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Assessment of the current status of water quality and nutrients enrichment of rivers Kisat and Auji and Nyalenda wastewater sedimentation ponds using multivariate technique

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Abstract

Monitoring the condition of aquatic ecosystems is important because they provide ecological goods and services on which human beings depend. The present study analyzed the physico-chemical parameters and nutrients enrichment in rivers Kisat and Auji as well as wastewater sedimentation ponds to inform appropriate management measures. The water samples were collected from eight sampling sites starting at the source running downstream and at the wastewater sedimentation ponds beginning from February to October 2021. The physico-chemical parameters were measured *in situ*, while nutrients were analyzed at the laboratory. The results of the study indicated inconsistencies in the variation of physico-chemical parameters and nutrients enrichment among the sampling sites. The results revealed that dissolved oxygen (DO), electrical conductivity (EC), salinity (sal), total dissolved solids (TDS), turbidity and total nitrogen (TN) showed significance difference between the sites. Similarly principal component analysis revealed variations indicating (temperature, TDS, EC, Sal, TN and Total phosphorus (TP) are the major variables influencing the water quality variations. The overall results demonstrated some sampling sites are heavily contaminated with pollutants attributable to anthropogenic activities. The results of the present study are important for decision making regarding the management of water quality in urban rivers and wastewater sedimentations ponds.

Keywords: water quality, anthropogenic activities, multivariate analysis, aquatic ecosystems, pollution

1. INTRODUCTION

The management of water quality in aquatic systems is of utmost importance to achieving the Sustainable Development Goals for water, food security and health. Therefore, it is of great concern that water pollution has worsened since 1990s in most of the urban rivers in Africa [33]. Up and until relatively recently, interest in water quality was solely centered on direct human uses with little attention paid to monitoring and maintaining water quality in freshwater ecosystems [32]. This is even though surface waters are the most susceptible and vulnerable to pollution because of being exposed to various types of wastes and runoffs [5]. Physical, chemical, biological and hydrological degradation of these systems can lead to functional and structural changes that not only reduce their beneficial value but also may lead to situations that require large expenditures of resources to restore or mitigate these changes [12].

The quality of water in aquatic system is governed by natural factors including weathering, precipitation, mineral deposits, erosion and other geological phenomena [31]. However, water quality of most freshwater bodies around the globe are also impacted to a greater extent by human activities particularly the discharge of waste products (including sewage) or addition of sediments, salts and minerals with run-off from agriculture and urban settlements leading to pollution of these water bodies [33]. Consequently, pollution and the resulting deterioration in water quality not only compromises the ecological goods and services provided by aquatic ecosystems but also directly increases the cost associated with water treatment for drinking as well as increased healthcare cost related to the treatment of water borne diseases [28]. Furthermore, declining water quality attributable to environmental perturbation threatens biotic stability and integrity further hindering ecosystem services and functions through such processes as biomagnification, accumulation of pollutants and eutrophication [24, 39]. Thus, sound knowledge in water quality is essential to understanding the underlying causes and developing evidenced based policies to improve it, including identifying and control at the source, wastewater treatment, ecosystem management and new forms of local governance. Moreover, evaluation of surface water quality as drinking water source is important since they can be the main conduit for the dissemination of toxic pollutants and pathogenic microorganisms [40].

River Kisat and Auji are tropical urban rivers in Kenya, providing water for domestic as well as agricultural use [28]. Unfortunately, the catchments of the two rivers have become degraded over time because of increasing pollutants loads from both point and non-point sources including industrial and municipal discharges [22, 29]. Human population growth has increased especially in informal settlements which has resulted into increased domestic effluents into the rivers causing a massive pollution. Use of fertilizers, pesticides and effluents from the recreational facilities along the rivers represent other diffuse and point sources of pollution into the rivers [18, 28]. Thus, understanding the trend in water quality, both in the past and present is vital if we are to come to terms with risks associated with poor water quality and devise ways to mitigate these risks. Moreover, knowledge in water quality monitoring of River Kisat and Auji can form the basis for future projections of water quality under the influence of the global demographic and climate change.

Water quality monitoring refers to the acquisition of quantitative and representative data on the physical, chemical, and biological characteristics of a water body over time and space [3]. Monitoring of water quality in aquatic ecosystems can be achieved either by direct measurements of both physical (temperature, turbidity, secchi disk depth, color, salinity, suspended solids, dissolved solids etc.) and chemical parameters (dissolved oxygen, biological oxygen demand, chemical oxygen demand, nutrients, hardness, alkalinity etc.) of water or by analyzing the inhabiting biota thus the aquatic ecosystem's quality depends on both the physico- chemical qualities of water and the biological variety of the system [32]. In this study, physico- chemical parameters such as temperature, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity, pH, salinity, alkalinity, hardness, and nutrient (total nitrogen and total phosphorus) were considered as water quality indicators.

Unlike the other previous studies of these aquatic systems, this work focused on detailed analysis of the water quality based on physicochemical data through the application of multivariate statistical techniques. Multivariate statistical technique such as Principal Component Analysis (PCA) have been successfully applied to understand the underlying relationships between water quality variables. The task of monitoring water quality can be facilitated if the relationship between various water quality parameters can be established. Knowledge of these relationships can help identify human activities that significantly contribute to pollution as well as areas that are at risk and promote management practices to reduce non-point sources of pollution [6]. Accordingly, the result of the present study will be useful for identifying the pollution sources within rivers Kisat and Auji for further monitoring and better management actions.

2. MATERIALS AND METHODS

2.1 Study Area and Sampling

Surface water was obtained from two rivers traversing Kisumu City: Kisat and Auji rivers monthly from July February 2021 to October 2021. Water samples were also obtained from Nyalenda wastewater sedimentation ponds. Both rivers Kisat (RK) and Auji (RA) receives wastewater from both industrial and residential sources. Three sampling sites were selected along RK at Migosi wetland, Obunga informal settlement, and Kisat conventional sewerage treatment plant (CSTP) discharge point. Migosi wetland represented the upstream of RK. Obunga is at a point located after RK has passed through the informal settlements areas. This sampling site represented the midstream of RK. KIWASCO was located at a point where the wastewater from KIWASCO conventional sewage treatment plant (CSTP) and runoff from Kisumu golf club enters the lake and thus represented Kisat river mouth. For River Auji, three sampling points were selected with reference to the discharge points from wastewater stabilization ponds (WWSP) located in Nyalenda, Kisumu and to informal settlements located within the study area. Sampling along RA was done upstream (Car wash) midstream (Yellow bridge). Yellow bridge lies downstream of WWSP and also receives wastewater from the nearby informal settlement (Nanga slams). Further downstream was the sampling point near a recreational centre (Hippo-point), Hippo-point which represented the river mouth. WWSP water samples were from Nyalenda wastewater sedimentation ponds (NWWSP). The sampling sites were (inlet) representing pretreatment of the influents and (outlet) representing post treatment effluents. NWWSP was selected because it is located at the eastern part of Kisumu city adjacent to Nyalenda informal settlement area, it receives both wastewater from health facilities and domestic wastewater from the affluent areas within the city and lastly, it discharges the processed water directly into River Auji. The GPS locations of the sampling sites are shown in table 1 and further illustrated in figure 1.

Table 1: GPS Locations of the various sampling points

River	Sampling Points	Representation	GPS Locations Latitude	Longitude
Kisat	Migosi wetland	Upstream	S 00.0738^{0}	E 034.77574^{0}
	Obunga Slums	midstream	S 00.07999^{0}	E 034.75935^{0}
	Kiwasco Discharge	River mouth	S 00.08456^{0}	E 034.74849^{0}
Auji	Car wash	Upstream	S 00.07879^{0}	E 034.78772^{0}
	Yellow bridge	Midstream	S 00.12804^{0}	E 034.74733^{0}
	Hippo point	River mouth	S 00.12535^{0}	E 034.74519^{0}
Nyalenda wastewater sedimentation ponds	Influent pond	Pre-treatment		
	Effluent pond	Post-treatment	S 00.11763^{0}	E 034.77414^{0}

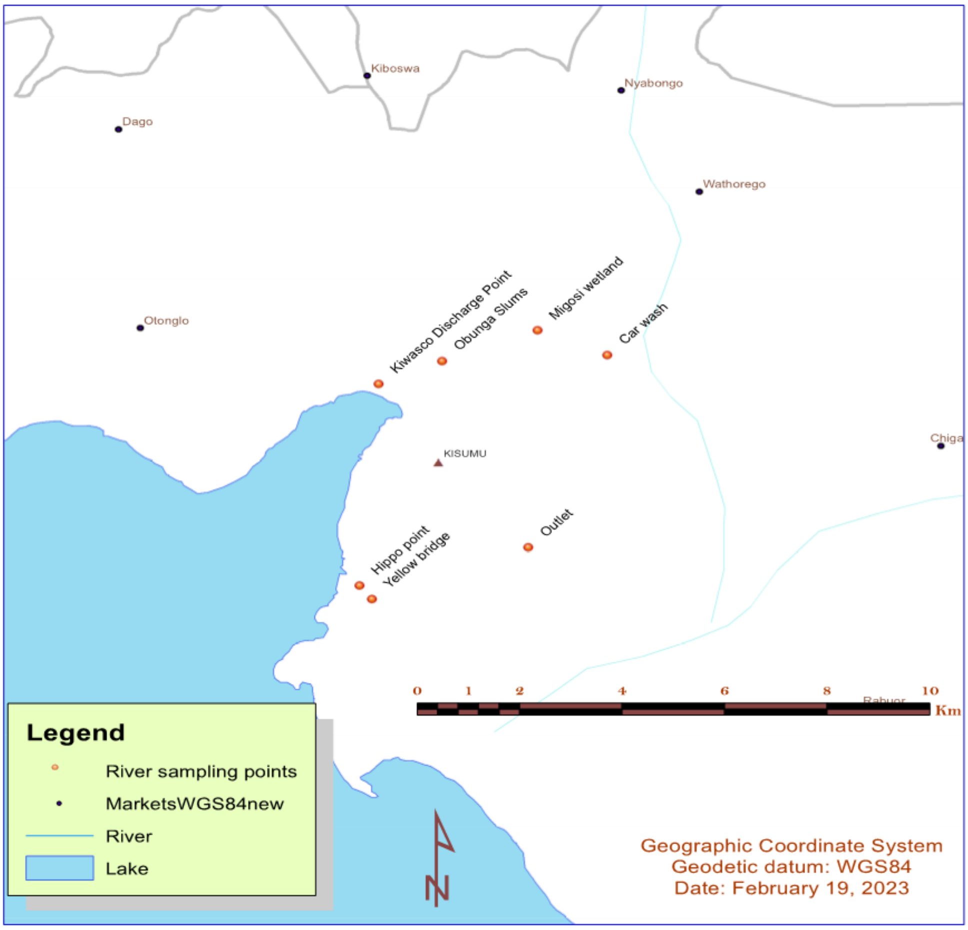

Figure 1. Location of sampling points in rivers Kisat, Auji and Nyalenda wastewater sedimentation ponds, Lake Victoria basin, Kenya

2.2 Measurements of physical chemical parameters

Water samples were collected and analyzed monthly from February 2021 to October 2021 at the eight sampling sites (Figure 1). Eleven physico-chemical parameters were determined including temperature, dissolved oxygen, electrical conductivity, total dissolved solids, pH, turbidity, alkalinity, hardness, total nitrogen and total phosphorus. In situ measurements of water temperature, dissolved oxygen (DO), conductivity, total dissolved solids (TDS), salinity, pH and turbidity were performed using portable YSI Professional Plus multi – parameter instrument (YSI, 35C). Water samples for nutrients analyses were collected in 1 liter polyethylene sample bottles pre-cleaned with (double distilled water). Water samples for determination of total nitrate (TN) and total phosphorous (TP) were collected directly from the two rivers and the wastewater sedimentation pond (WWSP). The bottles were labeled, filled with surface or wastewater and stored in cooler boxes at temperature of 4^{0}C waiting for further laboratory analysis. The water samples were then processed and analyzed using a UV spectrophotometer. The TN and TP concentrations were determined with Ascerbic Acid Reduction method and Diazotization method according to APHA [4]. Total alkalinity was obtained by measuring the amount of acid required to bring the sample to a pH of 4.5. Measurement of total hardness followed a similar procedure using 0.02N ethylene diamine tetra acetic acid (EDTA) as titer.

PRIMER 6 was used to test for variations in physico-chemical variables between the sites. Canonical Analysis of Principal Components (CAP) was used to visualize the relationships between the physico-chemical parameters and the sampling sites.

3. RESULTS

3.1 Variation of physicochemical water quality parameters in rivers Kisat and Auji and Nyalenda WWSPs

The water quality parameters measured at each sampling site in rivers Kisat and Auji and Nyalenda wastewater sedimentation ponds are summarized in Table 2. The study demonstrated substantial changes in the parameters as the rivers flowed to Lake Victoria. During the sampling period, temperature varied accordingly with highest temperature recorded in River Auji whereas the lowest values were recorded in River Kisat. The lowest value 22.20 (0.01) ^{0}C was obtained upstream of River Kisat while the highest 27.69 (2.76) ^{0}C was recorded at the midstream of River Auji. Mann – Whitney test showed no significant difference ($p > 0.05$). The lowest dissolved oxygen (DO) level of 1.63 (0.70) mg/l was recorded at pre-treatment ponds of the WWSP along River Auji while the highest value of 8.07 (0.24) mg/l was recorded upstream of River Kisat. The Mann-Whitney test showed that the mean DO values in the sampling sites were significantly different ($p < 0.05$). The conductivity was lowest upstream of River Kisat 329.51 (29.94) µS/cm. The highest conductivity of 837.07 (39.59) µS/cm was observed at pre-treatment pond of the WWSP. One–way ANOVA test revealed significance difference ($p < 0.05$). The lowest recorded value 245.55 (76.76) mg/l was recorded for TDS at Auji river mouth, while the highest value of 526.01 (36.51) mg/L was observed at pre-treatment pond of the WWSP. One–way ANOVA test showed a significant difference between sites ($p < 0.05$). The highest level of salinity 0.40 (0.02) PSU was recorded at the pre-treatment sampling site, while the lowest value 0.10 (0.03) PSU was recorded at upstream of River Kisat. One – way ANOVA showed a significant difference between the sites ($p < 0.05$). The lowest pH levels 3.88 (1.46) were recorded at Auji post-treatment pond, while the highest level of 7.85 (0.48) was recorded upstream of River Kisat with most sampling stations having a near neutral pH, which falls within the ranges of 6.5 to 8.5 levels for natural water bodies recommended by the World Health Organization guidelines for drinking-water quality. The non-parametric, Mann- Whitney test showed no significance difference in the mean values of pH among the sampling sites ($p > 0.05$). The highest value of turbidity 222.17 (310.77) NTU was recorded at Kisat midstream and lowest value 43.2 (45.16) NTU was recorded upstream of River Kisat. Mann – Whitney test showed significance in the mean values of turbidity ($p < 0.05$).

Total nitrogen (TN) and Total Phosphorus (TP) increased downstream of River Kisat. TN ranged from 218.12μg/L to 1622.97μg/L, whereas the TP ranged from 89.98μg/L to 1088.98μg/L (Table 2). On the other hand, TN and TP decreased downstream of River Auji. The TN value of 1614.10μg/L was obtained at upstream of River Auji while 767.66μg/L was recorded downstream while highest level of TP (966.94μg/L) was obtained upstream of River Auji and the lowest value (542.29μg/L) was recorded downstream. The TN value of 3451.41 (585.80) μg/L was obtained at the pre-treatment of the wastewater sedimentation pond while a reduction in TN value, 1445.55 (365.71) μg/L was obtained at the post-treatment pond. The TP values increased from 1876.64 (434.09) μg/L at the pre-treatment pond to 2201.80 (748.46) μg/L at the post-treatment pond respectively. One–way ANOVA showed a significant difference in the means of TN among sites ($p < 0.05$) while there was no significant difference in the mean values of TP.

3.2 Multivariate analysis of water quality parameters

Variation of how water quality parameters relate to the sampling sites was further summarized in Principal Component Analysis (PCA) (Fig.2). From the PCA, salinity is increasing towards the direction of Nyalenda Wastewater sedimentation ponds (pre-treatment and post-treatment) while temperature, TDS, and conductivity are increasing towards the upstream and midstream of Kisat River, respectively. On the separation of sampling sites, pre-treatment and post-treatment sampling sites are more separated from the other sampling sites. However, there is no separation in terms of the water quality parameters between the two rivers.

3.3 Multivariate analysis of nutrients alkalinity and hardness parameters

Principal component analysis was applied to show the relationship between the nutrient, alkalinity and hardness concentration and the sampling sites and the result are presented in a biplot (Fig. 4.2). The first two axes of PCA (PCA 1 and PCA 2) represent 85.4% of the total variance. The first axis (horizontal) explained 47.8% of the total variability. The second axis (vertical) explained 37.6% of the total variability. The results revealed no clear separation of nutrients between the two rivers. However, total nitrates and phosphates seem to increase towards pre-treatment sampling site.

Table 2: Mean values +SD (in parenthesis) for physicochemical water quality parameters and nutrients for rivers Kisat, Auji and Nyalenda wastewater sedimentation ponds.

	River Kisat			River Auji			Nyalenda WWSP	
Physico-Chemical Parameters	Upstream	Midstream	River Mouth	Upstream	Midstream	River mouth	Pre-treatment	Post-treatment
Temp (^{0}C)	22.20 (0.01)	26.65 (3.10)	26.85 (2.48)	25.90 (1.40)	27.69 (2.76)	25.90 (1.24)	26.15 (0.43)	26.35 (2.11)
DO (mg/L)	8.07 (0.24)	3.95 (1.21)	3.08 (1.13)	3.78 (1.05)	4.13 (0.59)	5.33 (0.47)	1.63 (0.70)	4.87 (0.94)
EC (µS/cm)	329.51 (29.94)	421.73 (157.93)	497.83 (209.19)	422.67 (110.67)	476.01 (102.42)	364.07 (127.17)	837.07 (39.59)	614.61 (77.13)
TDS (mg/L)	272.04 (94.45)	283.01 (15.56)	345.97 (110.90)	291.26 (59.73)	307.62 (38.72)	245.55 (76.76)	526.01 (36.51)	388.14 (78.49)
Sal (PSU)	0.10 (0.03)	0.18 (0.08)	0.20 (0.05)	0.20 (0.05)	0.21 (0.04)	0.16 (0.06)	0.40 (0.02)	0.30 (0.04)
pH	7.85 (0.48)	7.04 (0.79)	6.50 (0.39)	7.19 (0.60)	7.03 (0.71)	7.73 (0.34)	3.88 (1.46)	6.65 (0.42)
Turbidity (NTU)	43.2 (5.16)	222.17 (10.77)	116.47 (4.38)	190.16 (7.03)	89.62 (5.74)	55.60 (1.79)	194.87 (7.89)	183.73 (4.90)
Alkalinity (mg/L)	95.0 (17.40)	113.14 (24.19)	100.0 (47.93)	114.86 (31.26)	103.14 (26.33)	110.29 (41.14)	103.50 (14.64)	108.0 (42.24)
Hardness (mg/L)	94.0 (5.29)	93.43 (19.62)	76.29 (30.03)	83.14 (17.16)	79.71 (17.26)	86.85 (19.32)	92.50 (36.64)	80.57 (28.09)
				Nutrients				
TN (µg/L)	218.12 (80.54)	1003.07 (302.63)	1622.97 (464.60)	1614.10 (673.52)	1348.26 (558.60)	767.66 (211.40)	3451.41 (585.80)	1445.55 (365.71)
TP ((µg/L)	89.98 (54.35)	492.37 (234.51)	1088.98 (438.48)	966.94 (358.97)	756.94 (345.41)	542.29 (225.02)	1876.64 (434.09)	2201.80 (748.46)

Temp, DO, EC, TDS, Sal, TN and TP refers to Temperature (0C), Dissolved Oxygen (mg/L), Electrical conductivity ((µS/cm), Total dissolved solids (mg/L), Salinity (PSU), Total nitrates ((µg/L), and Total phosphorus ((µg/L)

4. DISCUSSION

4.1 Variation of physicochemical water quality parameters in rivers Kisat and Auji and Nyalenda WWSPs

The physical characteristics (temperature, turbidity, salinity and TDS) and chemical characteristics (DO, pH, nutrients, hardness, and alkalinity) have been used as water quality monitoring tools and were considered as water quality indicators in this study. The highest mean temperature of 27.69^{0}C was obtained midstream of River Auji, while the lowest mean value was obtained upstream of River Kisat. The higher temperature can be attributed to direct heating of the open waters by radiation from the sun since the sampling site has little vegetations [28]. The possible explanation of low temperature recorded in sampling site upstream of River Kisat is that the site is sheltered with wetland vegetation, which can result in minimal heating and penetration of direct sun rays. Higher temperatures were also recorded in sampling stations along the River Kisat (midstream and river mouth) and in pre-treatment and post-treatment sedimentation ponds respectively. The higher temperature observed in these sampling stations (along River Kisat) could be due to high turbidity of the waters which absorbs and retain solar energy and also by the thermal heat from the factories situated just before the sampling points. This is supported by a technical report by Kenya Marine and Fisheries Research Institute KMFRI [17] that documented persistent high temperatures in areas with high suspended and dissolved solids. The temperature was noted to be increasing in both river Kisat and Auji compared to [18] and [28] reported in the previous studies and also higher than what [27] reported in River Awach Kibuon (Table 3). The downstream increase in temperature in River Kisat showed a clear agreement with the findings that the maximum temperature increases downstream [36], while the maximum range is found in the midstream [34] as observed in the midstream of River Auji. The source of dissolved oxygen in water bodies include photosynthesis by aquatic plants, atmospheric pressure and rate of its solubility while losses are brought about by decomposition of dead decaying matter, respiration and decay by aerobic bacteria [10]. The presence of oxidizable organic matter can cause a decrease in the concentration of DO in surface waters due to the oxygen depletion by aerobic decomposition of organic waste by microorganisms [38].

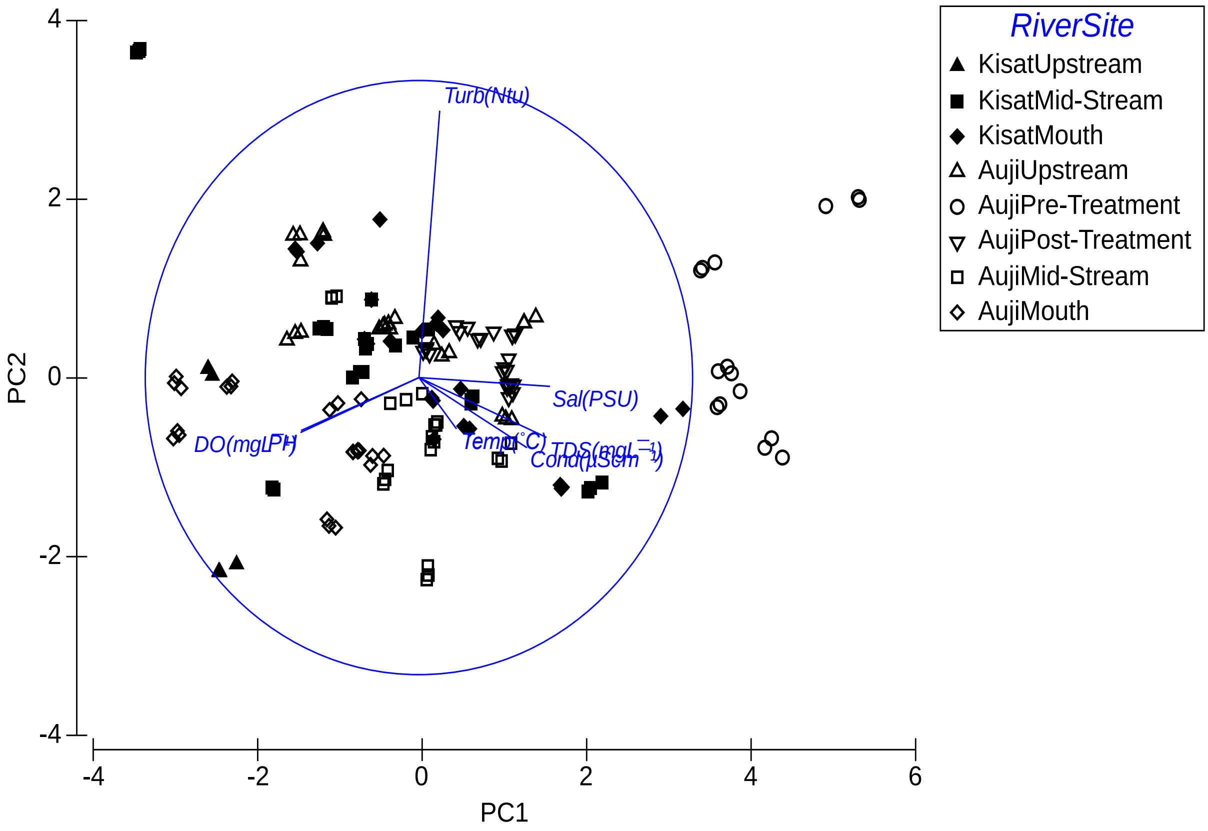

Figure 2: Comparison of physicochemical variables in river Kisat, Auji and Nyalenda WWSP based on sampling sites.

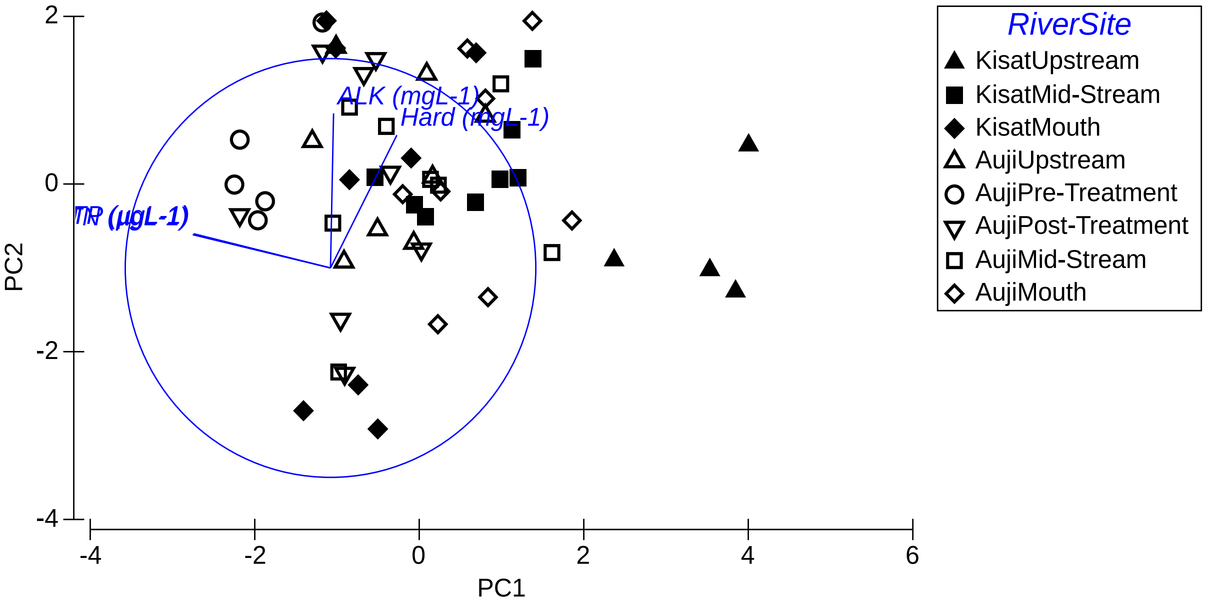

Figure 3: Comparison of nutrients, alkalinity and hardness variables in river Kisat, Auji and Nyalenda WWSP based on sampling site

The amount of oxygen molecule dissolved in water is a major indicator to determine the water quality. Naturally, the DO concentration in 100% saturated freshwater ranges from 7.56 mg/L at 30^0C to 14.62 mg/L at 0^0C. In the present study, the sampling stations showed some remarkable fluctuated results in the surface water dissolved oxygen. For example, only one site (upstream of River Kisat) showed DO levels above 7 mg/L. This could be attributed to the area having minimal disturbances from human activities such as dumping of wastes that deplete oxygen due to decomposition of the organic matter. The sampling sites Kisat river mouth, upstream of River Auji, midstream of River Kisat, midstream of River Auji and post-treatment of the WWSPs showed very low range of DO of 3.08 mg/L, 3.78 mg/L, 3.95 mg/L, 4.13 mg/L and 4.87 mg/L respectively indicating existence of water pollution. The lowest DO (1.63 mg/L) was obtained for water samples at the pre-treatment sampling site, and this was due to dissolved oxygen depletion for oxidation of large amounts of nutrients rich organic and inorganic materials in the sewage discharges into the wastewater sedimentation pond. Furthermore, the increased rate of oxygen uptake through the breakdown of organic matter by microorganisms could be the leading cause of DO deficit [8]. In comparison with other rivers, the levels of DO recorded in this study was lower than what [19, 27] reported in Mara and Awach Kibuon rivers respectively but comparable to the levels reported by [18,28]. upper Victoria Nile river also reported higher DO levels to our studied rivers [7]. Notably, the recorded DO levels in this study are not enough to satisfactorily support aquatic life [15]. Prolonged exposure to low levels (< 5 mg/L) increases an organism’s predisposition to other environmental stressors [26] and has detrimental effects on the survival of fish and other aquatic biota because reduced DO activates physiological regulatory mechanisms liable for maintaining the oxygen gradient between water and tissue, which is necessary for the operation of aerobic metabolic pathways [1].

Table 3. Previous physicochemical water quality parameters in surface water from rivers in Kenya and other parts of the world and the WHO standards

References		Water Quality Parameters										
		Temp (^{0}C)	DO (mg/L)	EC (µS/cm)	TDS (mg/)	Sal (PSU)	pH	Turb (NTU)	Alk (mg/L)	Hard (mg/L)	TN (µg/L)	TP(µg/L)
[18]	R. Kisat	24.2 – 25.2	0.1- 5.8	435.6-795.2	Na	Na	7.2-7.7	98.9-348.1	Na	Na	4948-7116.7	851-1090.1
[28]	R. Kisat	24.63-25.07	3.42-5.92	390.75-839.65	Na	Na	7.08-7.49	32.37-122.9	107.2-199.6	Na	400.7-857.8	342.7-1227.38
[19]	Mara river	14.2-18.5	6.7-7.5	70.5-127	40.5-83.5	0.03-0.06	4.9-6.1	Na	Na	Na	400-800	100-200
[27]	Awach-Kibuon	18.1-22.5	7.23-7.57	55-95.9	42-74	Na	7.42-7.98	51-342	Na	Na	654-1740	50-223
[21]	Vaigai	26-28	2.1-7.5	70-270	100-305	Na	5.8-8.1	4-5	10.5-215	Na	500-900	Na
[14]	River Nile	17.36-30.48	6.98-8.36	346.9-457.6	na	Na	7.32-7.68		Na	Na	27.55-41.23	Na
[16]	Standards	Na	Na	Na	1200	Na	6.5-8.5	5	Na	Na		Na
[36[	Standards	Na	Na	1000	1200	Na	6.5-8.5	5	100	500	Na	Na

Na, Temp, DO, EC, TDS, sal, Turb, Alk, Hard, TN and TP refer to Not available, Temperature (0C), Dissolved oxygen (mg/L), Electrical conductivity ((µS/cm), Salinity (PSU), Turbidity (NTU), Alkalinity (mg/L), Hardness (mg/L), Total Nitrogen ((µg/L) and Total Phosphorus ((µg/L)

Electrical conductivity of water is used as indicator of ionic concentration, its level are governed by total dissolved solids deposited in the water. In tropical river systems, noticeable seasonal variations in rainfall and temperature as well as the flow rate, evapotranspiration and time of residence also affect their conductivity [11]. In the present study, electrical conductivity was lowest (329.51µS/cm) upstream of River Kisat. This was probably due to few dissolved solids thus less contamination of the water because of limited anthropogenic activities. The highest conductivity of 614.61µS/cm and 837.07µS/cm were recorded at post-treatment and pre-treatment sampling sites, respectively. This high electrical conductivity may be attributed to an increase in the concentration of salts as a result of degradation of organic matter and also due to high concentration of dissolved solids due to the discharge of high volume of untreated municipal, domestic and hospital wastes into the WWSP. However, the levels of electrical conductivity reported in the present study particularly River Kisat (329.51 – 497.83µS/cm) were lower than those reported by [18] (435.6 – 795.2) and [28] (390.75 – 839.65) (Table 2) but higher than what [27] reported in Awach Kibuon River. The results of EC observed in the present study were within the WHO standard limit of 1000 µS/cm [37].

Total dissolved solids is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. TDS measures the solids remaining in a water filtered through a 1.2µm filter [38]. In the present study, the lowest TDS value was recorded upstream of River Kisat sampling station while the highest was at the pre-treatment of the WWSP. The high TDS recorded could be due to the dissolved salts in the pre-treated wastewater. The levels of TDS obtained in this study were higher than that found by [19,21,27[in rivers Mara, Vaigai (India) and Awach Kibuon. Similarly, TDS recorded in both River Kisat and Auji was higher compared to those reported in River Gudar (133.00 – 179.00), a peri-urban river in Ethiopia [25] This suggests that there is an addition of organic matter and solid wastes into the studied rivers. However, TDS values recorded were below WHO permitted levels for drinking water of 1200 mg/L [37].

Salinity of water is a crucial parameter for quick assessment of water quality. According to [35], salinity increases pollutants buildup and has an inverse relationship with the water levels. The highest salinity level 0.40 mg/L was recorded at pre-treatment sampling site, while the lowest 0.10 mg/L was recorded upstream of River Kisat. Salts are widely used in chemical and food industries; therefore, the discharge from chemical and food industries within Kisumu municipality into the WWTP could have been the cause of high salinity wastewater recorded. The levels of salinity observed in this study were within the same range with [19].

The concentration of carbonate and bicarbonate alkalinity, along with carbon dioxide in solution, determine pH under natural conditions while in aquatic systems, pH is dependent on the balance between photosynthesis and respiration [32]. The pH affects biological and chemical processes, pollutant solubility as well as natural aquatic life [13]. pH can rapidly change, which in turn may have severe effects on aquatic organinisms [21]. A suitable range of pH is necessary for the survival of fish in water bodies and acid waters reduce appetite of fish and their growth [21]. The pH in both River Kisat and Auji as well as WWSPs in general showed a neutral, slightly alkaline and acidic tendency in some stations. The minimum pH recorded during the study period was 3.88 at pre-treatment sampling station and the maximum noticed was 7.85 upstream of River Kisat. The relatively lower pH might be explained by rapid break down of organic wastes deposited at the influent of the WWSP. These organic wastes use the dissolved oxygen in the water to decompose which causes the formation of humic acid [28], which lowers the pH levels. On the other hand, the pH of the remaining sampling stations was within the range of 6.5 to 8.5 levels for natural water bodies recommenced by European Union. This may be explained by the river's ability to naturally buffer and adequately withstand any basic or acidic discharges. The mean range of pH obtained in this study were comparable to the previous studies by [18] and [28] and were also within the permissible levels of 6.5 – 8.5 for domestic water use recommended by [37].

Turbidity is an extremely useful indicator that can yield valuable information quickly, relatively cheaply and on an ongoing basis. Measurement of turbidity is applicable in a variety of settings from low – resource small systems all the way to large and sophisticated water treatment plants. The lowest turbidity of 43.2 NTU was recorded upstream of River Kisat while the highest turbidity of 222.17 NTU was recorded midstream of the same river. The wetland vegetations near the upstream sampling site acted as a filter, removing most of the sediments before they could be deposited into the river, which is why the recorded turbidity was the lowest. The cumulative effects of re-suspension of sediments conveyed by the river flow from Obunga informal settlement and the associated activities, such as the deposition of wastes into the river, may have caused the highest turbidity measured during this study period. High turbidity in the water samples is an indication of pollution and usually due to direct discharge of wastewater into the river. The results of turbidity reported in this study were lower than what [18] reported but somewhat comparable to what Otieno [28] reported in river Kisat. Furthermore, the levels reported exceeded WHO [37] permissible limit of 5 NTU for surface freshwater bodies. The levels were also higher than 5 NTU recommended by [16]. The high turbidity observed indicates that the rivers and the WWSP contain some dissolved solids and microbial concentrations that can pose problems to aquatic biota [2].

Alkalinity in surface water bodies is primarily influenced by the concentrations of bicarbonate, carbonate, and hydroxyl ions [20]. These ions are created when carbon dioxide in water reacts with basic substances like calcium carbonate from chalk or limestone [30]. Alkalinity is a measure of buffering capacity of water and is important for aquatic life in freshwater systems because it equilibrates the pH changes that occur naturally as a result of photosynthetic activity of phytoplankton [21]. In the present study, low values of (95.0 mg/L) alkalinity were recorded upstream of River Kisat whereas high values of 113 mg/L and 114 mg/L alkalinity were recorded at Kisat River mouth and upstream of River Auji respectively. The low water flow rate observed at these sampling sites may have increased the amount of time the water spent in contact with the parent rock thus accelerating weathering process which resulted into the high alkalinity recorded. Another reasonable explanation for the high levels of alkalinity would be attributed to the ongoing construction of roads and residential buildings at these sampling points. Construction makes use of cement that can be deposited in water as cement is manufactured from limestone that is rich in carbonate thus increasing the levels of alkalinity. The low levels alkalinity observed upstream of River Kisat may be attributed to photosynthesis processes by the wetland plants that have colonized the area and make use of carbon dioxide. Lower levels of alkalinity can also be due to low evaporation rates that increase dilution of the carbonate and bicarbonate ions as limited amount of sun rays reach the river as most of the solar energy are blocked by wetland plants. Results of alkalinity were comparable to [28] but differed greatly with [18]. An alkalinity range of 100 – 250 mg/l $CaC0_3$ for a river is considered to stabilize the pH of a river [38]. The results of alkalinity in this study were slightly high compared with WHO permissible limit of 100 mg/L [37] except for two sampling station upstream of River Kisat and Kisat river mouth.

4.2 Nutrients Analysis

Variation in nutrients levels in surface water systems are attributed to domestic and industrial inputs, municipal and domestic sewage discharges, agricultural runoff, rainfall frequency, atmospheric sources, leachate from refuse dumps and vegetation types and size of the catchment [9]. In the present study, an increase in concentration of TN was obtained in sampling stations downstream River Kisat compared to the upstream sampling sites suggesting possible eutrophication of Lake Victoria. High levels of TN in midstream of River Kisat, Kisat River mouth, upstream and midstream of River Auji sampling sites may be attributed to agricultural runoff from agricultural farms in the neighborhood in which synthetic fertilizers are applied to improve crop productivity, domestic effluents which constitute biodegradable household wastes such as vegetable and animal matter dumped in the rivers and along the riverbanks which is later washed off into the river. The lowest mean values of TN recorded upstream of River Kisat and Auji River mouth sampling sites can be explained by minimal agricultural activities as opposed to domestic, municipal and industrial discharges that have greater loads of nutrients and sequestration by the wetland plants covering an expansive part of the sampling sites. Consequently, the high mean levels of TN obtained at pretreatment sampling site was mainly due to the discharge of municipal and domestic wastewater rich in nutrients. The low levels of TN recorded at post-treatment sampling site were expected since WWSP are effective in removing organic pollutants.

Comparing with other previous studies (Table 3), the concentration of TN in River Kisat was lower than those recorded by [18]. Similarly, the levels were also lower than those recorded by (27) in River Awach Kibuon but comparable concentrations in TN was reported by (28) and [21] in River Vaigai in Maduri City, Tamil Nadu, India. The concentration of TN in River Kisat was higher than those reported by [19] in Mara river, Kenya, River Nile and El-Rahawy drain in Egypt [14] implying that River Kisat is heavily polluted than Mara river and River Nile. In River Auji, the concentration of TN was comparable to those reported by [27, 28], but lower than those reported by [18] but higher than those reported by [19].

Phosphorous that enters the aquatic environment through anthropogenic sources such as fertilizers, run-off and domestic wastewater inflow could be incorporated into either organic or inorganic components. Once phosphorous accumulate within an aquatic system, it can cycle through its water column and promote algal bloom indefinitely [3]. In the current study, the levels of TP increased downstream River Kisat with the highest concentration recorded at Kisat River mouth. This is attributable to the industrial discharges especially from the nearby soap industries as well as cumulative effects of discharges from domestic wastes originating from Obunga informal settlements as well as fertilizers from the Kisumu golf club. The low levels of phosphorus upstream of River Kisat may be as a result of minimal human activities. On the other hand, the levels of TP decreased downstream River Auji with the highest level recorded upstream of River Auji. The high level of TP in this site can be attributed to discharge of grey water from residential areas high in detergents into the river. The use of detergents rich in phosphorus are the main sources of phosphorus in surface waters especially in urban areas [23]. The lowest levels of TP at sampling site Auji River mouth can be attributed to uptake of the nutrients by the high population of wetland plants as wetland vegetations are known to actively take up nutrients.

Additionally, it was noted that the concentration of TP increased rather than decreased in WWSP. This can be attributed to continuous addition and cumulative effects of partially treated effluents from the primary oxidation ponds. TP in River Kisat was lower compared to the previous studies to indicate significant reduction [18, 28]. Comparing the concentration of TP with other rivers, we noted that the concentration of TP in both River Kisat and Auji were higher than those reported in Upper Victoria Nile, Uganda (53.49 – 89.6 μg/L) by [7] and River Nile, Egypt (48 – 387μg/L) by [3].

4.3 Multivariate approach to assessment of water quality

The relationship between the water quality parameters and the sampling sites was assessed by means of Principal Component Analysis. Results showed that temperature, TDS and EC are increasing downstream of River Kisat while salinity, TN and TP are increasing towards the Nyalenda wastewater treatment plant. The increase in temperature, TDS and EC may be attributed to the increased and continuous sewage and industrial discharges as well agricultural activities that lead to the loosening of soils which are eventually washed into the river via runoff. Increase in salinity, TN and TP towards the WWSP ponds could be due to an increase domestic, municipal and industrial discharges that have greater load of salts and nutrients. The results obtained also revealed no separation of water quality parameters between the sampling sites of the two rivers. However, water quality parameters from Nyalenda wastewater sedimentation ponds clustered separately from those of the rivers suggesting a difference in the sources of pollutants among the sites. For example, while the two rivers may be receiving pollutants majorly from diffuse sources (non - point), WWSP receives pollutants from a well-defined source (point source) hence the clear separation observed in this study.

5. CONCLUSION

Based on the data reported above, the following conclusions can be drawn regarding the current water quality status in Rivers Kisat and Auji and wastewater sedimentation ponds

- The temperature is increasing as compared to other previous studies. Drastic temperature changes can be detrimental to aquatic life since temperature controls the rate of all chemical reactions and affect fish growth, reproduction and immunity.
- The decreasing levels of dissolved oxygen in rivers Kisat and Auji indicates increasing organic and inorganic anthropogenic inputs into the rivers.
- Turbidity obtained in this study was higher than the recommended levels by NEMA indicating that the rivers contain some dissolved substances that can pose problems to aquatic biota.
- There is an increase in the levels of nutrients within the rivers and the wastewater sedimentation ponds.

Although nutrients are essential for a healthy aquatic ecosystem, excess nutrients can affect aquatic and human health.

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