a profound effect on the nutrient cycling and their dynamics in both wastewater and freshwater systems. Highest temperature 24.1°C at S5 and lowest 22.3°C at S1, were within the range required for effective nitrification which reaches an optimum at temperatures of 30° C. At temperatures below 20 ° C nitrification proceeds at a slower rate, but will continue even at slightly less than 10°C (Water Planet Company). This variation obtained could be attributed to the influence of ambient air temperature. Site S1 was always sampled first in the mid-morning hours and while site S5 was sampled later close to noon when the temperatures were warmer. However, due to high altitude in Nyeri, the ambient temperature does not exceed 30° C. However, it's important to note that maturation ponds are biological systems, which operates under the influence of environmental conditions such as temperature, wind speeds and light intensity (Gray, 2004). Therefore, seasonal change in temperature is a major factor affecting biological wastewater treatment. Lippi et al. (2009) suggested that temperature has a very strong influence on the oxygen saturation levels within treatment systems. Low dissolved oxygen levels were recorded at the primary tank (S1). This is due to high organic load received and a site where decomposition by bacteria actively occurs. The bacterial activity on wastewater organic component may accelerate oxygen consumption leading to anoxic conditions hence favouring denitrification and (volatilization) of ammonia (Mara, 2004). There was improved oxygen levels at maturation ponds, due to light availability hence, algal photosynthesis coupled to reduced organic load. The active breakdown of organic matter due to improved aerobic conditions releases nutrients into the water column that become readily available to algae. Therefore, high algal biomass in the maturation ponds accelerates photosynthesis hence oxygen production. The pH values in the studied sites (S1-S5) ranged between (7.6 - 7.8). pH variation can inhibit nutrient cycling if it falls below or above the range of 6-8, best for bacterial activity (USEPA, 2000). Above and below this pH range would result to slow-down of nutrient s removal (N and P). In this study, highest conductivity at S1, (1352µS/cm) was observed and lowest at S5 (856 µS/cm) that can be attributed to release of ions and nutrients from organic matter decomposition (hydrolysis), leaching and mineralization especially at anaerobic pond (S1) into the water column. However, reduction in conductivity in different sites could be attributed to ion exchange by algal bio-uptake, precipitation, denitrification, adsorption and nutrient lock on substrates and sediments. Generally, degradation and mineralization of organic matter along treatment pathway at primary tank could have resulted to the consistent decline of BOD5 moving from S1 to S5 sites. This can be attributed to increase in oxygen concentration from anaerobic conditions of S1 to improved oxygen levels in sites S2-S5 which resulted to an enhanced organic matter breakdown by bacteria thus reducing the BOD5 significantly in S5. The highest TSS value, recorded at S1, is due to high organic load and suspended debris from the raw sewage after screening and grit removal.

The reduction in TSS between S4 and S5 can be attributed to increased breakdown of organic matter by bacteria to readily available nutrients, attachment and settling. The sedimentation of suspended matter may adsorb some nutrients such as phosphorus in form of precipitates thus becoming readily unavailable for biological uptake. Slight increase of TSS at S5, may be due to high algal productivity accelerated by readily mineralized available nutrients. Some studies have also found that high-suspended solids are associated with algae problem (Mara, 2004 and Kaya et al., 2007). Another possible phenomenon is physical disturbance by fish in the ponds which act as bio indicators, swimming birds and wild ducks frequenting these ponds for feeding. This may result to resuspension of matter in the water column. Shallow depths of stabilization ponds can easily be mixed by wind (USEPA, 2011). Therefore, it is possible that increased TSS at maturation 3 (S5), could have been caused by turbulence and mixing action close to the surface as water flows out of the pond (S5).

Ammonia concentrations declined from S1 to S5 consistently, which could be explained by increase in oxygen concentration thus enhancing nitrification process. The ammonia may have been removed by volatilization as ammonia gas, also through uptake by microbiota or denitrification at anaerobic / ”dead” zones. As it was evident, nitrates increased progressively from S1 to S3, with the highest concentrations at S3, which coincided with the highest dissolved oxygen at the same site. This could indicate a likelihood of high nutrient availability, increased algal activity through active photosynthesis occurring at site 3.

There was no significant removal of phosphorus (TP and SRP) in the sites, which could be attributed to neutral pH which was evident throughout the system. However, the little change in pH, which remained within range of 7, is another factor for non-significant variation of P in the plant sites. Low pH is a limiting factor in the solubility of phosphorus and subsequent precipitation; hence, most phosphorus remained in water column inhibiting significant removal. Elevated pH increases the solubility of metal phosphates, where phosphorus precipitates to metal ions at high pH values above 9 (Zimmo et al., 2003). As indicated by the TN:TP ratio of 31:1, it is possible that P was a limiting nutrient in the ponds thus a possibility of low algal biomass in the maturation ponds. In general, there is a very slow removal of nutrients, BOD and TSS in maturation ponds according to Mara, (2004). Sedimentation and adsorption could be another factor besides algal uptake for phosphorus removal, which makes it readily unavailable in water column (Kayombo et al., 2010). Disturbance of ponds settled matter by fish in the maturation ponds could be a factor resulting to resuspension of phosphorus to the water column from sediments thus affecting the net phosphorus removal from the wastewater. Findings in site S3 indicated a higher peak for dissolved oxygen, conductivity, nitrates and SRP than the other sites. This could mean that S3 may act as an internal source of nutrients to the water column. This phenomenon could be explained by possible accumulation of fine sludge from sedimentation of the remnant suspended matter from secondary tank, since there was no routine desludging undertaken within the plant for almost 10 years according to the plant operator in charge. There is a high possibility that accumulation of fine sludge over time could act as a nutrient or pollutant source. Other factors that have influence on the performance of maturation ponds are inflow, volume and surface area of the ponds (Faleschini et al., 2012). Nevertheless, wastewater concentration, the loading rate, microbiota, and the hydraulic retention time may limit plant’s removal efficiency. Influent into a sewage plant can reduce concentrations of pollutants by dilution effect. Based on findings by Kaczor et al., (2017), influent can increase pollutants in wastewater, with possible increase of pollutant loads despite dilution. Therefore, influent variation affects treatment plant effectiveness, and in consequence, quality of wastewater. Chebor et al., (2017) working in Eldoret Kenya (same climatic conditions as our study area) found that wastewater treatment plant recorded lower values of the parameters during wet season than during dry season.

Conclusions and recommendations

Physico-chemical variables measured during the study showed a spatial-temporal variation across the sites. In contrast, pH did not show significant variation among the sites. Nitrogen showed a significant variation across the sites with most of nitrogen removal in form of organic nitrogen. However, phosphorus did not show a significant variation in the sites sampled. Kangemi Sewage Treatment Plant has high efficiency in the removal of nitrogen and organic matter and low and variable removal efficiencies of phosphorus, nitrates and nitrites within different treatment stages. High BOD5 and TSS at the effluent maybe attributed to high algal productivity or disturbance and re-suspension of organic matter at (S5). Lack of routine desludging of the ponds may be responsible in reducing the efficiency of the plant. Thus regular desludging of the system ponds might improve the plants organic matter removal efficiency. A long-term extensive monitoring of the system structure, water quality and perfomance of Kangemi wastewater Sewage Plant needs to be put in place in order to have a comprehensive understanding of its effectiveness both on spatial and temporal scales. The plant requires proper set up procedure and routine monitoring as part of management and maintenance measures to improve the plants efficiency.

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References

APHA (2005). *Standard Method for the Examination of Water and Wastewater*, 20th Edition. America Water Works Association and Water Control Federation Washington D.C.

Bakare, A., Lateef, A., Amuda, O.S. and Afolabi, R.O. (2003). The Aquatic toxicity and characterization of chemical and microbiological constituents of water samples from Oba-River, Odo-oba, Nigeria. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences,* 5, 11–17.

Chebor, J., Kiprop, E. and Mwamburi, L. (2017). Effect of Seasonal Variation on Performance of Conventional Wastewater Treatment System. *Journal of Applied & Environmental Microbiology,* 5(1), 1-7. DOI: 10.12691/jaem-5-1-1.

China Development Gateway (2015). Wastewater Technology Transfer Partnership: East African Wastewater Treatment and Reusage. http://en.chinagate.cn/archives/wastewater/2015-03/24/content_35140726.htm. (Accessed 25 January 2017).

Faleschini, M., Esteves, J.L. and Valero, M.A. (2012). The Effects of Hydraulic and Organic Loadings on the Performance of a Full-Scale Facultative Pond In: A Temperate Climate Region (Argentine Patagonia). *Water Air & Soil Pollution* 223, 2483–2493.

Gray, N., 2004. "Biology of wastewater treatment", University of Dublin, Ireland.

Hosetti, B. and Frost, S. (1998). A review of the control of biological waste treatment in stabilization ponds. *Critical Review of Environment Science & Technology* 28,193–218.

Kaczor B.G., Chmielowski K. and Bugajski P. (2017). Influence of accidental waters on the quality and loads of pollutants in wastewater discharged into the treatment plant. *Journal of Water and Land Development*, 33, 73–78. DOI: 10.1515/jwld-2017-0021.

Kaya, D., Dilek, F.B and Goekcay, C.F. (2007). Reuse of Lagoon Effluents in Agriculture by Post-Treatment In A Step Feed Dual Treatment Process. *Desalination* 215, 29–36.

Kayombo, S., Mbwette, T.S., Katima, J.H., Ladegaard, N. and Jorgensen, S.E. (2010). Waste Stabilization Ponds and Constructed Wetland Design Manual. UNEP International Environmental Technology Center.

Kithiia, S.M. (2012). *Water Quality Degradation Trends in Kenya over the Last Decade, Water Quality Monitoring and Assessment,* Dr. VOUDOURIS (Ed.), ISBN: 978-953-51-0486-5.

KNBS, (2010). *The 2009 Kenya population and housing census*. Kenya Ministry of State for Planning, National Development and Vision 2030. Government Print Press: Nairobi.

Lippi, S., Rosso, D., Lubello, C., Canziani, R. and Stenstrom, M.K. (2009). Temperature modelling and prediction for activated sludge systems. *Water Science & Technology 59*, 125–131.

Mara, D. (2004). Domestic Wastewater Treatment in Developing Countries, *Earthscan*, London.

Orodho, A. B. (2001). Country Pasture/Forage Resource Profiles. Food and Agriculture Organization. Retrieved (online) December 2016- http://www.fao.org/ag/AGP/AGPC/doc/counprof/Kenya

Solomon, U.U. (2009). The state of solid waste management in Nigeria. *Waste Management Journal,* 29 (10), 2787 – 2790.

USEPA, (2000). *National Recommended Water Quality Criteria EPA-822-R-02-047*. Office of Science and Technology, New York.

USEPA (2011). Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers. EPA 600-R-11-088. Office of Research and Development, Cincinnati.

Water Planet Company, Nitrogen Removal from Wastewater: *Nitrogen Chemistry*, New London Connecticut, www.cleanwaterdrops.com (accessed 20, April, 2018).

Water Quality Regulations, (2016). *Environmental Management and Coordination Act*. (EMCA, 2015), Kenya gazette supplement, Government printer, Nairobi.

Zimmo, O. R., van der Steen, N. P. and Gijzen, H. J. (2003). Comparison of Ammonia Volatilisation Rates in Algae and Duckweed-Based Waste Stabilisation Stabilization Ponds Treating Domestic Wastewater. *Water Research*, 37(19), 4587–4594.

Contact details

Saeed Hassan Kariunga,
Biological Sciences Department,
Egerton University,
P.O Box 536-20115, Egerton.
Tel: +254712846684
Email: hassaeed@hotmail.com

Prof. Kitaka & Dr. Muia,
Biological Sciences Department,
Egerton University,
P.O Box 536-20115, Egerton.
Tel: +254722275856, +254722934560
Email: nkitaka@yahoo.com
wairimumuia@yahoo.com