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Assessment of Primary productivity, Nutrient levels and Trophic status of Kuinet dam, Kenya

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Abstract
This study was carried out in Kuinet (Chepkongi) Dam within Uasin-Gishu County, Kenya to assess primary productivity, nutrient levels and trophic status of the dam. Water samples were collected at four sampling stations (inflow, outflow and in the middle) of the dam monthly from November 2014 to January 2015. The samples were used to assess the chloropyhll-*a*, net primary productivity and the main physico-chemical variables. Phytoplankton was sampled using a phytoplankton net, identified and counted using an inverted electronic microscope. Canonical Correspondences Analyses was carried on to ascertain the correspondence relationships of the sampled parameters. The trophic status was calculated using the Carlson method considering the parameters: chloropyhll-*a*, Secchi Depth and Total Phosphorus. The phytoplankton community of Kuinet Dam is composed mainly of four families; Bacillariophyceae and Chlorophyceae families each had 11 species followed by Cyanophyceae with 5 species and Desmidiaceae with 3 species. The family Chlorophyceae dominated in abundance in all months. Net primary productivity ranged from 0.182±0.09 $mgO_2L^{-1}d^{-1}$ in December to 0.299±0.13 $mgO_2L^{-1}d^{-1}$ in November. Dissolved Oxygen, net primary productivity, Biological Oxygen Demand and temperature displayed similar trends during the three sampling months. Chlorophyceae had near correspondence with these three parameters than the others according to CCA. The trophic status of the Dam resulted both mesotrophic and eutrophic. From the study, we reject the H_O hence the primary productivity of Kuinet dam favors aquaculture during the dry spell period. This in turn aids in facilitating the achievement of attaining the estimated potential production level of 2000 tons according the Uasin Gishu district environment action plan 2009-2013.

Keywords: Assessment, Primary productivity, Nutrient level, Trophic status, Kuinet dam

1. Introduction
Primary productivity is a desirable attribute for environmental health of surface waters (dams, rivers, lakes, estuaries and oceans) [13]. The critical importance of ensuring an optimum environmental quality of any aquatic environment is a major factor in obtaining good productivity and ultimately high fish yields (Ryder, *et al.* 1982.)
The quality of surface waters in this environment is determined by the chemical, physical and biological characteristics but owing to inadequate management of wastes, freshwater for production potential has been reduced due to widespread pollution. Previous studies have shown deterioration of water quality and low faunal abundance and diversity caused by stress imposed by effluents from land based sources [11]. This, therefore, calls for continuous investigation into the processes that occur in our water systems.
There is need to know the trophic status of dams/reservoirs ecosystems in order to know the aquaculture potential, which have not yet been exploited much for aquaculture production despite their potential, since this information is not available despite their potential [13].
Among the 3,000 minor reservoirs (<0.1km^2) in Kenya that have been constructed to supply water for industrial and domestic use, irrigation farming and watering livestock and wildlife (Balarin, 1985), many reservoirs have been stocked with fish, with the aim of increasing their productivity and support local livelihoods. Before the year 2030, the Kenyan government has plans to add around 2,000 dams in arid areas [20].
Among the constructed dams to supply farmers with water for irrigation [25], some have been stocked with fish, however, their suitability and potential for aquaculture is not yet established. In Uasin Gishu country there are over 120 dams with an average annual production of 3000kg of fish and the fisheries production patterns in these environment has been increasing drastically and has an estimated potential production level of 2000tons, this has a drawback

since there is still Lack of awareness, need for stocking and more research to be done on such environments [22, 23].

The general objective of this study was to assess the potential of Kuinet Dam's potential for aquaculture production. The Specific objectives were; To determine primary productivity and nutrient levels in the Dam, to determine nutrient levels and physical and chemical characteristics of the dam and use them to determine its trophic status, to determine diversity, composition and relative abundance of various phytoplankton taxa in the dam and finaly t o assess the potential of the dam for fish production.

The main research hypothesis that was tasted for the study was $H_{O.}$ The primary productivity doesn't favor aquaculture.

2. Methods

2.1 Study area

The study area is a privately owned satellite dam located in Uasin Gishu county Kenya, latitude and longitude of 0.643314°'N, and 35.298132°'E, respectively (GPS readings, Garmin model) (Figure 2).

The dam covers approximately 2,450 m^2 with a maximum depth of 4 m. The area has two general climate seasons: the wet season (April-September) and the dry season (October-February) [14]. 3000 species of Nile tilapia *Oreochromis niloticus* were introduced in the dam by the private owner in the year 2012. The most common land use is maize and dairy farming, although horticulture mainly kales and tomatoes is also practiced, as evidenced by the existence of a greenhouse on the edge of the dam. The dam was selected for this study on the basis of the main anthropogenic disturbances impacting it: crop farming, agroforestry, private and public uses which have implications on water quality, run-off, nutrient input and general pollution into the dam.

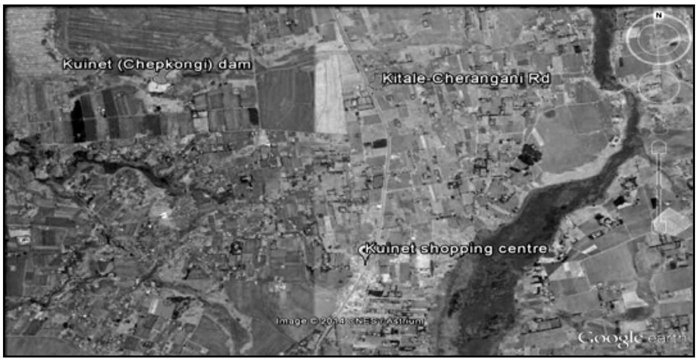

Fig 1: Location of Kuinet (Chepkongi) Dam Satellite image (Source: Google Earth).

2.2 Research design

Four different stations (A, B1, B_2 and C) were selected throughout the dam as representative of the total area: one at the inlet, two at the center of the dam so as to reduce the sampling error because of the dam's dynamics and the last at the dam's outlet (Figure 2).

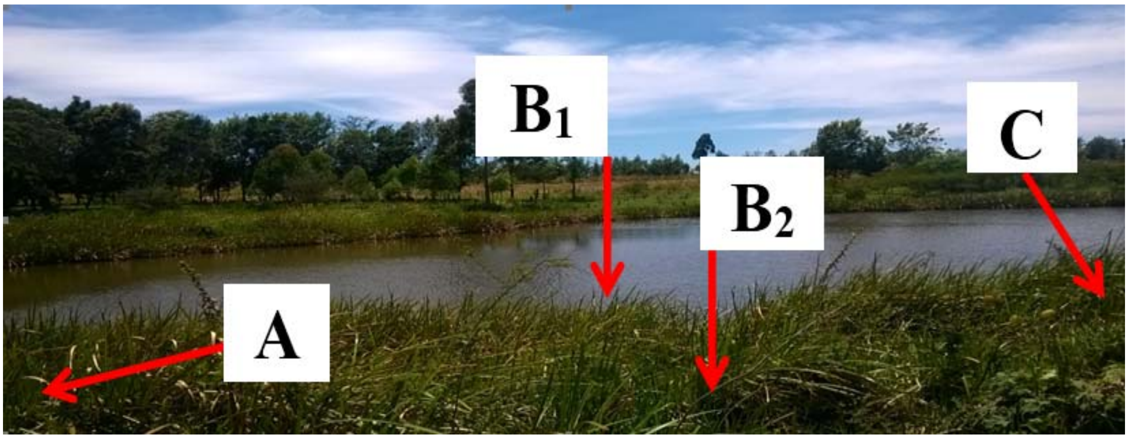

Fig 2.1: Sampling sites in kuinet (Chepkongi) Dam

2.3 Data Collection

Sampling was done for three months (November and December 2014, and January 2015) where by triplicate samples were taken during the morning hours (10.00– 11.00 AM) from the three sampling stations as in the research design for the sampling site.

Temperature and pH were measured *in situ* using a combined pH/temperature-meter (OAKTON®, Model pH/Mv/°C METER, Singapore).

The dam's water conductivity was determined with portable digital meters. (Conductivity meter OAKTON®, Model WD-35607-10, and Singapore). These three parameters were measured at a depth of approximately 10 cm below the water surface for about 2 minutes.

Water samples for nutrients (total nitrogen, total phosphorus) were taken immediately after sampling for the physico-chemicals but before sampling for phytoplankton to prevent contamination. The samples were then fixed with 3 drops of concentrated sulphuric acid in the field and transported in a cool-box to maintain the nitrogen balance to the laboratory for further analyses.

2.4 Physico-chemical variables and Nutrients

Replicate water samples from the four sampling stations (A, B1, B_2 and C) were sampled in borosilicate bottles for 5 days Biological Oxygen Demand (BOD_5) and Dissolved Oxygen (DO) using Wrinkler method (APHA 2003) method[1].

$$\text{BOD (\%)} = \frac{(\text{Initial DO level} - \text{final DO level})}{(\text{Initial DO level})}$$

Total nitrogen and Total phosphorus were analyzed as according to APHA (2000) standard methods[2].

2.5 Phytoplankton and species composition

For the analysis of phytoplankton species composition, 250 ml of water was collected in a polyethylene bottle and fixed immediately with Lugol's iodine solution. The samples were then left undisturbed for 48 h to allow the particulate matter to settle. The lower water layer (20–25 mL) containing the settled algae was decanted into a glass vial and stored in a cool, dark room for subsequent analysis. The known volume of the concentrated sample was used to identify and count the phytoplankton, using an inverted electronic microscope. The phytoplankton species was identified using methods of Nedham (1962) [12].

The frequency of the occurrence of each species was calculated on the basis of 1000 cell counts per sample. As a measure of the number of species and its frequency of presence in the community, the species diversity (H') and species richness (MI) indices were used. Shannon Weaver diversity index, H' (Ortiz *et al.,* 2016.)Was calculated as:

$H' = - \Sigma Pi \log2Pi,$

Where Pi was the frequency of presence for i species.

MI was calculated according to Margalef (1961):

$MI=(S-1)/\ln N,$

Where S was the number of identified species for total counted cells (N).

The ratio of cyanobacteria: chlorophytes was used to indicate the succession of either group of phytoplankton over the studied time. For calculation, the frequency of cell counts of either group of phytoplankton was used.

2.6 Ttrophic state of the dam

To determine the trophic state of the dam, Carlson's trophic state index (Carlson *et al.*,1977),which uses multi-parameter indices was computed from the three interrelated water quality parameters: Secchi disk depth (SDD), chlorophyll-a concentration (Chl-a), and total phosphorous (TP) concentration [6, 9]. The following formulas were used, ignoring the negative results.

$$TSI(SDD) - 10\left(6 - \frac{Ln\ SDD}{Ln\ 2}\right)$$

$$TSI(Chla) = 10\left(6 - \frac{2.04 - 0.68\ Ln\ Chla}{Ln\ 2}\right)$$

$$TSI(TP) = 10\left(6 - \frac{Ln(48/TP)}{Ln\ 2}\right)$$

Table 1: Trophic state classification of lakes adopted by (KDHE, 2001)

Trophic state classification of lakes	
0 - 30 TSI	Oligotrophic
31 - 49 TSI	Mesotrophic
50 - 100 TSI	Eutrophic

2.7 Primary productivity

Primary productivity was measured using the light and dark bottle method as described in Wetzel and Liken (1991) method [27].

Samples for light and dark bottles was taken from 0.5m depths and distributed to bottles that was suspended at successive 1/2m depths, up to 2.5 m. Primary production will be estimated by noting the difference in oxygen content of the light and dark bottles exposed at different depths for periods of 6-8 hours and the results computed for a unit area by totaling the average of values between successive 1/2m layers.

2.8 Data Analysis

Microsoft Excel 2010 was used to tabulate the data obtained, after the analysis, phytoplankton was analyzed using PAST Statistical Package (Version 2.10) for ranking using the Shannon-Wiener Index. The logarithm transformed data was consequently used to carry out correlation and multivariate analysis between other physical variables using (Principal component analysis (PCA) and Canonical correspondence analysis (CCA) (Orfanidis *et al.,* 2007). Species abundance, diversity, richness and evenness indices that showed significant difference among sites were further subjected to post hoc comparisons using Tukey's Honestly Significant Difference test. The H_O was tested against the mean daily primary production 0.62 $mgO_2L^{-1}d^{-1}$ of East African lakes[4].

3. Results

3.1 Temperature, DO, BOD and pH

During the study period, the temperatures dropped from 20ºC in November, to 18 ºC in December and 17.2 ºC in January. The pH was6.6 in November to 8.3 in December and 8.0 in January.

There was a positive relationship between temperature and pH (p = 0.01) among the sites in the month of November which could be a result of the static condition of the dam water during that month. In December, a positive correlation between both pH with DO (p- = 0.049) and BOD (p = 0.044) was also observed among the four sampling stations that is (A, B_1, B_2 and C). During the same three sampling months, using Pearson correlation, there was no significant difference between pH and Temperature (p = 0.439), was observed since they both formed a rising trend (Figure. 2.)

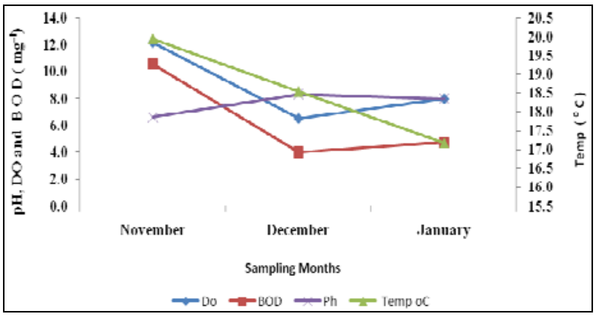

Fig 2: DO, BOD concentrations and Temperature, pH presentations of Kuinet (Chepkongi) Dam recorded during the three sampling months.

3.2 Secchi depth and conductivity

There was no significant differences between Secchi depth, conductivity and other physico-chemical parameters; DO, BOD, Temp, pH, TP, TN, NPP and chlorophyll-a according to Pearson correlation (*p*>0.05). Water transparency and turbidity (NTU) were used to describe water clarity. Secchi depth ranged from 0.31 to 0.33m. Secchi depth was slightly higher in November than in January (Figure. 3.). High Secchi depths were recorded during December and January due to the limited algal development during this season and to the dilution of algal particles in the water column, as a consequence of dry season. Mean surface conductivity values ranged seasonally from 0.513 µS/cm in December to 0.075 µS/cm in November and 0.075 µS/cm in January.

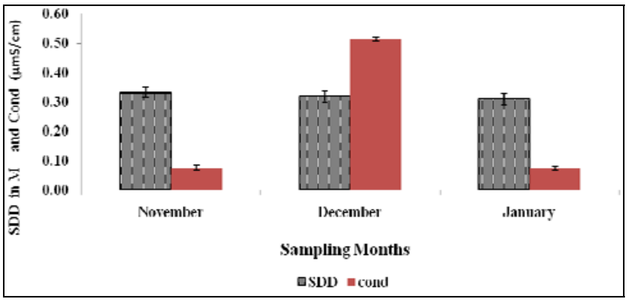

Fig 3: Mean Secchi depth (SDD) and conductivity in Kuinet (Chepkongi) Dam recorded during the three sampling months.

3.3 Chlorophyll-*a*

A discernible increase in chlorophyll-*a* was noted with the exception of November when high turbidity depressed the primary production at the station (A) close to the river mouth. However, there was no significant difference in chlorophyll-*a*among stations during the three sampling months (One-way ANOVA, p = 0.62; using the single factor analysis of variance test) this was achieved by using mean monthly samples.

The mean chlorophyll-a concentration ranged from 1.648 gl^{-1} in November to 1.968 gl^{-1} in January. Using the results of all months, a mean chlorophyll-a concentration of 1.791gl $^{-1}$ was obtained for the whole dam. Based on the three months results, chlorophyll-a showed a negative correlation to all the parameters measured.

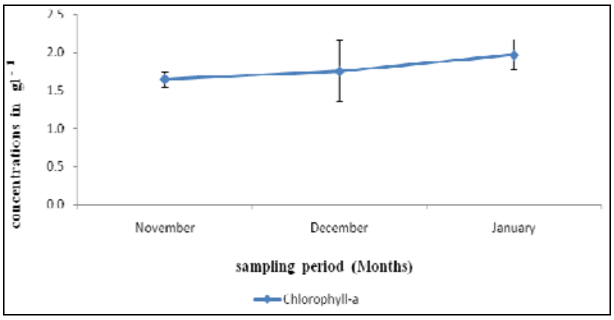

Fig 4: Concentrations of chlorophyll-a Kuinet (Chepkongi) Dam recorded during the three sampling months.

3.4 Total Phosphorus and Total Nitrogen

Total Phosphorus (TP) concentrations were higher in November (0.033 ± 0.007) mg^{-1} and started falling drastically in December (0.028 ± 0.006) mg^{-1} then being least concentrated in the month of January (0.026± 0.005) mg^{-1}. Concentrations for total nitrogen (TN) were highest in the month of December (0.105 mg^{-1}) followed by January (0.024 ± 0.010) mg^{-1} and November (0.011 ± 0.001 mg^{-1}); Pearson correlation of TP and TN, (p = 0.764) did not indicate significant difference in the dam (Figure 5).

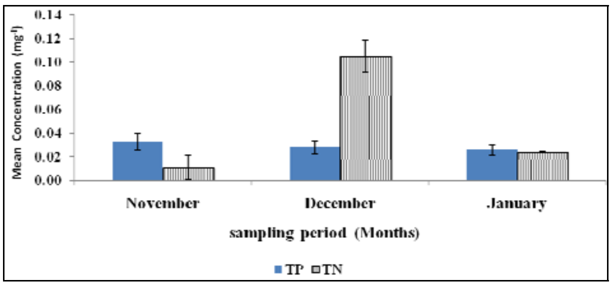

Fig 5: Mean concentrations of total phosphorus (TP) and total nitrates in the Kuinet (Chepkongi) Dam recorded during the three sampling months.

3.5 Phytoplankton species composition

In the month of November, 20 taxa were recorded in the dam, 56 individuals and a Shannon diversity index value of 2.823 was calculated. The species Evenness was 0.841 with a dominance of D 0.068.

In the month of December, 21 taxa were recorded, with 68 individuals and a Shannon diversity index value of 2.867. The species Evenness was 0.8373 with a dominance of D 0.066.

In the month of January, 27 taxa, were recorded, 86 Individuals and a Shannon diversity index of 3.173. The species Evenness was 0.884 with a dominance of D 0.046. A taxonomic list and occurrence were provided in Table 2.The most dominant phytoplankton families in the dam were both Bacillariophyceae and Chlorophyceae with both 11 species followed by Cyanophyceae having 5 species and Desmidiaceae with 3 species.

Table 2: Summary of the Phytoplankton species (Ordered according to Hasle and Syvertsen (1977) identified in Kuinet (Chepkongi) dam from November to January

		Months		
Family	**Species**	**November**	**December**	**January**
Bacillariophyceae	Cyclotella	-	+	-
	Diatoma	-	+	+
	Gyrosigma	-	+	-
	Melosira	-	+	+
	Navicula	-	+	-
	Navicula	-	+	-
	Pinnularia	-	+	-
	Pinularia	-	+	+
	Stephanodiscus	-	+	-
	Synedra	-	+	+
	Synedra	-	+	-
Chlorophyceae	Coelastrum	+	-	-
	Coelastrum	+	-	+
	Dictyosphaerium	+	-	-
	Microspora	-	-	+
	Mougeotia	-	-	+
	Protococcus	-	+	+
	Richterella	+	-	+
	Spirogyra	+	+	-
	Spyrogyra	+	-	+
	ulothrix	-	-	+
	Zygnema	-	-	+
Cyanophyceae	Anabena	-	+	+
	Nostoc	+	-	+
	Phormidium	+	-	-
	Polycystis	-	-	+
	Tetrapedia	+	-	+
Desmidiaceae	cosmarium	-	-	+
	Netrium	-	-	+
	Nostoc	+	-	-

The most abundant phytoplankton family in November was Chlorophyceae followed by Cyanophyceae then Desmidiaceae, among the three families identified. In December, there were only two families identified the most abundant cells were Chlorophyceae then Cyanophyceae. In January, four families were identified and the most abundant were Chlorophyceae followed by Desmidiaceae, Bacillariophyceae Cyanophyceae. (Figure 6)

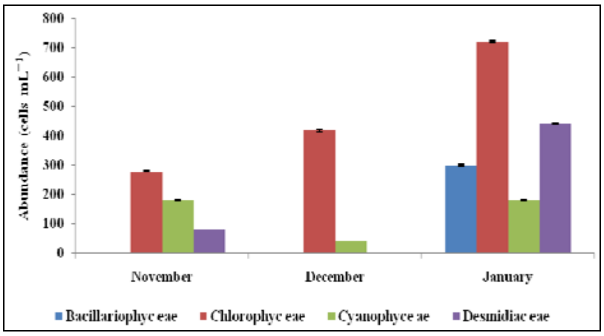

Fig 6: Mean ± SE Phytoplankton abundance during the three sampling months in Kuinet (Chepkongi) Dam.

After categorizing phytoplankton and other parameter data in terms of the sampling periods, the data were subjected to Levene's homogeneity of variance test. Phytoplankton data that were normally distributed, Kolmongorov-Smirnov goodness of fit test for normality was effected were by it resulted that (p<0.05).This validated the phytoplankton data for parametric analysis using one way ANOVA.

From this study the chart shows that DO, NPP and BOD corresponded much with the three sampling months (November, December and January) and Temperature Chlorophyceae was near correspondence to the main three parameters than the other parameters and phytoplankton. There was an eigenvalue of 75.8% in axis 1 and 24.3% axis 2. (Figure 7)

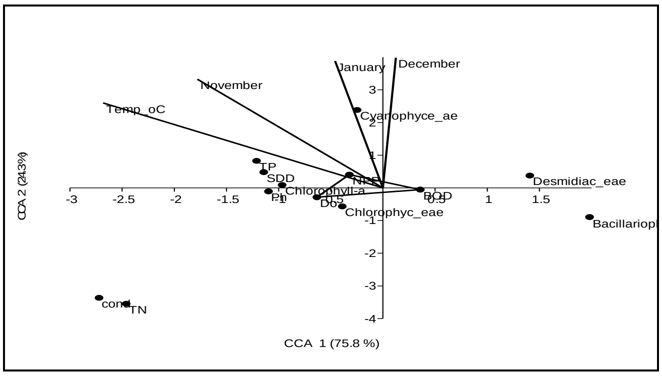

Fig 7: Canonical correspondence for the phytoplankton cells and the physico-chemical variables

3.5 Primary productivity

Generally, NPP for the three months ranged from (0.182±0.09) $mgO_2L^{-1}d^{-1}$ to (0.299± 0.13) $mgO_2L^{-1}d^{-1}$. Production peaked in the month of November (0.299 ± 0.13) $mgO_2L^{-1}d^{-1}$ followed by December (0.212 ±0.31) $mgO_2L^{-1}d^{-1}$ but there was least NPP in January (0.182±0.09) $mgO_2L^{-1}d^{-1}$. (Figure.8.).

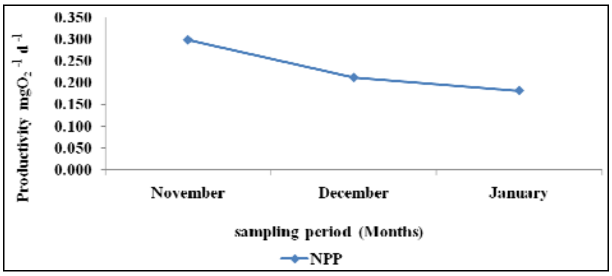

Fig 8: Net primary productivity variations of Kuinet (Chepkongi) Dam recorded during the three sampling months

Relationship between primary productivity and other variables

There was a significant difference in monthly primary productivity during the study period (t-test =- 0.07, p< 0.05). There were no relationships with other parameters; DO, BOD, Temp, pH, TP, TN, and chlorophyll-a during the study period. This can be associated with the dry spell effect of the three months.

4 Trophic state of the Dam

From Kuinet (Chepkongi) dam it was established that when using SDD, there was a rise TSI which ranged from 75.9 IN to November 76.9 in January. Using Chlorophyll-a, TSI ranged from 53.5 in November to 37.2 in January. (Figure. 8) reveals that values of the three indices are fairly far among each other in the sampling months but depicts the same rising trend from November it rises till December. TSI (SDD) is significantly larger than TSI (Chlorophyll-a) and TSI (TP) during the same month.

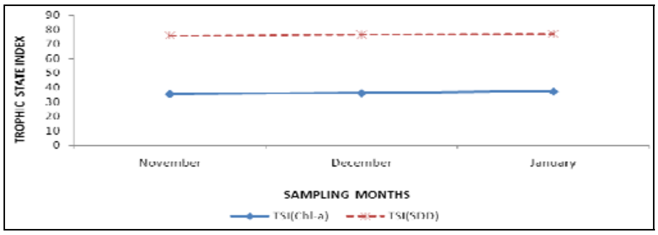

Fig 9: Monthly trophic state indices calculated from Secchi disk transparency (SDD) and Chlorophyll-a (Chl-a) for Kuinet (chepkongi) dam.

Considering the average TSI of the Kuinet (chepkongi) dam within the three months, TSI (Chl-a) =36, TSI (TP) = - 47 and TSI (SDD) = 76 was obtained ploted in (Table 3.) The TSI obtained tend not to fluctuate as other parameters like TP, TN, DO, BOD, Cond, NPP, Temp and Chl-a. The less variation among the individual TSI fluctuation may be as a result of the dry spell.

Table 3: Trophic state index obtained from Kunet (Chepkongi) Dam in the months of November, December and January

Sampling Period	TSI (Chl-a)	TSI (SDD)	TSI (TP)
November	35	76	-45
December	36	76	-47
January	37	77	-49
Mean TSI	36	76	-47

Table 4: Trophic state classification for Kunet (Chepkongi) Dam in the months of November, December and January

Sampling Period	Tsi (Chl-A)	Trophic classification	TSI(SDD)	Trophic classification
November	35	Mesotrophic	76	Eutrophic
December	36	Mesotrophic	76	Eutrophic
January	37	Mesotrophic	77	Eutrophic
Mean TSI	36	mesotrophic	76	Eutrophic

5. Discussion and Conclusion

The physico-chemical parameters and phytoplankton communities together form comprehensive ecosystem and as in any ecosystem, there are interaction between the phytoplankton and the water quality. These interactions are directly or indirectly subjected to the complex influences, some of which results in quantitative and seasonal changes [7].

There was an episodic family change throughout the study period, which was attributable to the interaction of physicochemical parameters [17]. The appearance and disappearance of phytoplankton families, included Bacillariophyceae in the month of November and December. This is attributed by the small rains during the time which salinity was influenced by increasing through runoffs. This is also subjected to the change in the water conductivity. In the month of January when there was no rain at all, the four families; Bacillariophyceae, Chlorophyceae, Cyanophyceae and Desmidiaceae were present.

From this study, it was observed that, higher DO and BOD concentrations were recorded in the Dam at lower temperatures than in higher temperatures. The concentration of DO and BOD in surface water is controlled by temperature which has both a seasonal and daily cycle. Cold water can hold more DO and BOD than warm water [13] who studied small water bodies in Lake Victoria Basin, Kenya. This observation is also similar to that of [22]. That did a similar study in Chepkanga Dam, Eldoret, Kenya.

A possible explanation for higher DO and BOD concentrations at lower temperatures is that, higher temperatures induce increased biological activity in the water column, with larger organisms requiring more DO for respiration and the smaller microorganisms increasing their demand for DO in order to carry out aerobic biodegradation of deposited organic matter in the water body this results into increased BOD levels too. Both the DO and BOD concentrations fell and started rising again just after heavy down pour and remained static during dry spell becoming lower than initially.

Specific conductivity is an important water quality variable because it gives a good idea of the amount of dissolved material in water. High specific conductivity indicates high dissolved solids concentrations; dissolved solids can affect stability of water for domestic industrial and agricultural uses. This studies concurs with the assumptions made by [16, 6] who deduced from their experiments that there a large increases in Secchi disk depth at low chlorophyll-a concentration with aquatic ecosystems with very low color or turbidity, Less significant changes in the levels of chlorophyll-*a* showed a less seasonal change that was related to the river inflow pattern in the wetland. The resumption of river inflow into the dam in November, December and January (beginning of the dry season) led to an almost a static measurements of less increase and decrease in chlorophyll-a levels at all dam's stations.

Primary productivity in reservoirs is controlled by the same energy and nutrient inputs that govern other planktonic systems [10, 5]. Whereas nutrient and light control are generally recognized as the most important limiting factors to production in natural lakes and rivers respectively, the two are usually regarded as important in reservoirs [19]. At the Dam positive relationship (p= 0.020) with total phosphorous showed that it is a critical variable for the primary productivity.

Generally the dam having higher total phosphates concentrations than total nitrogen and being dominated by the Bacillariophyceae and Chlorophyceae, which suggested eutrophic status classification that is achieved by considering three parameters (nutrients, chlorophyll-a and SDD) that is previously discussed in this context.. The findings of this study support that of [16].

Three major classes oligotrophic, mesotrophic, and eutrophic, are used in many applications; however, other applications, usually with high nutrient loads, also exploit more trophic state classes such as slightly eutrophic, fully eutrophic, very eutrophic, and hyper eutrophic [15], dystrophic[8], and polyeutrophic[28], for higher TSI values.

In this study, based on the Chla concentration and SDD, two trophic state classes are established for the Kuinet (Chepkongi) dam, that is TSI (Chl-a) = 36 shows that the Dam is mesotrophic and, TSI(SDD) = 76 shows that the dam is eutrophic, were as TSI(TP) = - 47 doesn't depict any state of the three classifications. (Table 3.). These classes are delineated by considering the range of Chla concentrations observed in the dam and with reference to Chlorophyl a ranges adopted by [9] and SDD for trophic state classification of lakes.

Generally, net primary productivity ranged from (0.182 ± 0.09) $mgO_2L^{-1}d^{-1}$ December to (0.299 ± 0.13) $mgO_2L^{-1}d^{-1}$ November in Kuinet (chepkongi) dam which is viewed as being low during the dry season. There was no significant difference among the sampling stations in the dam p = 0.764 with the nutrient. Total Phosphorus (TP) concentrations were higher in November (0.033 ± 0.007) mg^{-l} and started falling drastically in December (0.028 ± 0.006) mg^{-l} then being least concentrated in the month of January (0.026± 0.005) mg^{-l}. Concentrations for total nitrogen (TN) were highest in the month of December (0.105± 0.014) mg^{-l} followed by January (0.024 ± 0.010) mg^{-l} the November (0.011 ± 0.001) mg^{-l}. In the months of November, December and January Trophic state classification of the Dam could be sated as both eutrophic and mesotrophic. Kuinet (Chepkongi) Dam is composed of four phytoplankton families in the dam, both Bacillariophyceae and Chlorophyceae having 11 species each followed by Cyanophyceae having 5 species then Desmidiaceae with 3 species in the order of their relative abundance. The most abundant was the family Chlorophyceae, thus it is seen that the average Shannon diversity index (H') value of 3 of phytoplankton and occurrence of these in water bodies are to maintain and increase the productivity of Kuinet (Chepkongi) dam and to Highly productivity culture of fish and maintain ecological balance.

From the study using one-sample t-test, subjected on the net primary productivity and the mean daily primary production 0.62 $mgO_2L^{-1}d^{-1}$ of East African lakes [4]. Resulting to a p =0.008 which is <0.05, we fail to reject the H_O hence the primary productivity of Kuinet (chepkongi) dam doesn't favor aquaculture during the dry spell period. This in turn doesn't aid in facilitating the achievement of attaining the estimated potential production level of 2000 tons according the Uasin Gishu district environment action plan 2009-2013 and the projected thousand metric tons for developing countries being the net fish exporters in 2020.

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