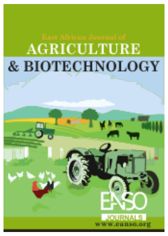

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Original Article

Effects of Agricultural Nutrients Influx on Water Quality in Thiba River basin, a sub-catchment of Tana River Basin in Kirinyaga County, Kenya.

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ABSTRACT

Excessive enrichment of waters with nutrients and the associated adverse biological effects leads to eutrophication, which is one of the major environmental problems across the world. Various studies have revealed the overuse of inorganic fertilizers to increase agricultural productivity in Kenya contributes to pollution of water bodies. In order to meet increasing demand for clean water, sustainable use and conservation of available water resources is therefore paramount. This study was done to find out effects of agricultural nutrient pollution in Thiba River, a sub-catchment of Tana River Basin, located in Kirinyaga County, Kenya. The study area was divided into four distinct agro-ecological zones based on different anthropogenic activities. Ecological survey design was used in the study. Sampling was done during the wet and dry season. Water samples were analysed for temperature, transparency, pH, electrical conductivity (EC), salinity, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), phosphates, nitrates, nitrites, ammonia, and toxic microalgae. All parameters showed both spatial and temporal variations with statistically significant differences ($p<0.01$). Temperature of the river ranged from 14.57 ^{0}C to 28.08 ^{0}C due to climatic changes along the agro-ecological zones. The pH ranged from 7.02 to 8.51. The DO values decreased from the highlands to lowland within the range of 9.00 mg/l at the reference site to 5.43 mg/l at the most polluted site. EC ranged from 20.54 µScm^{-1} at the reference site during the wet season to 251.2 µScm^{-1} at the rice irrigation scheme site during dry season. The TDS ranged from 16.9 ppm at the reference site to 167.05 ppm at the most polluted site. Salinity also had a high variation with a range of 0.01 ppt at the reference site to 0.07 ppt at the most polluted site. The highest values of BOD (3.49 mg/l) were recorded at the rice irrigation scheme during the wet season and the lowest (0.22 mg/l) at the forest edge reference site.

The lowest levels of NH_4, P, NO2 and NO3 were recorded at the forest edge reference site at 1.088 µg/l, 1.177 µg/l, 0.217 µg/l and 0.148 µg/l respectively during the dry season while the highest values for the same nutrients were recorded at the rice irrigation site at 11.439 µg/l, 4.933 µg/l, 1.518 µg/l and 2.721 µg/l in the same order. There was a high peak of all nutrient levels at the rice irrigation scheme zone which was attributed to the extensive use of inorganic fertilizers. Dam water samples were analysed for members of Cyanobacteria group of microalgae which are bio-indicators of eutrophic waters. Out of the seven members of this group that were identified four were toxic genera. These were *Nostoc, Oscillatoria*, *Anabaena* and *Microcystis.* During the wet season *Nostoc* had the highest population followed by *Oscillatoria* and *Anabaena.* No *Microcystis* was observed during the wet season. There was a steady increase of all the genera during the dry season with *Microcystis* making appearance. *Microcystis* and *Oscillatoria* had a very high correlation. This study concludes that various anthropogenic activities especially agriculture along the study site are the main factors of Thiba River pollution hence a major threat to human, livestock and aquatic organisms. Environmental protection laws should be enforced by the government.

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INTRODUCTION

Agriculture is among the greatest contributor of non-point source pollution to water sources in various parts of the world where intensive agriculture occurs (Berka et al., 2001). Agricultural nonpoint sources and other anthropogenic inputs are important contributors of nutrients to the aquatic environment, especially nitrogen (N) and phosphorus (P) (Borbor-Cordova et al., 2006). Phosphorus found in fresh water bodies is mainly anthropological in origin with about 38% coming from agriculture (Mekonnen & Hoekstra et al., 2018). Excessive enrichment of waters with nutrients and the associated adverse biological

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effects leads to eutrophication, which is still one of the major environmental problems across the world water (Bøgestrand et al., 2005). Environmental consequences of nutrient pollution from agriculture may include the degradation of downstream water quality, the eutrophication of water bodies and elevated concentrations of nitrous oxide, a powerful greenhouse gas (Mozumder & Berrens., 2007). Most water bodies where such contamination has occurred have been attributed by fertilizer application practices in agricultural production. These in turn affects the physical and chemical characteristics of the water leading to deterioration of the water quality. This further affects the health of humans and aquatic organisms (USEPA, 2017) as well as increasing water treatment costs (Omer, 2019).

Kenya is classified as a water-scarce country with a water supply of 690 cubic metres per capita per annum against the global benchmark of 1000 cubic meters (Marshall, 2011). The country has been experiencing rapid population growth with a need to enhance agricultural productivity. Various studies have revealed the overuse of inorganic fertilizers to increase agricultural productivity in Kenya contributes to water pollution mainly through runoff (Njuguna et al., 2017). This is evident in Kenyan inland lakes. For instance, the Kenyan side of Lake Victoria has the highest Biological Oxygen Demand (BOD) with atmospheric deposition and land runoff together accounting for 90% of P and 94% of N input into the lake (Scheren *et al*., 2020). Large scale farming of cash crops has also been identified as a major source of inorganic fertilizers that pollute water bodies (Maghanga *et al*., 2013). In order to meet increasing demand of water needs, sustainable use and conservation of available water resources is therefore paramount.

Thiba River Basin, which is part of the Tana River Basin transverses along large-scale agricultural areas that experience extensive irrigation in the highlands. Tana River basin covers approximately 21% of Kenya's total land area and produces about 33.5% of the country's surface water and 23.8% of ground water that supports about seven million people (Njuguna et al., 2020). The river is at risk of eutrophication due to phosphorus deposition among other nutrients from various anthropogenic activities including leached fertilizers from encroached riparian zones. The water is also used for various domestic purposes and discharges into Kamburu Dam, one of the five hydroelectric power generation dams in Kenya. Economic activities along the lake and the rapidly growing population, have mounted environmental pressure on this important source of freshwater in central Kenya (Muriuki et al., 2016). Pollution practices observed can be alleviated to reduce detrimental effects on the health of human and aquatic organisms.

According to Heisler *et al*. (2008), there is a relationship between nutrient pollution and harmful algal blooms. Phosphorus in water is a major driver of eutrophication. Eutrophic water is characterized by harmful algal blooms formed mainly by members of cyanobacteria group or blue green algae. These produce several types of toxins that are collectively called cyanotoxins. These toxins are contained within the cell walls but are released into the water after rupturing of the cell wall upon death and lysis of the alga (USEPA, 2017). Some species are believed to release the toxins extracellularly into the water while still living (Dow & Swoboda, 2000). This study therefore assessed the effects of agricultural- related nutrients pollution on water quality in Thiba River basin, a sub-catchment of Tana River Basin in Central Kenya.

MATERIALS AND METHODS

This study was carried out in Thiba River basin, a sub-catchment of Tana River Basin that covers a surface area of 1,648 square kilometres in the central region of Kenya. It is located in Kirinyaga County situated at 0°34'23.43''S and 37°19'31.7''E (*Figure 1*). The County has a total area of 1,478 square kilometres. The basin is characterized by intensive agricultural activities including large-

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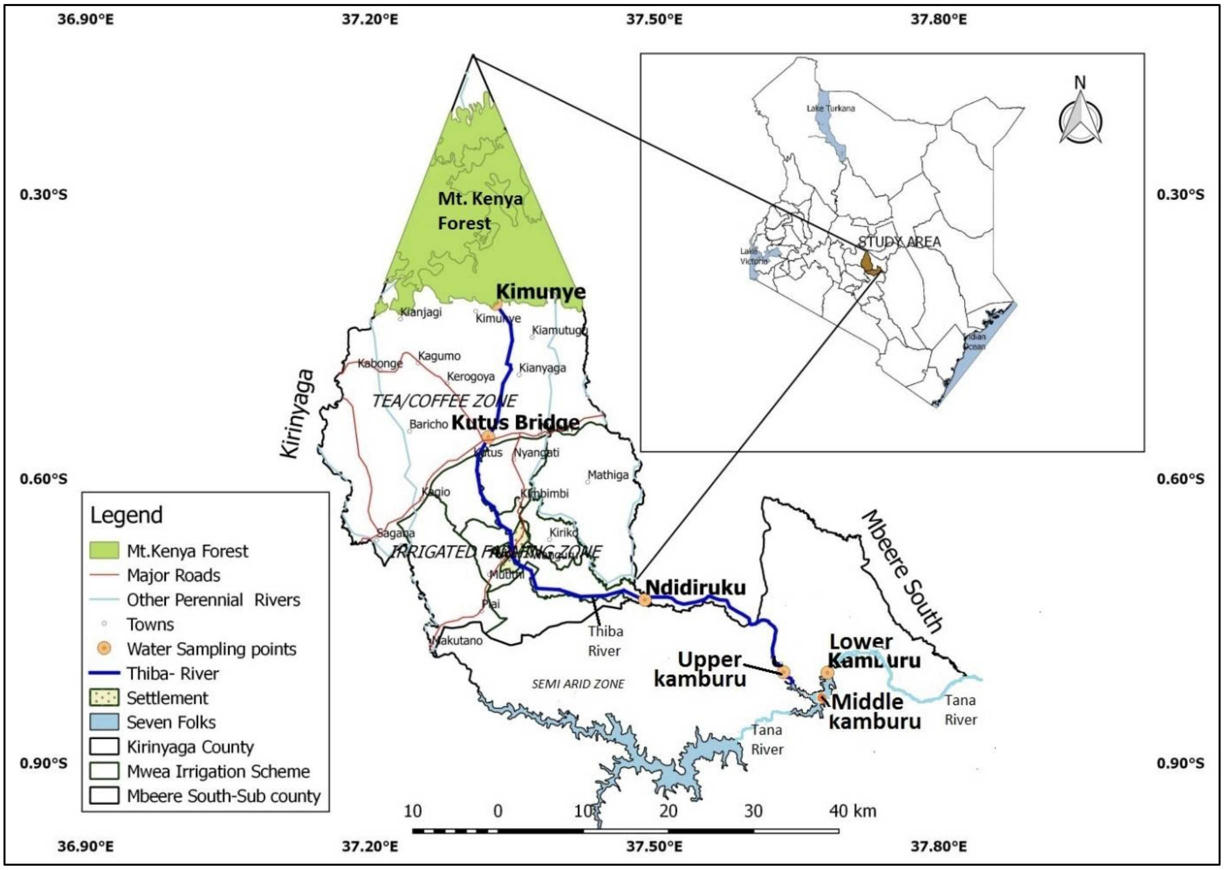
scale cultivation of crops and the largest rice irrigation scheme in Kenya (Veldkamp et al., 2012). The river passes through the middle of the County and discharges into Kamburu Dam, a main source of hydroelectric power generation in Kenya.

Figure 1: Map of the study site



Study design and Selection of Sampling Stations

The method adopted in this study was ecological survey design. In this design the data was collected and analysed without manipulation. The study area was divided into four distinct agro ecological zones (*Figure 1*). The first zone formed the forested area with very minimal anthropogenic activities. In this zone, sampling was done at the forest edge (Kimunye) and served as the reference point on account of its minimal human interference. The second zone was the highlands zone that was dominated by large-scale cultivation of tea and coffee (Kutus Bridge). There were also minimal dairy farming activities and small-scale agriculture for subsistence. The third zone was the midlands zone characterized by extensive rice irrigation scheme and horticultural farming (Ndindiruku Bridge). The fourth zone was in the lowlands and semi-arid, characterized by high temperatures and generally insufficient rains (Kamburu Dam). This zone was dominated by free range livestock farming and subsistence rain-fed farming of food crops that are tolerant to drought. In the dam, three sampling points were selected that were equally spaced from the point of entry of the River into the Dam to the point of exit. Sampling activities were carried out for one year covering both the wet and the dry seasons.

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Analysis of Water Samples

Water samples were collected according to Musselman (2012). They were collected from the river in sterilized 250 ml plastic bottles and transported to the lab in an ice box at 4^0C.

The physical and chemical parameters analysed were temperature, transparency, pH, electrical conductivity, salinity, total dissolved solids, and dissolved oxygen. These were recorded *in situ* using a digital meter model 605596-YSI-Proplus USA. Agricultural nutrients analysed were Phosphates, Nitrates, Nitrites, and Ammonia. These and BOD were done according to standard procedures as outlined by Matsche and Kreuzinger (2001) and APHA (2012). Phytoplankton were collected by filtering 20lts of sample water through a 25µm mesh size cone shaped plankton net with a 50 ml concentrate bottle. Microalgae were examined under a phase contrast microscope using a bright field at a magnification of ×100 and ×400. Identification of the algae was done using standard morphological taxonomy approach that uses features that are observable under light microscopy such as arrangement of cells, shape and size of the cells and shape of colonies where applicable. Microalgae were counted using Sedgwick rafter chamber method. Data analysis was done using computer software SPSS version 22.0.

RESULTS

Analysis of Physical and Chemical Parameters

Analysis of variance (ANOVA) of the data showed highly significant differences ($p<0.01$) for all parameters in all sampling stations in both spatial and temporal variations with the exception of pH and DO. At Kutus bridge there was a significant difference ($p=0.02$) for pH which was not as highly significant as the other stations all of which had $p<0.01$. For DO the same station did not show any significant difference ($p=0.39$) in temporal variation. Machan'ga also did not show any significant difference ($p=0.59$) in temporal variation of the same parameter. All the other sampling stations showed highly significant differences ($p<0.01$) for the two parameters. There were highly significant differences ($p<0.01$) in both spatial and temporal variations for all the four agricultural nutrients in all the sampling stations.

The spatial temperature of the river ranged from 14.57 ^{0}C to 28.08 ^{0}C. The lowest temperature was recorded at the reference point near the forest edge during the dry season while the highest temperature was recorded at the middle of the dam during the wet season. There was a general increase in average temperatures from the forest zone towards the lowlands with the uppermost sampling point registering the coldest temperatures and the lower-most sampling points registering the warmest temperatures. The mean annual recordings were 14.57 ^{0} C at the forest edge, 18.6 ^{0} C at large-scale agriculture site, 22.72 ^{0} C at rice irrigation scheme site and a mean of 28.08 ^{0}C at the dam. This pattern of variation conformed with weather conditions of various agro-ecological zones in the study site from the sub-humid to semi-arid.

The pH ranged from 7.02 at the forest edge during the wet season to 8.51 at the dam during the dry season. The pH values increased as the river flowed from the highlands to the lowlands with the lowest values being recorded at the forest edge and the highest at the upper part of Kamburu Dam. The pH values during wet season were 7.024, 7.490, 7.262, 7.87, 8.348 and 8.36 for Kimunye, Kutus Bridge, Ndindiruku Bridge, upper Kamburu, middle Kamburu, and lower Kamburu respectively.

The DO values showed both temporal and spatial variation within the sampling points (*Figure 2*). The highest was recorded at the forest edge (9.002 mg/l) during the wet season. The average values of DO decrease from the highland zone towards the lowlands zone. The annual same site averages were 8.587 mg/l, 7.840 mg/l and 6.403 mg/l for the reference point, large-scale agriculture point and rice irrigation scheme site, respectively. The annual

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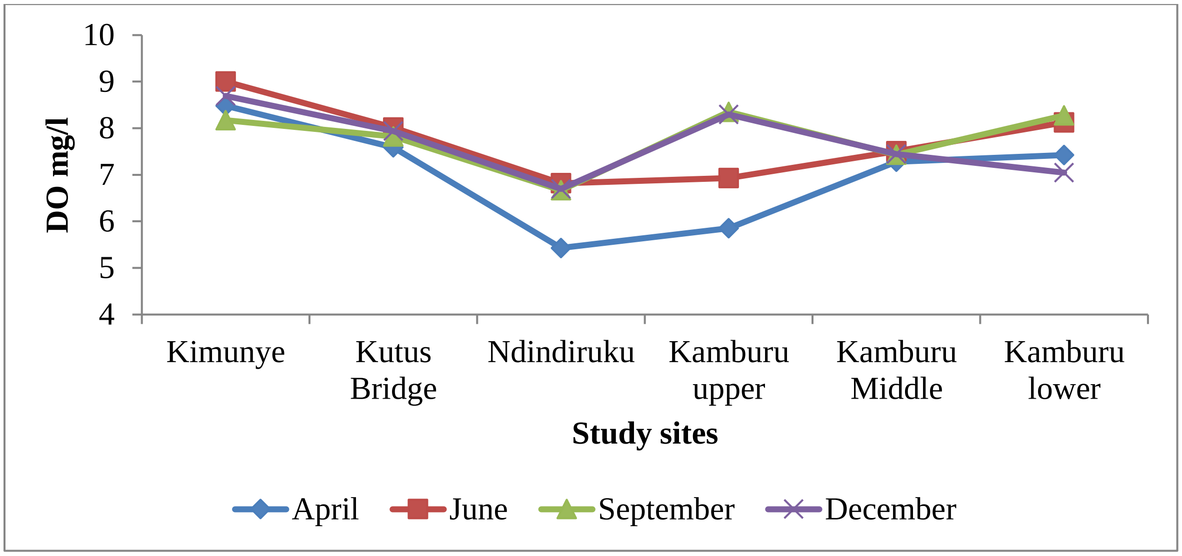
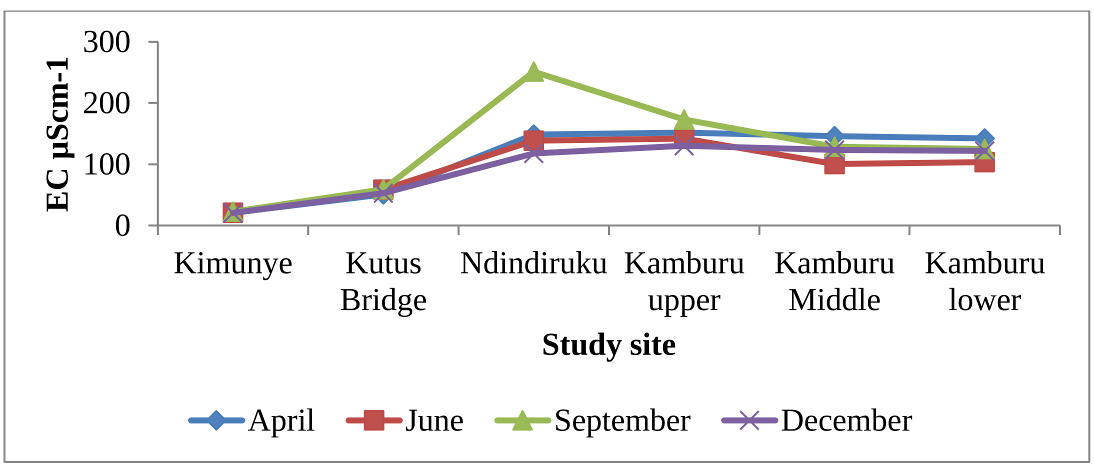
averages within sampling points in the Dam were 7.357 mg/l, 7.416 mg/l and 7.718 mg/l for upper Kamburu where Thiba River enters the Dam, middle part of the dam and lower Kamburu where water exits the Dam respectively. The average values for all Dam sites taken at different seasons showed that DO was lower during the wet season at 6.851 mg/l compared to the dry season in which the average was 8.021 mg/l.

Figure 2: Spatial and temporal changes in DO values along the study site



There was a big variation in Electrical Conductivity (EC) along the sampling site. The highest value was 251.2 µScm^{-1} recorded at the rice irrigation scheme area during the dry season while the lowest (20.54 µScm$^{-1)}$ was recorded at the forest edge during the wet season (*Figure 3*). Temporal variations of EC at the same site were as varied as between the sites. The highest variation was 133.72 µScm^{-1} recorded between the dry and wet seasons at the irrigation scheme area. The lowest same site variation was 1.96 µScm^{-1} recorded at the forest edge between the dry and wet seasons as well. The EC values also followed a similar pattern noted on other parameters of steady increase from upstream to downstream. However, the increase was drastic at the rice irrigation scheme area during the dry season.

Figure 3: Spatial and temporal variations in EC values along the study site



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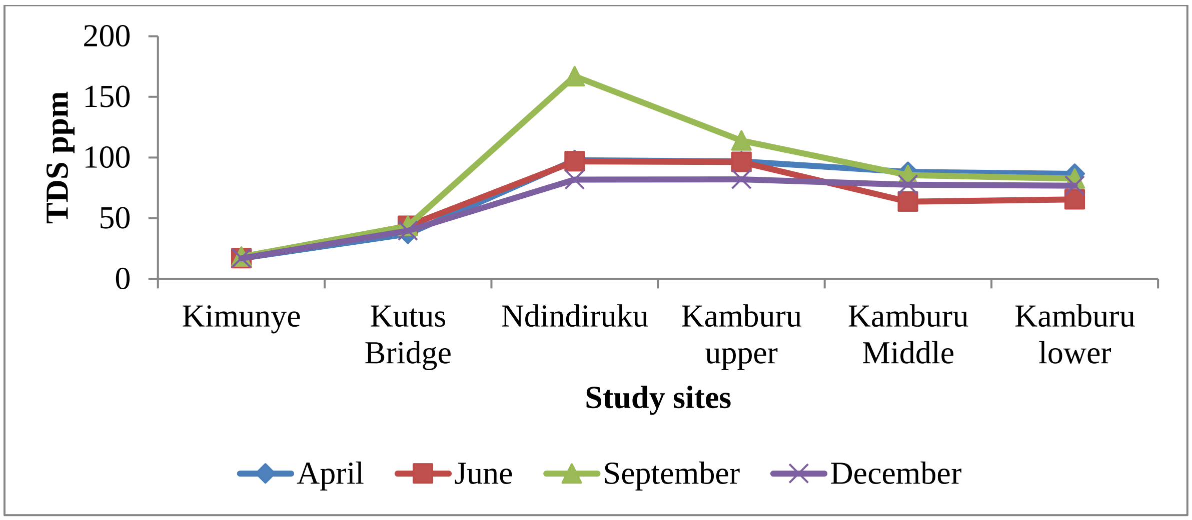
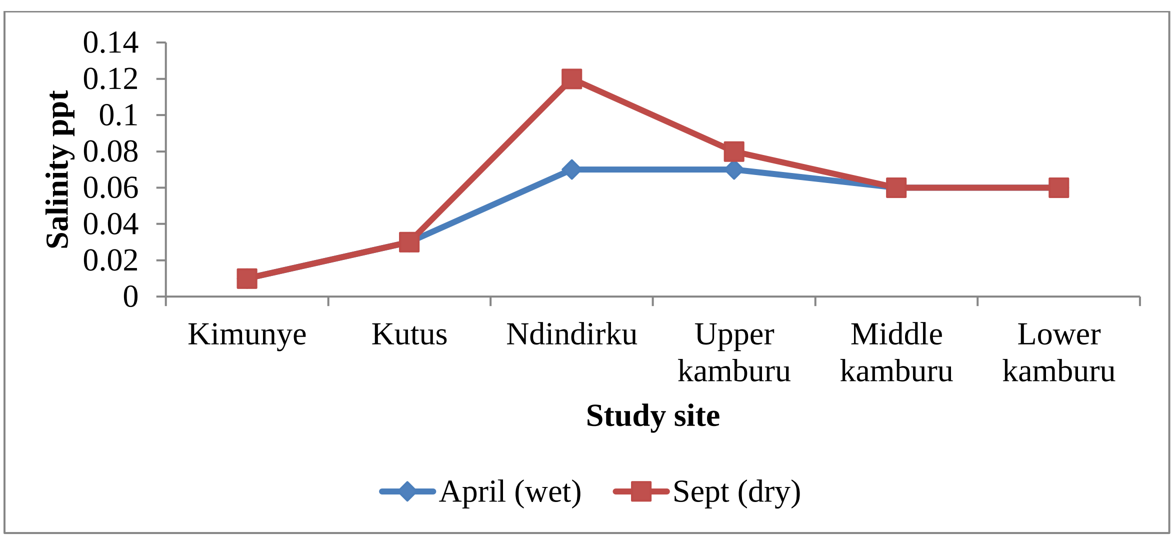
The total dissolved solutes (TDS) also showed a clear variation within and between the sites. The highest value of TDS was 167.05 ppm recorded at the irrigation scheme area during the dry season while the lowest value was 16.9 ppm recorded at the forest edge during the wet season (*Figure 4*). Temporal variations at the same site differed greatly with the lowest being 1.3 ppm recorded at the forest edge while the highest same site range was 85.15 ppm recorded at the irrigation scheme. The general trends of TDS values increased steadily from upstream to downstream with a sharp increase at the irrigation scheme area and stabilized at the Dam.

Figure 4: Spatial and temporal variation in TDS values along the study site



Salinity showed a similar trend of increase from upland to the lowlands in both seasons. The lowest salinity was 0.01 ppt recorded at the forest edge followed by a sharp increase (0.07) at the irrigation scheme site and then decreased and stabilized at the dam (*Figure 5*).

Figure 5: Spatial and temporal changes in salinity at the study site



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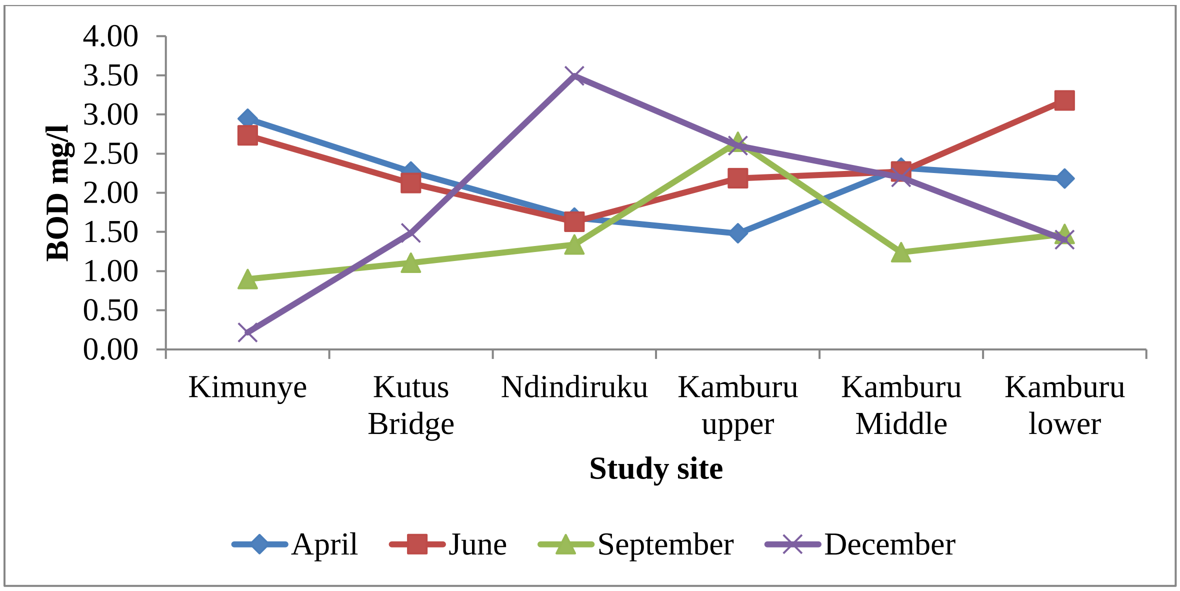
Biological Oxygen Demand (BOD) showed a lot of spatial and temporal variations. The highest value of 3.49 mg/l ±0.192 was recorded at rice irrigation scheme area during the wet season. (*Figure 6*). The lowest BOD value was 0.22 mg/l ±0.10 recorded at the forest edge during the wet season. Same site variations of BOD were highest at the forest edge at a range of 2.72 mg/l and lowest in upper part of the dam at 0.94 mg/l. Unlike other parameters, BOD trends along the study site changed drastically between seasons. For instance, during the long rains, the BOD showed a downward trend from the forest edge through the large-scale agricultural area to the rice irrigation scheme with wide fluctuations at the dam. During the dry season the trend was opposite starting low at the forest edge and increasing downstream with also wide fluctuations in the Dam. During the dry season BOD peaked at 3.49 mg/l ±0.192 in the rice irrigation area then took a downward trend downstream to 1.40 mg/l ±0.081at the lower end of the dam. BOD values were comparatively lower during the dry season but showed an increase at the upper part of the dam where the river discharged its water.

Figure 6: Spatial and temporal variation in BOD values along the study site



Correlation Analysis for Physical and Chemical Parameters

Correlation analysis showed that most of the parameters had similar correlation during both the wet season and dry seasons except for DO and pH that had negative correlation during the wet season (*Table 1* and *2*). DO showed negative correlation with all the parameters during the dry season but during the wet season it showed a strong correlation of 0.92 with water clarity. Water clarity and temperature were strongly correlated during the wet season at 0.86 but this became very weak during the dry season at 0.05. Water clarity and pH were also strongly correlated during the wet season at 0.902 but during the dry season the two become inversely correlated at −0.28. During the dry season the two become inversely correlated at −0.11. Water clarity and EC were also strongly correlated during the wet season but during the dry season the two became inversely correlated at −0.93. Ammonia and pH showed a weak correlation of 0.42 which increased to 0.63 during the dry season. Water clarity and agricultural nutrients are inversely correlated during both wet and dry seasons.

Table 1: Pearson correlation matrix for physical and chemical parameters during the wet season

	Temp.	pH	D.O	E.C	TDS	Salinity	Water clarity	PO4	NO2	NO3	NH4
Temp.	1.0000										
pH	0.8832	1.0000									
D.O	-0.4723	-0.053	1.0000								
E.C	0.9259	0.6557	-0.7523	1.0000							
TDS	0.8929	0.5938	-0.8075	0.9960	1.0000						
Salinity	0.8713	0.5660	-0.8425	0.9852	0.9953	1.0000					
Water Clarity	0.8698	0.9025	0.9295	-0.9943	-0.9560	-0.8963	1.0000				
PO4	0.5005	0.0519	-0.9556	0.7641	0.8132	0.8307	-0.985	1.0000			
NO2	0.6500	0.2686	-0.9749	0.8745	0.9131	0.9372	-0.951	0.9369	1.000		
NO3	0.6287	0.2078	-0.9548	0.8652	0.9026	0.9122	-0.998	0.9809	0.973	1.000	
NH4	0.7863	0.4241	-0.9001	0.9556	0.9760	0.9788	-0.997	0.9164	0.966	0.973	1.00

Table 2: Pearson correlation matrix for physical and chemical parameters during the dry season

	Temp.	pH	D.O	E.C	TDS	Salinity	Water clarity	PO4	NO2	NO3	NH4
Temp.	1.0000										
pH	0.8279	1.0000									
D.O	-0.3149	0.1878	1.0000								
Conductivity	0.7775	0.5077	-0.5825	1.0000							
TDS	0.7583	0.4798	-0.5903	0.9992	1.0000						
Salinity	0.7591	0.4782	-0.5813	0.9979	0.9993	1.0000					
Water clarity	0.0543	-0.2812	-0.1177	-0.9336	-0.9240	-0.8536	1.0000				
PO4	0.5934	0.3512	-0.6166	0.9523	0.9563	0.9479	-0.9796	1.0000			
NO2	0.5598	0.4112	-0.4948	0.9270	0.9310	0.9272	-0.7054	0.9648	1.0000		
NO3	0.6964	0.3948	-0.6747	0.9558	0.9557	0.9451	-0.9433	0.9727	0.8899	1.0000	
NH4	0.7917	0.6358	-0.4564	0.9750	0.9686	0.9636	-0.8206	0.9405	0.9400	0.9314	1.0000

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Analysis of Inorganic Nutrients

Inorganic nutrients analysed were ammonia (NH_4), phosphates (P), nitrogen dioxide (NO_2^-) and nitrates (NO_3^-). These nutrients had similar trends. The lowest levels of NH_4, P, NO_2 and NO_3 were recorded at the forest edge site at 1.088 mg/l, 1.177 mg/l, 0.217 mg/l and 0.148 mg/l, respectively, during the dry season. The highest values for the same nutrients were recorded at the rice irrigation site at 11.439 mg/l, 4.933 µg/l, 1.518 mg/l and 2.721 mg/l for NH_4, P, NO2 and NO3, respectively (*Figure 7* and *8*). These levels remained high during the wet season but were slightly lower than those recorded on the same site during the dry season. There was a high peak of all nutrient levels in the rice irrigation site.

Figure 7: Inorganic Nutrient levels along the study site during the dry season

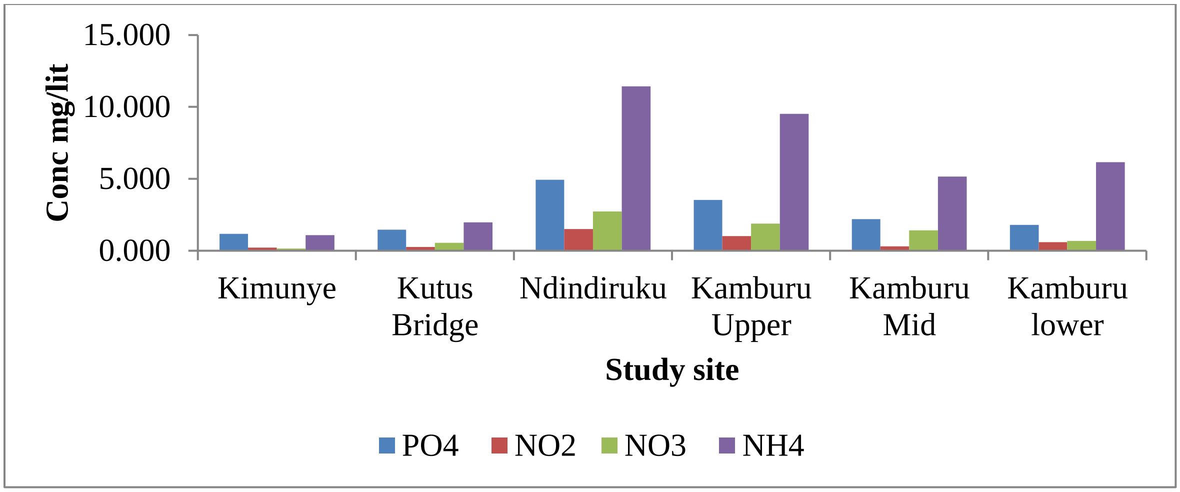
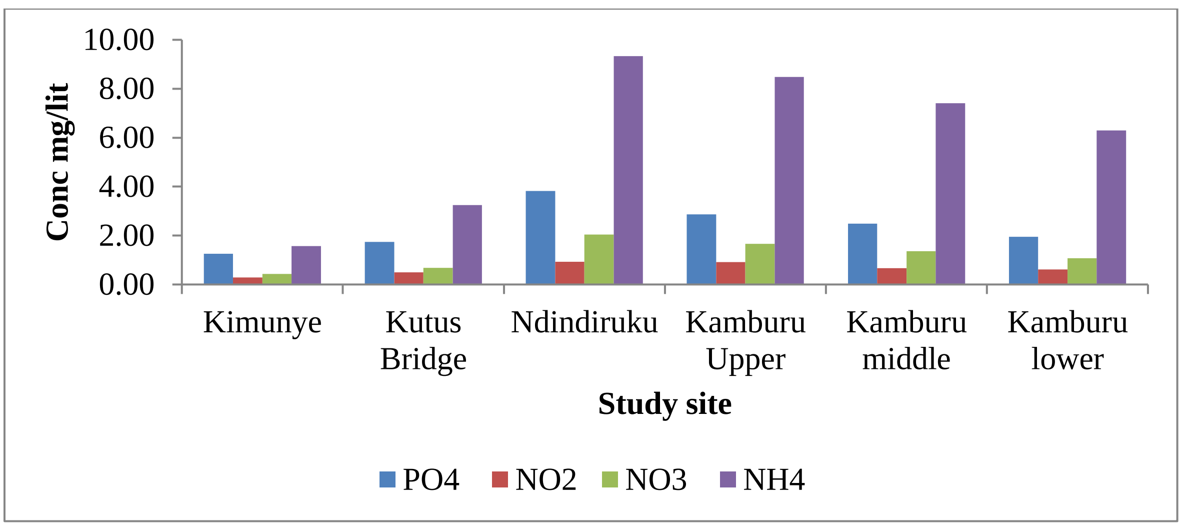


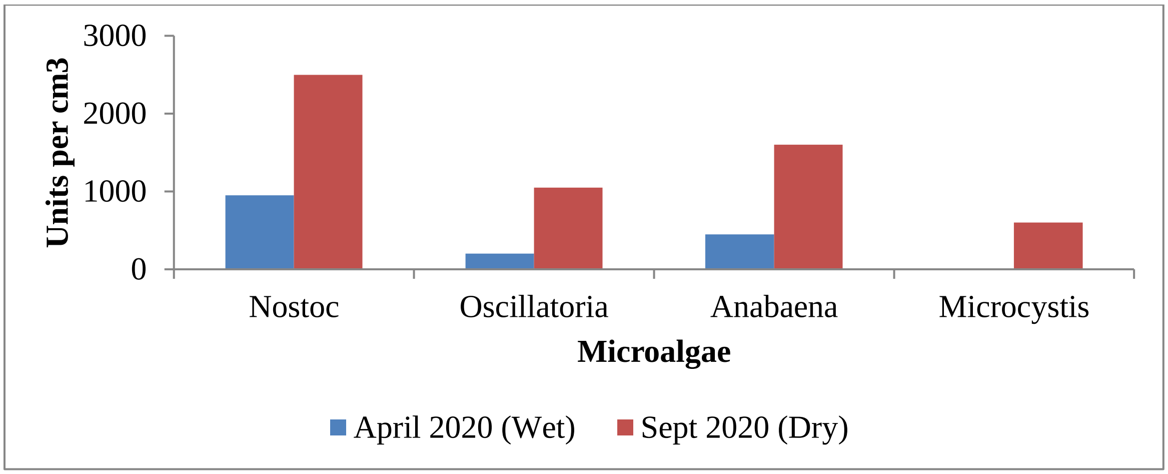
Figure 8: Inorganic Nutrient levels along the study site during the wet season



Characterization of Microalgae from Kamburu Dam

Analysis of microalgae present in the water samples revealed a total of thirty-two genera. Most of the microalgae were from Chlorophyta (12 genera), Ochrophyta (8 genera), Cyanobacteria (7 genera), Charophyta (3 genera) and Euglenozoa (2 genera). This study focused on the division of Cyanobacteria or blue green algae because it has toxic species that pollute water bodies and form harmful algal blooms that produce cyanotoxins that are a health hazard to both humans and animals. Out of the seven genera in this division, four were found to be toxin producing species. These were *Microcystis*, *Anabaena*, *Nostoc* and *Oscillatoria* (*Figure 9*). The population of these microalgae varied greatly between seasons. During the wet season the highest population belonged to *Nostoc* (950) followed by *Oscillatoria* (200), *Anabaena* (450) and none for *Microcystis*. During the dry season the population increased to 2,500, 1,050, 1,600 and 600 for *Nostoc*, *Oscillatoria*, *Anabaena* and *Microcystis* respectively. Generally, the population of microalgae was lower during the wet season with no *Microcystis* being observed but increased considerably during the dry season.

Figure 9: Seasonal variations in abundance of toxic algae in Kamburu Dam



On correlation analysis *Anabaena* and *Nostoc* were negatively correlated while *Microcystis* and *Oscillatoria* had a very high correlation with each other. In one of the samples *Oscillatoria* was observed to grow inside a colony of *Microcystis*. There was also a strong correlation between the microalgae and the four agricultural nutrients. For instance, there was a strong correlation between *Nostoc*, PO_4 and NH_4. For *Oscillatoria* and *Microcystis* the strongest correlation was with NO_2.

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Table 3: Correlation analysis for toxic algae and nutrients within study site

	Nostoc	Anabaena	Oscillatoria	Microcystis	PO4	NO2	NO3	NH4
Nostoc	1							
Anabaena	-0.04	1.00						
Oscillatoria	0.31	0.54	1.00					
Microcystis	0.28	0.48	1.00	1.00				
PO4	0.78	0.55	0.75	0.71	1.00			
NO2	0.63	0.22	0.90	0.90	0.81	1.00		
NO3	0.65	0.72	0.51	0.45	0.91	0.50	1.00	
NH4	0.72	0.30	0.87	0.86	0.90	0.98	0.64	1.00

DISCUSSION

The temperature range of 13.6 ^{0}C – 28.84^{0}C recorded in the study site was notably wider compared to other tropical water bodies but falls within the normal range. Water temperature is important in distribution of aquatic species as well as their performance (Pörtner & Farrel, 2008). A study conducted in Kenya on rivers in the Lake Victoria Basin showed that mean temperatures ranged from 23.2 ^{0}C – 25.2 ^{0}C (Kobingi *et al*., 2009). While water reservoirs in central Kenya showed a mean range of 21.6 ^{0}C – 24.3 ^{0}C (Kitur, 2009), these values show a narrower range compared to the current study. The wider temperature range recorded in this study is attributed to the geographically wide study area that cuts across several different ecological zones with the coldest temperatures being recorded at the forest edge. The results were more agreeable to those recorded in a similar study done on Molo River in Kenya that found the range to be 14.02 ^{0}C - 31.5 ^{0}C (Chebet et al., 2020). A study conducted in Nigeria revealed that surface temperatures for main rivers ranged from 22.6 ^{0}C – 31.0 ^{0}C (Ajibade *et al*., 2008). Thiba River is comparatively cooler in upper zone but warmer than the Lake Basin Rivers and Central Kenya reservoirs. The range of temperatures of Thiba River from highlands to lowlands can be attributed to the different climatic conditions through which the river passes. The forest site had the highest altitude at 1,831.2 meters above sea level and had the lowest annual average temperatures while lower Kamburu Dam was at a much lower altitude of 1,011.3 meters above sea level and had the highest annual average temperatures. This indicates the relationship between temperature and altitude in water bodies. The values of temperature in Kamburu Dam ranged from 22.88 ^{0}C – 29.04 ^{0}C, which is comparatively wider compared to that of Masinga Dam (24.93 ^{0}C – 27.53 ^{0}C) in the same agro-ecological zone (Nzeve, 2015).

Solar radiation is the natural source of heat for all water bodies. Thiba River originates from the melted snow of Mt. Kenya and flows at high altitude passing through the thick Mt. Kenya Forest whose thick canopy shields it from direct sunlight and creates cool conditions in the forest floor. This explains why water temperature is low at the reference site. Turbidity is very low at this forest site owing to minimal human interference and cold temperatures. According to Storey (2014) the optimum temperatures for growth of the common fresh water species such as Tilapia is 21.11 ^{0}C-29.44 ^{0}C while El-Sayed and Kawanna (2008) found the optimal conditions to be 25 ^{0}C – 32 ^{0}C. This type of fish could therefore perform optimally in Kambru dam hence a factor for consideration in aquaculture development.

The pH range of the study site (7.024-8.5) was optimal compared to other water bodies located in

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the same area such as the Masinga dam that showed a pH range of 6.22-8.85 (Nzeve, 2015). Some studies on local rivers obtained similar results. A study on Molo River in Kenya found the range to be higher at 7.90 – 9.66 (Chebet et al., 2020). In Nigeria the range for Asa inland lake ranged from 7.3 to 8.1 with higher values being observed during the dry season (Araoye, 2009). For the current study site, pH was slightly lower during the wet season compared to the dry season. This could be attributed to various factors such as agricultural inputs and chemical pollutants. In the current study there is a higher pH in the dam than in the river. This increase could be attributed to increased algal growth in the dam due to accumulation of agricultural nutrients. Carbon dioxide exists as weak carbonic acid in water. The process of photosynthesis by algae in the Dam extracts CO_2 from the water hence making the water more basic. This explains why pH is higher in the Dam than in the river where there is less algae growth. According to Osman and Kloas (2010), most fresh water bodies have a pH range of 6.0-8.0. A pH range of 6.5- 8.5 is considered safe for both humans and animals (EPA, 2002). This is also the optimum range for growth of common fish such as Nile tilapia (Ngugi et al., 2007). Therefore, the pH range for the study site is therefore ideal for fish production.

Dissolved Oxygen is the amount of oxygen present in the water. It is an important parameter for measuring water quality because it indicates the ability of a water body to support aquatic life. The amount of DO is influenced by temperature. Cold water holds more oxygen than warm water (Taseli, 2006). This explains why the levels of DO are comparatively higher at the forest edge site where temperatures are low. Secondly at higher altitudes land gradient is much steeper compared to the lowlands where gradient is very gentle resulting in faster flow of the water at the highlands. There is therefore more mixing of the water with air especially owing to the many rapids and cataracts created by the rocky bed that is characteristic of high-altitude rivers. According to Hall Jr & Ulseth (2020) gas transfer velocity in rivers varies spatially and is usually higher in rapids and lower in quiescent sections of the river. The ideal DO range for fresh water aquatic life is 6.5 mg/l – 8.0 mg/l hence the value of 5.43 mg/l recorded at the rice irrigation scheme site is too low for aquatic life. This is the section of the river where agricultural activities were highest and highest levels of nutrient pollution were recorded. The main factor is that most of the rice processing plants do not have proper system of disposing large amount of organic waste material. These wastes eventually end up in the river through runoff where oxygen demanding microbial process of decomposition occurs. This could be attributed to the abnormally low DO recorded at the same site. It was observed that DO levels improved in the Dam. This is attributed to photosynthetic activity of microalgae that releases oxygen into the water.

Electrical Conductivity indicates the number of dissolved substances in the water that releases ions. Electrical Conductivity values in the study site showed a very drastic change increasing sharply downstream from 20.54 µScm at the reference site to 251.20 µScm at the rice irrigation site. This is considerably high compared to the range of Masinga Dam within the same basin whose range was narrower at 89.70 µScm – 168.83 µScm (Nzeve, 2015). However, the range for the study area is lower compared to that of Lake Naivasha which seems much more polluted at 270 µScm – 305 µScm (Mwamburi, 2013). The value of EC is dependent on the concentration of ions and temperature. The sharp increase of EC downstream could be attributed to ion releasing pollutants especially inorganic fertilizers from irrigation farming. The values of TDS and salinity were similar to that of EC. These parameters increased steadily downstream to peak sharply at the irrigation scheme, a clear indication of increased water pollution.

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Biological Oxygen Demand is one of the most important and widely used parameter for characterizing the organic pollution of water. It is estimated by determining the amount of oxygen required by aerobic microorganisms to degrade the organic matter in the water to carbon dioxide and water (Jouanneau *et al*., 2013). Sources of organic matter are natural decaying of plants and animals as well as anthropogenic activities such as agricultural runoff, urban runoff, and industrial wastewater discharge. Occurrence of these pollutants in high levels may result in the aerobic microorganisms using all the oxygen in the water for their degradation creating anaerobic conditions that kill aquatic life and cause bad odours (Brenniman, 1999). The data obtained from the current study suggests that wide variation in BOD was as a result of both natural and anthropogenic causes. The sharp BOD raises at the irrigation scheme site and upper Kamburu could be attributed to pollution of the river by agricultural and urban runoff.

The BOD values recorded at the reference forest site of Kimunye during the long rains is predominantly from natural origin coming from terrestrial sources. According to Reyes *et al*. (2016) large amount of dead plant material that decomposes on the forest floor generates large amounts of water-soluble organic substances such as humic and fulvic acids. These find their way to rivers and lakes through surface runoff and leaching during the rains where they cause large changes in BOD. A similar study conducted in Brazil on the Rio Negro River found that dense vegetation cover and warm temperatures created favourable conditions for organic chemistry to provide runoff containing high concentrations of humic and fulvic acids (Syvitski *et al*., 2014). In the current study, BOD levels ranged from 0.216 mg/l at the reference site to 3.49 mg/l at the rice irrigation site. According to Mocuba (2010), BOD less than 4 mg/l is considered to be reasonably clean therefore the value of 3.49 mg/l recorded at one of the study sites shows that the water at this point is at the verge of becoming unsuitable for human use and needs very close monitoring.

Ammonia exists in water as unionized ammonia (NH_3) or as ionized ammonia (NH_4^+). The proportion of these two forms of Ammonia in water is dependent on pH (Hargreaves & Tucker, , 2004). The unionized ammonia is the toxic form and is dependent on temperature (Eddy, 2005). In the current study, ammonia levels ranged from 1.088 µg/l to 11.439 µg/l. Ammonia in levels of 0.53 mg/l – 22.8 mg/l are considered toxic to fresh water organisms leading to poor feed conversion, reduced growth, and low immunity (WHO, 2003). At lethal concentrations fish go into a coma and die (Hargreaves & Tucker, 2004). Excessive and continuous input of nitrogen contaminants into rivers is the fundamental reason for high concentration of ammonia nitrogen in rivers (Zhang *et al*., 2007). In the current study, very high levels of Ammonia were recorded at the rice irrigation site and downstream stations during both wet and dry seasons peaking at 11.439 µg/l at the irrigation site. The high levels are due to the intensive agricultural activities and use of fertilizers (Du *et al*., 2017). The decline in ammonia levels downstream is attributed to microbial activities taking place in the water whose action forms part of the nitrogen cycle. Microbial action is affected by temperature and DO (Covatti & Grischek, 2021; Hargreaves & Tucker, 2013). This means that nutrients levels are interplay of several parameters.

Nitrates and Nitrites are naturally occurring ions and are part of the Nitrogen cycle. The transformation of nitrogen from nitrite to nitrate is affected by temperature (Zheng *et al*., 2016). Being unstable NO_2^- is more reactive and has serious health consequences in both humans and animals. At high levels it creates nitrite toxicity which causes fish mortalities and blue baby syndrome in children (Tilak *et al*., 2007). In human, nitrites can also react with amines and amides in the body to form highly carcinogenic N-nitroso compounds (Parvizishad *et al*., 2017). Regular monitoring of Nitrite levels in

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water is therefore important. Nitrates and Nitrites are discharged into water bodies mainly through surface runoff and leaching (Puckett *et al*., 2002). Nitrate ions (NO_3^-) are loosely bound in soil and being water soluble they are easily carried by surface runoff and also leached into ground water during the rains (Puckett *et al*., 2002).

A research study demonstrated that early stages of rainfall are crucial in loss of farmland fertilizer and accumulation of nitrates in ground through surface runoff (Wang *et al*., 2015). An analysis of long-term data on Nitrate levels in Warta River in Poland showed a clear increasing trend in Nitrate concentration that was associated with the increasing use of inorganic fertilizers (Gorski *et al*., 2017). A similar study in tea plantations in Kenya found the levels of nitrates in nearby rivers to be linked to application of fertilizers on the tea plantations (Maghanga *et al*., 2012). In the current study high nitrate values at the rice irrigation scheme is the result of extensive use of inorganic fertilizers. The decrease in the levels of the nutrients in the dam is attributed to absorption of nutrients by aquatic plants in the dam, microbial action by nitrifying bacteria and binding of the nutrients to sediments (Pastén-Zapata *et al*., 2014).

Sources of phosphates in water are mainly non-point such as erosion and sedimentation, decomposition of naturally occurring minerals, atmospheric deposition, and agricultural runoff (USEPA, 2017). Phosphorus may also be from point sources where industrial and organic wastes such as sewage are discharged into rivers. Phosphorus is critical in supporting aquatic life but is a major driver of eutrophication in water bodies when in excess (Hossain *et al*., 2006). In the current study temporal and geographical distribution of phosphates was found to follow a similar pattern to that of nitrates although comparatively higher in quantities. These results were similar to those documented by Adesuyi *et al*. (2015) who found the same relationship between nitrates and phosphates in a study conducted at Nwaja Creek, Nigeria. This strongly suggests that the phosphates and nitrates have common origin chiefly inorganic fertilizers from irrigation agriculture practiced around the study site.

Algae are known to be good indicators of pollution owing to their wide temporal and spatial distribution, rapid reproduction rates and short life cycles (Omar, 2010). Algae species are specific and well correlated with particular types of pollution. Cyanobacteria or blue green algae which are classified as toxic grow well in organically polluted waters and their absence is an indicator of clean water (Sen *et al*., 2013). *Oscillatoria* on the other hard is known to be tolerant to organic pollution and is a good indicator of organically polluted water. Excessive growth of toxic algae is largely caused by nutrient pollution particularly Nitrogen and Phosphorus (Anderson *et al*., 2002). In high densities cyanobacteria are an undesirable component of fresh water ecosystems because they produce cyanotoxins that disrupt food webs by killing aquatic organisms (Bruun, 2012). *Microcystis, Anabaena, Nostoc*, and *Oscillatoria* produce microcystin and cyanopeptolin which are neurotoxins and hepatotoxins (Havens, 2008). Cases of cyanotoxin poisoning have been reported in Kenya. In 1999, about 30,000 flamingoes died in Lake Bogoria, Kenya and continue to cause mass deaths of flamingoes every year (Krienitz *et al.*, 2003). In addition, mass mortalities of fish along the Kenyan coast have been attributed to harmful algal blooms, although not much has been adequately studied (Kiteresi et al., 2013). Another case of phycotoxin poisoning in Kenya was in 2002 when a large number fish died along the Kenyan coast (Kotut *et al*., 2006). In a study on Lake Baringo, Kenya by Andreas *et al*. (2002) found the phytoplankton community in the lake to be largely dominated by cyanobacterium *Microcystis aeruginosa.* An investigation into toxic cyanobacteria in Kenyan standing waters found *Microcystis* and *Anabaena* to be the most common species while *Anabaena* and *Anabaenopsis* were

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common in alkaline saline lakes (Kotut *et al*., 2006). Microcystin and anatoxin-a have been detected in seven Kenyan lakes and a hot spring (Kotut *et al*., 2006). Exposure of humans to cyanotoxins can cause nausea, abdominal pain, atypical pneumonia and liver damage (Giannuzzi *et al*., 2011) hence they require continuous monitoring in aquatic ecosystems. The presence of four genera of toxic algae in Kamburu Dam is a matter of concern that requires immediate action to control nutrient pollution in Thiba River Basin.

In the current study *Nostoc* was found to be the most abundant of the four toxic genera that were identified in Kamburu Dam. This is attributed to ecological adaptations of this alga (Basheva *et al*., 2018). Perhaps the most important adaptation and which plays a key role in the abundance of this alga is the presence of special thick-walled cells called akinetes that can withstand extremely harsh conditions such as desiccation for many years and still remain viable (Dodds *et al*., 1995). *Nostoc* is also unique in that it exists in both aquatic and terrestrial habitats. According to Dodds *et al*. (1995), *Nostoc* can resist predation by grazing algivores by forming too large colonies that are surrounded by a sheath like material of toxic microcystins around it. However, it has the ability to fix nitrogen especially in rice (Dodds *et al*., 1995; Alvarez *et al*., 2020). This could be the reason why *Nostoc* had the highest abundance in the current study especially in the rice irrigation scheme. *Anabaena* is also filamentous and has the ability to fix nitrogen but does not form akinetes hence is not as abundant as *Nostoc*. *Microcystis* was found to be the least abundant of all toxic algae identified in the Dam with none being observed during the wet season. This is attributed to its annual life cycle that includes a benthic resting phase during the wet season and the planktonic proliferation phase during the dry season (Straub *et al*., 2011).

The increase in algal populations during the dry season is attributed to increased sunshine, warmer water temperatures and increased light penetration as a result of settling down of the suspended particulate matter all of which are favourable to algae growth (Lueangthuwapranit *et al*., 2011). During the rains water transparency is reduced and light penetration low due to increased turbidity mainly from soil particles from a degraded catchment. This curtails photosynthetic activity hence the low algae population during the wet season.

CONCLUSION AND RECOMMENDATIONS

This study concludes that various anthropogenic activities especially agriculture along the study site is the main factor contributing to water pollution hence a threat to human, livestock, and aquatic organisms. Values in physical and chemical properties varied along the site during both the wet and dry season while those of nutrients increased steadily from upstream to downstream. Major area of concern was at the rice irrigation scheme where high level of nutrient pollution was recorded rendering the site unsuitable for aquaculture. Pollution of Thiba River by agricultural nutrients from the irrigation scheme is responsible for the rapid growth of microalgae in Kamburu Dam. This poses an environmental threat to the reservoir if left uncontrolled. Another concern is the abundance of toxic microalgae in the dam that if left unchecked could make the Dam eutrophic and eventually an ecological disaster. To cub this trend, environmental protection laws in the County with particular emphases to water pollution should be strictly enforced. This would create a sustainable water resource that can be used to culture some of the common fish along the river for income generation and increased food security.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest in the publication of this work.

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