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Spatio-Temporal Variability in Water Quality and Zooplankton Assemblages within Chemususu Dam and Associated Rivers, Baringo County, Kenya

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Abstract

Zooplankton are important as they play a role in the food webs of aquatic ecosystem. However, anthropogenic activities have potential hazardous impact on zooplankton. Zooplankton responds rapidly to chemical and physical changes in the water environment they occupy. Thus, their presence in a reservoir is an important biological indicator of its water quality. The present study aimed to determine spatial and seasonal variation of zooplankton community structure in relation to water quality in Chemususu dam and associated rivers. Samples were taken from six sampling sites, River Sawich (R1) and River Barain (R2), which are the two main in-flowing rivers, in the dam three selected stations (D1, D2 and D3) and the outlet, river Chemususu (R3). The study was carried out during the dry season (December 2016 to March 2017) and wet season (May to July 2017). Water quality parameters was evaluated using YSI multiparameter, nutrients were analyzed using Hach calorimeter, and zooplankton composition using microscopy. Further the data analysis was done using diversity indices, descriptive statistics, analysis of variance and canonical correspondence analysis. The physicochemical parameters displayed disparity in relation to with temperature, dissolved oxygen, total dissolved solids, total soluble solids, salinity, pH, nitrates, and carbonates showed significant spatial variation while, conductivity, turbidity, phosphates, and chlorides indicated significant seasonal variation ($p<0.05$). Species diversity and evenness (Shannon Wiener) differed significantly ($p<0.05$) among the sampling sites. The highest values of both diversity and evenness were recorded in D1 while lowest value was reported in R. Chemususu. The highest values of both diversity and evenness were recorded during wet season. Findings further showed that physicochemical parameters recorded significant positive interrelationships with zooplankton abundance, which have links to anthropogenic activities within the study area. Canonical correspondence analysis (CCA) demonstrated that the first and second components accounted for 91.6% of variance with NO_3, DO, Cl, salinity and TDS influencing the abundance of Rotifera and Ostracoda in the wet season. Whereas turbidity, CO_3, conductivity and TSS influenced the abundance of Cladocera and

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Copepoda. There were significant interrelationships between physicochemical parameters and zooplankton abundance in the rivers and Chemususu Dam. However, there is need to examine trends of water quality over years and establish relationship between zooplankton and phytoplankton.

Keywords: Zooplanktons, water quality, correlation, chemususu dam

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Introduction

Zooplankton communities in temperate and tropical inland waters undergo regular temporal and seasonal fluctuations in abundance and composition similar to phytoplankton at various periods across the year (Zsuga *et al.,* 2021). Zooplankton plays an intermediary trophic role, reflecting both bottom-up and top-down processes (Dale & Polasky, 2007; Xiong *et al.,* 2020). The transitional trophic function played by zooplankton in the aquatic system help to mediate energy flows in the food web (Xiong *et al.,* 2020; Woszczynski & Whitman, 2004), and quickly respond over time to environmental change. The study of zooplankton community structure in freshwater systems provides an imperative insight in the way anthropogenic activities influence zooplankton community and structure. The examination of abiotic factors in relation with zooplankton abundance, density and diversity is important to provide information on the quality of water in a reservoir. Eldama Ravine region, have seen increased agricultural activities, for example, the introduction of aquaculture, livestock rearing, and growing of crops to cater for the mounting population and increased use of agrochemicals could cause environmental pollution on the surrounding of Chemususu dam (Manohar et al., 2016). Since there has been increasing human activities around Chemusu dam, with little information on the effect of these, therefore, this study investigated spatial and seasonal changes of water quality and their effect on zooplankton species and community structure of selected sites within Chemususu dam and its associated rivers in Baringo County, Kenya.

Methods

Study area

Chemususu dam and its associated rivers in Lembus forest of Koibatek Sub-County, Baringo County, Kenya was studied (Figure 1). The geographical coordinates of the dam are 0° 05' 16.34'' to 0° 06' 92.11'' North (latitude) and 35° 37' 59.00'' to 35° 38' 35.42'' East (longitude) and specifically found at the escarpments of the western side of the Eldama-Ravine town. The location of the dam is classified as highland terrain (2500m above sea level), with the population size that is approximately 142,878, projected from 2019 recent census (Kenya National Bureau of Statistics, 2021). The highland areas support agricultural activities because of fertile soils and adequate rainfall. The main livestock in the county include cattle (Figure 2), goats and sheep (Baringo County Integrated Development Plan, 2017). Crop production is a major activity in all the farms and under the lease 'shamba system' in Lembus forest surrounding the dam. Some of the crops grown in this area include maize, beans, and potatoes among others.

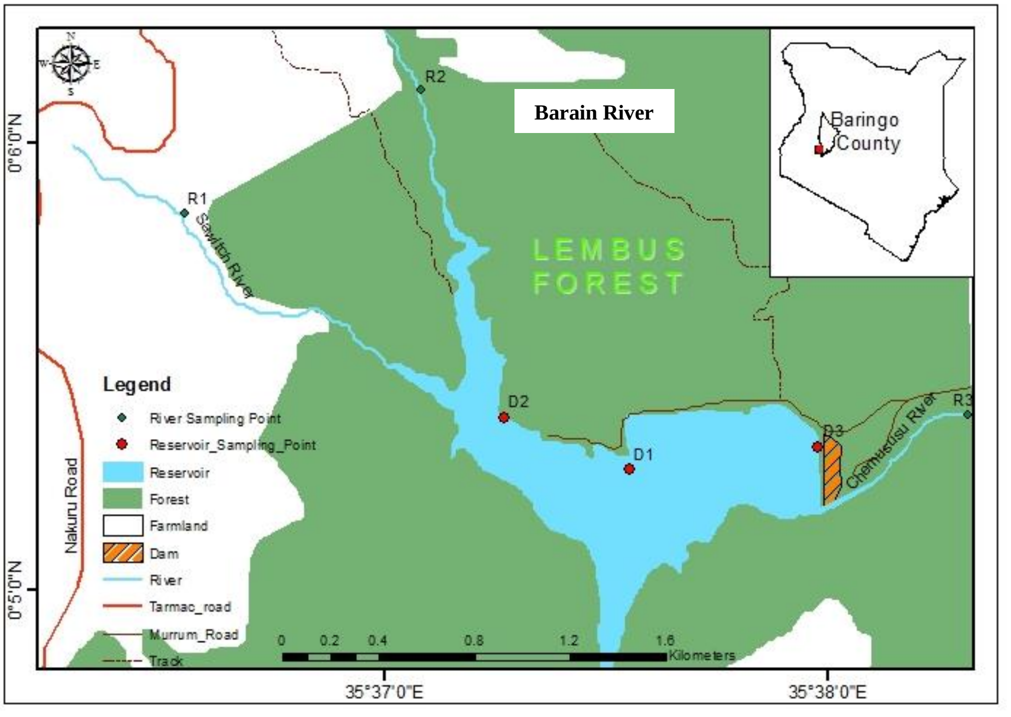

Figure 1: Map of Chemususu Dam indicating the sampling points for the study R1-River Sawich, R2-River Barain, R3-River Chemususu, while D1, D2, and D3 are sampling sites within the dam (https://www.arcgis.com/home/webmap)

The area receives an average annual rainfall of 1000mm to 1200mm with two marked peaks in April to May and July to August. It is thus an area that is wet most of the year with a slightly dry spell lasting from October to February. Temperatures are moderate with annual means of 15.3°C (Baringo County Integrated Development Plan, 2013 – 2017). This favourable climate tends to support luxuriant growth of aquatic vegetation in water bodies (Baringo County Integrated Development Plan, 2017). This reservoir mainly gets water from rainfall, two rivers (R. Sawich and R. Barain) and surface run-offs from farms and forests during the wet weather (Manohar *et al.,* 2016).

Figure 1: Some human activities: agriculture at Chemususu dam
(source author)

Sampling sites

Sampling for qualitative and quantitative analysis of zooplankton was carried out at three selected shore sites in the dam: D1, D2, D3 for the entire sampling period in Chemususu Dam and three rivers, namely river Sawich (R1) and river Barain (R2), which form the two main inlets and river Chemususu (R3), which is the outlet. They were sampled monthly throughout the study period of six months (December-March 2016 to April-July 2017). Global positioning system (GPS) was employed to identify and record sampling positions shown in Figure 1.

Chapter 1 Determination of water quality parameters

Water samples were obtained monthly for the six months for both physicochemical parameters and zooplankton. The study employed standard methods of water analysis according to APHA (1998). All physicochemical factors were determined at the water surface and under water in triplicates. Physical and chemical factors were evaluated in *in-situ* in the course of sampling using YSI multi-parameter (YSI Model, 2012, Ohio, USA) already calibrated before each sampling trip. The multi-parameter YSI instrument was used to measure conductivity, salinity, total dissolved solids (TDS), dissolved oxygen (DO), total suspended solids (TSS), pH and temperature. Turbidity was assessed by utilizing the turbidity meter (Hach turbidity meter model 2100P, 2014, Colorado, USA).

Chapter 2 Analysis of nutrients

Water for chemical analysis was sampled from a depth of 0.5 m using a 1-litre bottle (water sampler) and transported in icebox to the laboratory for analysis of nutrients as described by Manohar *et al.,* (2016). Macronutrients were measured according to the standard methods as explained by Wetzel and Likens (2010) and filtered using Whatman filters (APHA, 2005). Total phosphorous in mg/L was determined using the orthophosphate method where HACH Calorimeter was used to take the measurements at 810 nm wavelength. The principle of the method is that orthophosphate (PO_4) in water combines with molybdate reagent and gives a yellow colour in which its intensity varies according to the concentration of phosphates. The Beer-Lambert law applies in the measurement of the intensity of color changes according to the degree of concentration of analytes. The stored program numbers were pressed and zero appeared on the screen. In a 25 ml sample, 1 ml of molybdate reagent was added using 1ml calibrated dropper and then mixed and the sample was put in a cell holder and covered tightly with a cap. After 10 minutes, the key was pressed and the result in mg/l was displayed.

Total nitrates (mg/L) in water samples collected were determined by cadmium reduction method using HACH Calorimeter (DR/820). The principle of the test is that cadmium ions reduce nitrates to nitrites, which then react with diazo reagent comprising sulfanilamide and naphthyl-ethylene-diamine di-hydrochloride to give a red colour with varying intensities for colorimetric analysis at 540nm wavelength. The stored program number was entered for high range nitrate-nitrogen and zero icons were shown. Next, the contents of nitrate reagent powder were added and mixed well, after which the results were read and recorded.

Chlorides and carbonates were measured in the sampled water in the laboratory using titration method. The principle of titration is based on the neutralization of ions present in the solution based on target analytes. Chlorides were determined by titrating water sample with silver nitrate, leading to the formation of white precipitate of silver chloride. Next, silver chloride was reacted with potassium thiocyanate to form pale yellow precipitate of silver thiocyanate at end-point. Carbonates in water were determined using 0.02 N sulphuric acids with bromocressol green as indicator (Manohar et al., 2016). The concentrations of chlorides and carbonates ($CaCO_3$) were calculated as mg/L in each sampled water.

Chapter 3 Determination of species composition

The samples were mixed thoroughly and 1 ml subsample was taken using a pipette. A zooplankton chamber was used to observe, identify, and count the number of zooplankton species. Examination of the zooplankton was done by use of microscope (BaneBio, Labovert-FS, Maryland, United States) with a magnification x40 and identified by several guides. Zooplankton laboratory analysis was done using standard protocols and guidelines Scourfield and Harding (1966); USEPA, (2016). Cladocerans (class Branchiopoda), Ostracods and Copepods species (class Maxillopoda) were identified using the protocol of Korovchinsky (1992), while Rotifera species (classes are Monogononta, Bdelloidea, and Seisonidea) were identified based on the protocol of Koste and Shiel (1980) and Segers (1995). Zooplankton were identified and classified to their generic level by using factors described by Jeffries et al., (1984).

Estimation of abundance of zooplankton species

The number of zooplankton species in a litre of sampled water (D) was assessed using several diversity indices such as Simpson, Shannon Weiner Index, Brillouin, Menhinick and Margalef generated by PAST software (Version 4.03)

The prescription developed by Edmondson and Winberg (1971) was the basis using the formula described below.

D = N/V,

Where;

D = Abundance

N = quantity of organisms in sample, calculated as number in sample tested × volume of sample collected /volume of sample tested

V = capacity of dam water filtered = $\pi r^2 d$, r = radius of net (15cm) and

d = depth of haul (cm)

The overall abundance comprised the quantity of zooplankton in a litre of sampled water.

Determination of Species Diversity

Species diversity was calculated using the Shannon Weiner Index (1949).

Using the formula:

$H' = -\sum (Pi * In (Pi))$ where $Pi = ni/N$

In = the natural log

Pi = Proportion of total sample belonging to the i^{th} species

ni = total number of individuals in a species

N = total number of individuals

Data analysis

The study used PAST software (Version 4.03), Minitab software (version 19), and MS Office Excel (2016) in the analysis and presentation of data based on the significance level of 0.05. Descriptive statistics (Mean±SD) were used to analyse physicochemical variables and nutrients (water temperature, pH, conductivity, DO, TDS, TSS, chlorides, carbonates, turbidity, salinity, phosphates, and nitrates) for each site on each sampling occasion. The interrelationships between physicochemical parameters and zooplankton abundance were determined using Pearson's correlation at alpha level of 0.05. Several diversity indices (Morris *et al.*, 2014), such as Shannon's diversity index (H') (Magurran, 2005), were used to evaluate the diversity of zooplankton in each sample collected.

Canonical correspondence analysis (CCA) was done to evaluate permutational multivariate analysis of variance (PERMANOVA) (Bray & Curtis, 1957; Anderson, 2005; McArdle and Anderson, 2001). CCA was utilized to investigate the association between zooplankton composition, quality of water and nutrients in samples from the different sites. The study used similarity percentages analysis (SIMPER) to identify major zooplankton species that accounted for the deviations observed between water quality and sampled locations. The explanation of taxa and their contribution to dissimilarity index was measured between seasons and sites.

Results

Spatial and seasonal variations in water quality parameters in Chemususu dam

There was spatial difference in the quality of water in the sampled sites namely R. Sawitch (RS), R. Chemususu (RC), R. Barain (RB) and the dam sites D1, D2 and D3. The recorded water temperature ranged between 15.85±0.36 to 20.68±0.16 during the dry season in R. Sawitch (RS) and the dam site D3, respectively (Table 1). In the wet season, temperature ranged from 15.18±0.33 in RC to 20.70±0.66 in D3 (Table 2). The variation was significantly different in the mean temperature among the sampled sites in dry season, the mean temperature during dry season was higher than (18.44±0.61) that of the wet season (18.30±0.88). During the dry season the mean DO (mg/L) in the sampled sites of Chemususu dam and associated rivers was found to range between 2.27±0.36 to 3.0±0.38 mg/l, this was significantly different ($p = 0.011$) (Table 1). Similarly, there was significant difference between the DO in the sampled sites during the wet season, a higher DO ranging from 5.71±0.42 mg/l to 3.88±0.33 mg/l in R. Barrain and R. Chemususu, respectively (Table 2).

The recorded Total Dissolved Solutes (TDS (mg/L) during the dry season among the sites was significantly different (p = 0.015) with a mean range of between 40.92±0.96 and 86.83±0.04 mg/L in D1 and R. Barain respectively (Table 1). However, during the wet season a range of 49.88±0.23 to 92.17±0.45 in D1 and R. Barain was significantly different (p = 0.040) (Table 2). The analysis when the two seasons were combined in the sampling sites showed a significant difference among the sites. D1 had the lowest TDS among all the sites and all the rivers mean sites found to be higher than the dam sites. When TSS was measured during the dry season, a significant difference (p = 0.020) was observed, though a mean range of 11.68±0.08 and 25.45±0.51 mg/L in D1 and R. Chemususu, was observed, respectively (Table 1). A significant difference was recorded during the wet season but D3 recorded the lowest TSS at 13.75±0.14 mg/L. In general, the TSS was found relatively higher in the water in the rivers than within the dam.

The salinity of water recorded during the dry season was significantly dissimilar (p = 0.016) in the dam and associated rivers (Table 1), but during the wet season the sites was significantly different (p = 0.020). The pH during the dry season in Chemususu dam and associated rivers exhibited significant variation. Water conductivity during the dry season, ranged between 70.30±0.61 and 92.00±0.31 mg/L in R. Sawich and R. Chemususu, respectively (Table 1), which was not significantly different. However, a significant difference was observed in the wet season (p = 0.034), but the range was lower (56.30±0.23 mg/ml and 72.13±0.86 mg/l in R. Barrain and D2, respectively (Table 2). The water turbidity in Chemususu dam and associated rivers was not significantly different among the sites in dry season (p = 0.620) and wet season (p = 0.290). The phosphate nutrients were higher in R. Barain (3.60±0.26 mg/L), and lowest in D1 (1.27±0.02 mg/l), respectively during the dry season (Table 1), with no significant difference (p = 0.150). During the wet season, R. Chemususu (2.04±3.6 mg/L) recorded the lowest quantities, and still higher quantities (3.50±0.21 mg/l) in R. Barain, which was significantly different (p = 0.080) from all the other sites. The nitrates (mg/L) during the dry season were lowest in R. Sawich (1.95±0.34 mg/l and the highest in D1 (5.40±0.41 mg/l) but in all sites there was significant difference (p = 0.020). The mean nitrates were relatively higher within the dam sites in the range of 5.65**±**0.25mg/l in D1 and 3.85±0.25 in D3, when sites were compared in both seasons. The carbonates among the sites sampled was 9.15±0.75 mg/L during the dry season that ranged from 6.60±0.34 mg/l in R. Barain and 10.60±0.27 mg/L in R Chemususu was noted but was significantly different (p = 0.030). In dry season, chloride quantities were higher in D3 (2.70±0.09) mg/, but least in R. Barain and D1 (2.30±0.55 mg/L), with no significant difference (p = 0.112). During the wet season, the sites also did not show significant difference in chlorides (p = 0.250). Overall, the highest chlorides (mg/l) were recorded in the water sampled in point D3, followed by RC in both seasons.

Table 1: Spatial variation of physicochemical parameters and nutrients of Chemususu dam and associated rivers during the dry season (Mean±SE)

Sites	Temp (^{0}C)	DO (mg/L)	TDS (mg/L)	TSS (mg/L)	Sal. (ppt)	pH (Std_Units)	Condu. (µS/cm)	Turb (NTU)	PO_4 (mg/L)	NO_3 (mg/L)	Carbonates (mg/L)	Chlorides (mg/L)
D1	20.35±0.61a	2.30±0.12a	40.92±0.96a	11.68±0.08a	0.06±0.51a	5.88±0.32a	75.50±0.91a	0.58±0.41a	1.27±0.22a	5.40±0.4a	10.20±0.85a	2.30±0.55a
D2	20.05±0.24a	2.27±0.26a	46.45±0.56a	13.34±0.97a	0.07±0.54a	5.79±0.33a	73.40±0.09a	0.38±0.52a	2.39±0.07a	4.34±0.21b	10.00±0.73a	2.50±0.29a
D3	20.68±0.16a	2.32±0.27a	42.25±0.66a	12.08±0.81a	0.07±0.52a	5.82±0.36a	89.20±0.29a	0.40±0.87a	2.42±0.16a	3.58±0.24b	10.50±0.49a	2.70±0.09a
RC	16.83±0.23b	3.00±0.38b	68.00±0.06b	12.80±0.75b	0.08±0.44a	6.31±0.42b	92.00±0.31a	0.31±0.93a	2.57±0.77a	3.50±0.23b	10.60±0.27a	2.60±0.32a
RS	15.85±0.25b	2.97±0.56b	85.50±0.35b	25.05±0.67b	0.12±0.41b	6.55±0.78b	70.30±0.61a	0.32±0.48a	3.54±0.45a	1.95±0.34c	7.00±0.25b	2.40±0.37a
RB	16.85±0.36b	2.85±0.44b	86.83±0.04b	25.45±0.51b	0.13±0.21b	6.73±0.83b	76.00±0.33a	0.40±0.44	3.60±0.26a	2.68±0.64c	6.60±0.34b	2.30±0.38a
Mean	18.44±0.61b	2.62±0.94b	61.66±8.72	19.23±3.1	0.09±0.01a	6.18±0.17	79.4±3.65	0.33±0.08	2.63±0.35	3.58±0.5	9.15±0.75b	2.47±0.07
F values	7.23	1.35	2.32	1.96	2.36	3.87	1.65	3.24	2.56	3.81	3.26	1.25
P values	0.030	0.011	0.015	0.020	0.016	0.010	0.108	0.620	0.150	0.020	0.030	0.112

Means along the column followed by same letters are not significantly different, *Significant level $p<0.05$*

Table 2: Spatial variation of physicochemical parameters and nutrients of Chemususu dam and associated rivers during the wet season (Mean ±SE)

Sites	Temp (^{0}C)	DO (mg/L)	TDS (mg/L)	TSS (mg/L)	Sal. (ppt)	pH (Std_Units)	Condu. (µS/cm)	Turb (NTU)	PO_4 (mg/L)	NO_3 (mg/L)	Carbonates (mg/L)	Chlorides (mg/L)
D1	19.25±0.56a	5.22±0.15a	49.88±0.23a	14.37±0.23a	0.08±56a	6.45±0.25a	71.10±0.56a	0.25±0.25a	2.18±0.25a	5.89±0.24a	6.40±0.00a	2.00±0.067a
D2	20.65±0.75a	4.67±0.21a	51.58±0.62a	14.88±0.12a	0.08±86a	6.09±0.46a	72.13±0.86a	0.20±0.37a	2.48±0.27a	5.50±0.23a	6.40±0.23a	2.80±0.82a
D3	20.70±0.66a	4.51±0.22a	74.58±0.61b	13.78±0.14a	0.09±81a	5.72±0.78a	71.60±0.52a	0.15±0.26a	2.54±0.24a	4.05±0.21a	8.00±0.44a	3.30±0.78a
RC	15.18±0.33b	3.88±0.33b	76.92±0.25b	22.48±0.12b	0.09±14a	5.83±0.42a	72.60±0.26a	0.18±0.21a	2.04±0.36a	4.10±0.62a	8.00±0.24a	3.20±0.74a
RS	17.73±0.29b	5.03±0.38b	81.58±0.87b	20.88±0.45b	0.11±26b	6.81±0.78a	58.20±0.23b	0.20±0.24a	2.04±0.24a	5.26±0.63a	6.30±0.56a	2.10±0.72a
RB	16.30±0.42b	5.71±0.42b	92.17±0.45b	17.05±0.56b	0.10±25b	6.12±0.25a	56.30±0.23b	0.00±0.23a	3.50±0.21b	5.20±0.63a	6.40±0.52a	3.00±0.78a
Mean	18.30±0.88	4.84±0.26	71.12±0.91	17.24±1.49	0.09±0.00	6.17±0.16	66.99±3.1	0.16±0.04	2.46±0.23	5±0.31	6.92±0.34	2.73±0.23
F values	5.63	3.21	5.67	7.12	6.23	2.33	11.44	2.58	12.66	1.83	2.56	3.45
P values	0.04	0.080	0.040	0.030	0.020.	0.250	0.034	0.290	0.080	0.240	0.640	0.250

Means along the column followed by same letters are not significantly different, significant level $p<0.05$

Table 3: Zooplankton composition and distribution at Chemususu Dam

	Sites	D1		D2		D3		RC		RS		RB	
Taxa	Species/Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
	Adineta sp	-	-	-	√	-	√						
	Agnatha sp	-	-	-	√	-	√						
	Castropus sp	-	-	-	-	-	√						
	Chromogaster sp	-	√	-	-	-	-						
	Colotheca sp							-	-	-	√	-	-
	Colurella sp	-	-	√	√	√	√						
	Conochillus sp	-	-	-	-	-	√						
	Dicranophorus sp	-	-	-	√	-	-						
	Ephiphanes spp							-	√	-	-	-	-
	Estheria sp	-	√	√	-	-	√	√	√	-	√	-	√
	Filinia sp	-	√	-	-	-	-	-	√	-	√	-	-
	Floscularia sp	-	-	-	√	-	-						
	Gastropus sp	-	-	-	-	-	√						
	Kellicottia sp	-	√	-	√	-	-						
	Keratella sp	√	-	√	-	√	-	-	√	-	-	-	-
	Lecane sp	-	√	-	-	-	-						
	Malleate sp	-	-	-	√	-	√						
	Mytilini sp	√	√	√	-	√	√	-	√	√	√	√	√
	Notholca sp	√	-	√	√	-	-						
	Philodina sp	√	√	√	-	-	√	-	√	-	√	√	-
	Ploesoma sp	-	-	-	√	√	-	√	-	-	-	-	-
	Polyarthra sp.	√	√	-	-	-	-	-	√	-	-	-	√
	Rotaria sp	√	√	√	-	√	√	-	√	-	-	-	-
	Synchaeta sp	-	√	-	-	-	-	-	√	-	√	-	-
Rotifera	*Testudinella* sp.	-	√	-	-	-	-						

	Trichocerca sp							-	-	-	√	√	-
	Trichotria spp	-	-	-	√	-	-	-	√	-	-	-	-
	Canthocamptus sp	√	√	-	-	-	-						
	Cyclops sp	-	-	-	-	-	√						
	Diamtomus sp	√	√	√	√	√	√	-	√	-	√	-	-
	Eucyclops sp	-	-	√	-	-	-						
Copepoda	*Limnocalanus* sp	-	√	-	-	-	-						
	Acroperus sp							-	√	-	-	-	-
	Rosimia sp							-	√	-	√	-	√
	Alonella sp	-	√	-	-		-						
	Bosmina sp	-	-	-	-	-	√	-	√	-	-	-	√
	Camptocercus sp	√	√	√	√	√	-	√	√	√	√	√	√
	Chydorus sp	-	-	-	√	-	-	√	√	-	-	-	-
	Daphinia sp	√	√	√	√	√	-	-	-	-	√	-	√
	Diaphanosoma sp	√	√	√	√	√	√	-	√	-	√	-	-
	Eurycercus sp	-	√	-	√	-	-						
	Macrothrix sp	-	-	-	√	√	√	-	√	-	-	-	-
Cladocerans	*Simocephalus* sp	√	-	-	-	-	-	-	√	-	-	-	-
	Cypridopsis sp	√	√	√	√	√	√	-	√	-	√	-	-
Ostracodas	*Eubranchipus* sp	-	-	√	-	-	-						

((√) = present; (−) = absent)

Table 4: Spatial and seasonal differences in the diversity indices of zooplankton of Chemususu dam

	DRY SEASON						WET SEASON					
	D1	D2	D3	RC	RS	RB	D1	D2	D3	RC	RS	RB
Taxa_S	4	4	4	2	2	2	4	4	4	4	4	3
Individuals	31	37	35	22	20	11	257	196	179	140	154	85
Dominance_D	0.27	0.33	0.35	0.63	0.49	0.45	0.31	0.34	0.32	0.30	0.38	0.40
Simpson_1-D	0.73	0.67	0.65	0.37	0.51	0.55	0.69	0.66	0.68	0.70	0.62	0.60
Shannon_H	1.25	1.15	1.14	0.51	0.65	0.64	1.27	1.14	1.19	1.26	1.08	0.96
Evenness_e^H/S	0.87	0.79	0.78	0.84	0.96	0.95	0.89	0.78	0.82	0.88	0.74	0.87
Brillouin	1.13	1.06	1.04	0.46	0.59	0.56	1.24	1.11	1.16	1.22	1.05	0.92
Menhinick	0.72	0.66	0.68	0.43	0.45	0.60	0.25	0.29	0.30	0.34	0.32	0.33
Margalef	0.87	0.83	0.84	0.32	0.33	0.42	0.54	0.57	0.58	0.61	0.60	0.45
Equitability_J	0.90	0.83	0.82	0.74	0.93	0.93	0.92	0.82	0.86	0.91	0.78	0.88
Fisher_alpha	1.22	1.14	1.16	0.53	0.55	0.72	0.67	0.71	0.73	0.77	0.75	0.61
Berger-Parker	0.35	0.51	0.54	0.77	0.60	0.55	0.45	0.40	0.44	0.39	0.45	0.46

Key: D1= Dam site 1, D2= Dam site 2, D2= Dam site 3, RS = R. Sawich, RB= R. Baraini, and RC= R. Chemususu

Table 5: Pearson correlation analysis among zooplankton taxa with water quality variables and nutrients

ALL SEASONS												
	Tem (°C)	DO (mg/L)	TDS (mg/L)	TSS (mg/L)	Sal. (ppt)	pH	Condu. (µS/cm)	Turb (NTU)	PO_4 (mg/L)	NO_3 (mg/L)	CO_3 (mg/L)	Cl (Mg/L)
Rotifer	0.12	**0.86**	0.08	-0.20	0.07	0.17	-0.54	-0.40	-0.18	0.64	-0.68	0.07
Copepoda	0.02	0.24	-0.08	-0.04	-0.17	-0.18	-0.14	0.00	-0.51	0.32	-0.13	0.13
Cladocera	0.68	0.37	-0.38	-0.47	-0.36	-0.28	0.09	-0.01	-0.17	0.35	-0.12	0.15
Ostracoda	0.32	**0.82**	-0.06	-0.35	-0.08	0.04	-0.44	-0.31	-0.24	0.67	-0.58	0.04
% Cladocera	-0.52	0.57	**0.77**	0.51	**0.85**	**0.70**	-0.53	**-0.77**	0.64	-0.15	**-0.84**	-0.03
% Copepoda	0.19	-0.29	-0.44	-0.34	-0.52	-0.49	0.04	0.51	**-0.75**	0.31	0.38	0.05
% Ostracodas	-0.08	**-0.76**	-0.13	0.35	0.00	0.06	0.75	0.33	0.32	**-0.72**	0.58	-0.19
% Rotifera	0.34	**0.81**	-0.06	-0.58	-0.23	-0.22	-0.63	-0.26	-0.32	**0.82**	-0.44	0.23
DRY SEASON												
Rotifera	-0.27	0.62	0.61	0.52	0.61	0.55	0.03	-0.31	0.70	**-0.87**	-0.51	0.19
Copepoda	0.71	**-0.88**	**-0.84**	**-0.88**	-0.76	**-0.81**	-0.24	0.75	**-0.87**	**0.91**	0.54	-0.16
Cladocera	0.45	-0.35	-0.56	-0.35	-0.63	-0.67	0.49	0.44	-0.28	0.21	0.73	**0.89**
Ostracoda	**0.89**	**-0.99**	**-0.94**	**-0.98**	**-0.81**	**-0.94**	-0.06	0.72	-0.79	**0.82**	0.63	0.16
% Cladocera	-0.64	0.80	**0.95**	0.78	**0.98**	**0.96**	-0.22	**-0.82**	**0.89**	**-0.88**	**-0.90**	-0.36
% Copepoda	0.67	**-0.85**	**-0.82**	**-0.86**	-0.75	-0.78	-0.24	0.77	**-0.88**	**0.91**	0.53	-0.21

% Ostracodas	-0.62	0.73	0.51	**0.75**	0.32	0.44	0.52	-0.46	0.55	-0.61	-0.04	0.52
% Rotifera	**0.86**	**-0.98**	**-0.94**	**-0.98**	**-0.82**	**-0.92**	-0.07	0.75	**-0.83**	**0.85**	0.63	0.10
WET SEASON												
Rotifera	0.33	0.12	-0.67	-0.32	-0.22	0.55	0.13	0.63	-0.39	0.64	-0.59	-0.62
Copepoda	-0.17	-0.63	-0.17	0.56	-0.23	-0.10	0.48	0.49	-0.67	-0.28	0.45	-0.04
Cladocera	**0.98**	-0.05	-0.74	**-0.86**	-0.77	-0.26	0.67	0.44	-0.13	0.14	0.12	-0.06
Ostracoda	0.76	0.16	**-0.81**	-0.68	-0.57	0.28	0.44	0.67	-0.36	0.52	-0.26	-0.58
% Cladocera	-0.50	0.52	0.36	0.16	0.60	0.50	-0.76	-0.39	0.39	0.39	-0.68	-0.21
% Copepoda	-0.32	-0.73	0.02	0.70	-0.09	-0.20	0.41	0.35	-0.60	-0.45	0.55	0.14
% Ostracodas	**0.94**	-0.02	-0.47	**-0.91**	-0.65	-0.52	0.55	0.08	0.19	-0.09	0.27	0.28
% Rotifera	0.34	**0.85**	-0.02	-0.71	0.09	0.31	-0.43	-0.28	0.54	0.51	-0.54	-0.34
Legend: Temp. – Temperature, DO- Dissolved Oxygen, TSS-Total Suspended Solids, TDS – Total Dissolved Solids, Sal.-Salinity, Condu- Conductivity, Turb. – Turbidity, PO_4 – Phosphates, NO_3 – Nitrates, CO_3 – Carbonates, Cl – Chlorides.												

Table 6: Ranked abundance of zooplankton taxa based results of SIMPER analysis

DRY SEASON						WET SEASON					
Taxon	Av. Dissim	Contrib. %	Cumulative %	Mean DD	Mean RCD	Taxon	Av. dissim	Contrib. %	Cumulative %	Mean DW	Mean RCW
Copepoda	13.78	39.01	39.01	7.67	0	Ostracoda	14.23	33.19	33.19	90	39
Ostracoda	11.87	33.6	72.61	6.67	0	Copepoda	11.7	27.31	60.5	15.3	55
Cladocera	6.702	18.98	91.58	16	17	Cladocera	8.857	20.66	81.16	42	11
Rotifera	2.973	8.417	100	4	5	Rotifera	8.074	18.84	100	63.3	35
Taxon	Av. Dissim	Contrib. %	Cumulative %	Mean DD	Mean RSD	Taxon	Av. dissim	Contrib. %	Cumulative %	Mean DW	Mean RSW
Copepoda	14.29	32.75	32.75	7.67	0	Cladocera	9.619	41.55	41.55	42	7
Ostracoda	12.31	28.19	60.94	6.67	0	Ostracoda	7.052	30.46	72.02	90	63
Cladocera	9.643	22.09	83.04	16	12	Rotifera	3.541	15.3	87.31	63.3	69
Rotifera	7.404	16.96	100	4	8	Copepoda	2.937	12.69	100	15.3	15
Taxon	Av. Dissim	Contrib. %	Cumulative %	Mean DD	Mean RBD	Taxon	Av. dissim	Contrib. %	Cumulative %	Mean DW	Mean RBW
Cladocera	21.62	37.75	37.75	16	6	Ostracoda	16.84	40.29	40.29	90	39
Copepoda	17.18	30	67.76	7.67	0	Cladocera	10.87	26.01	66.3	42	10
Ostracoda	14.76	25.78	93.54	6.67	0	Rotifera	9.248	22.12	88.42	63.3	36
Rotifera	3.701	6.462	100	4	5	Copepoda	4.841	11.58	100	15.3	0

Spatial and seasonal zooplankton genera composition and distribution at Chemususu Dam

Higher numbers of genera were recorded for sampling sites D1 and D2, but RB had the lowest genera in both seasons recorded that was significantly different among the sampling locations (Table 3). The most common genera are *Estheria* sp., *Mytilini* sp., *Philodina* sp., *Camptocercus* sp., and *Cypridopsis* sp., whereas the least common genera are *Adineta* sp.,*Chromogaster* sp., *Colotheca* sp., *Conochillus* sp., *Dicranophorus* sp., *Gastropus* sp., *Lecane* sp., and *Limnocalanus* sp.

Zooplankton diversity indices

The diversity indices used to measure the zooplankton community structure in Chemususu indicated variation across all the sampling sites during both dry and wet seasons. A wide range was observed in Shannon_H (0.51 in RC to 1.25 in D1), Brillouin (0.46 to 1.27) in RC and D1 respectively in the dry season (Table 4). Most of the other indices showed a closer range, in the dry season. The highest range recorded was in Shannon_H (0.96 in RB to 1.27 in D1) which occurred during the wet season. However, most of the indices showed a closer range during wet season, with the least range in Menhinick (0.25 to 0.34) in D1 and RC, respectively. The taxa richness was least in RC and RS with only 2 taxa in the dry season.

Association between zooplankton abundance and the quality of water in Chemususu dam

The association between the zooplankton and the quality of water indicates a strong connection between abundance level of zooplankton and a number of the water physicochemical parameters and nutrients, which was less common in the wet season compared to the dry season.

When all the seasons were combined, it was established that DO, TDS, Salinity, pH turbidity and three nutrients PO_4, NO_3 and CO_3 had significant correlation with zooplankton taxa abundance in Chemususu dam (Table 5). DO positively correlated significantly to rotifer ($r = 0.86$) and ostracoda ($r = 0.82$), but negatively with ostracoda ($r = -0.76$). Cladocera correlation with TDS was significant but negative ($r = -0.77$), However, DO had a positive correspondence with salinity ($r = 0.85$, $p = 0.00$). Similarly, the percent of cladocera was negatively correlated with turbidity ($r = -0.77$), CO_3 ($r = -0.84$) and positively correlated for pH ($r = 0.70$, $p = 0.01$), PO_4 was negatively significantly related with percent copepod ($r = -0.75$, $p = 0.001$). A positive correlation between percent rotifer ($r = 0.82$) with NO_3, and a negative correlation was noted with percent ostracoda ($r = -0.72$) which was highly significant ($p = 0.01$).

Pearson correlation between zooplankton abundance and water quality during the dry and wet season

During the dry season, a positive significant correlation was established between temperature and % rotifer ($r = 0.86$) and ostracoda ($r = 0.89$) with a significant ($p = 0.02$). The DO correlation with the zooplankton taxa was highly significantly negatively correlated which was highest for ostracoda ($r = -0.99$) and % Rotifera ($r = -0.98$) with ($p = 0.00$). Similarly, copepod was also negatively correlated ($r = -0.88$, $p = 0.02$) (Table 5).

TDS influenced percent cladocera positively ($r = 0.95$) but negatively influenced abundance of percent rotifer ($r = -0.94$, $p = 0.01$), also significant variation was observed for copepoda ($r = -0.84$) and percent copepoda ($r = -0.82$, $p = 0.04$). TSS had a highly negative relationship with percent cladocera (r = -0.98) and percent rotifer (r = -0.98) also with copepod (r = -0.84, p = 0.04). Salinity had a highly significant correlation with percent rotifer (r = -0.82) and r = -0.81 for copepod (p = 0.05). The pH of water had a positive correlation with percent cladocera (r = 0.96) but highly negatively significantly correlated with ostracoda (r = -0.94), copepoda and percent rotifer relationship was also negatively significant (r = -0.81 and r = -0.92 respectively). The water turbidity was significantly correlated with percent cladocera (r = 0.82, p = 0.05). However, conductivity correlation had no significant correlation with zooplankton species.

The nutrient content correlated significantly with zooplankton abundance. PO_4 influenced positively only the % cladocera (r = 0.89, p = 0.02), but was negatively significant for copepod (r = -0.87, P = 0.03), % copepod and % rotifera (r = -0.88 and r = -0.83, respectively). Nitrates had a significant correlation with all zooplankton taxa in Chemususu dam. Carbonates had significantly negative correlation with percent cladocera (r = -0.90, p = 0.02) but chlorides had significantly positive correlation (r = 0.89) with a p = 0.02.

During the wet season, some parameters such as pH, salinity, conductivity, and turbidity and all the nutrients were significantly correlated with zooplankton abundance in Chemususu dam in the wet season (Table 5). The temperature influenced positively (r = 0.98) cladocerans and ostracoda (r = 0.94) with p = 0.00 and p = 0.01, respectively. The DO content of Chemususu showed a negative significant association with only rotifer taxa (-0.85, p = 0.03). Similarly, TDS negatively correlated with ostracoda (r = -0.81) at p = 0.05. TSS had a negative significant relationship with ostracoda (r = -0.91) and cladocera (r = -0.86) with p < 0.05.

Canonical correspondence analysis of water quality and zooplankton abundance

The canonical correspondence analysis (CCA) triplot was considered for sampling sites, seasons and water quality parameters (physicochemical parameters and nutrients) and zooplankton taxa showed a distinct arrangement relating the taxon association to seasons and water parameters. The components summation in the two-axis totaled 91.6%. CCA component 1 was 48.3% of the overall variation detected in the data set. CCA component 2 was 43.3%. The triplot CCA showed an influence of NO_3, DO, Cl, salinity, and TDS water parameters on the ostracoda and rotifer in the rainy season (Fig. 3). In the dry season the cladocera and copepod was found to associate with the influence of water turbidity, CO_3, conductivity and TSS. However, water temperature was noted to strongly affect river Chemususu (RC) during both wet and dry season, similarly turbidity and TSS was also found to overlap in both seasons. The copepod taxa were found to have strong relationship with sampling sites D1 and RC during both sampling seasons.

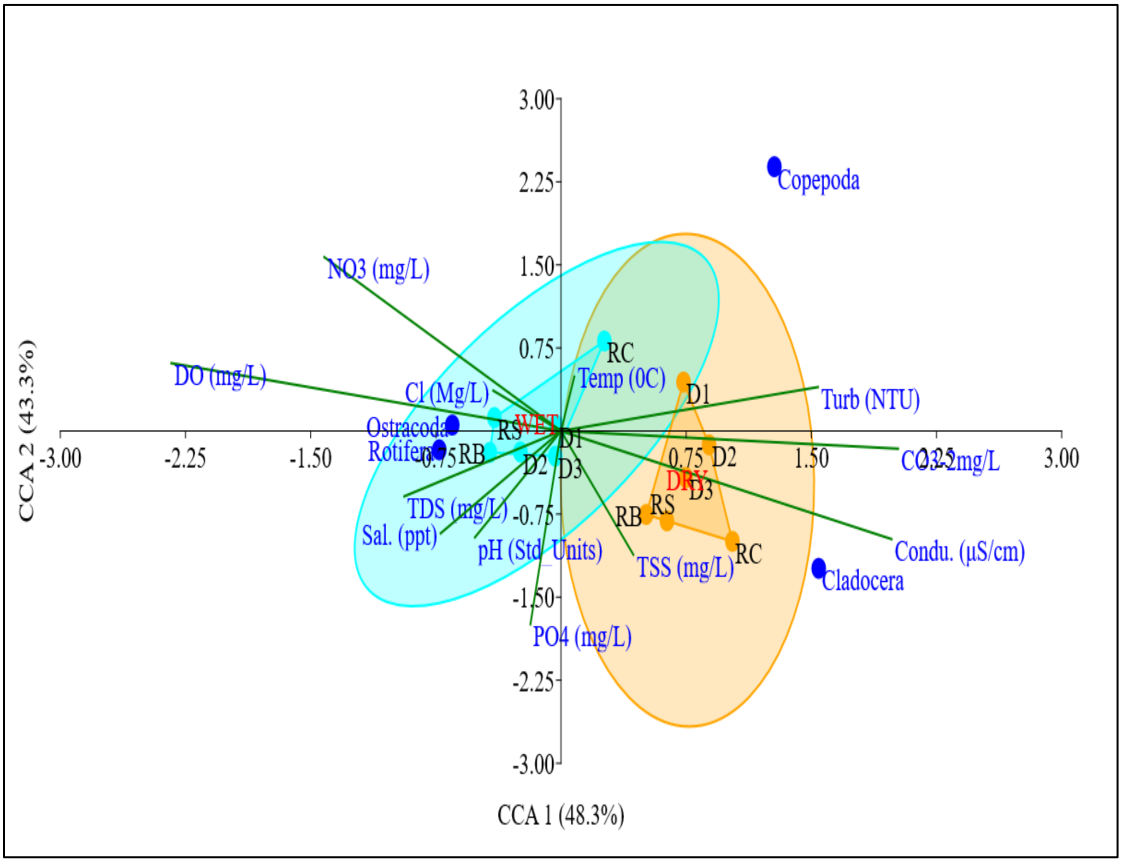

Figure 3: Canonical correspondence analysis Triplot indicating the interactive effect of seasons and quality of water quality on zooplankton taxa of Chemususu dam, Baringo County

Ranked abundance of zooplankton taxa based on SIMPER outcomes

The simper pairwise comparison of sites categories of individual rivers versus the combined dam sites in the two seasons showed a contribution of copepod taxon during the dry season, but ostracoda was found to be the common dissimilarity in the wet season (Table 6). In the comparison of the dam sites and R. Chemususu (RC) during the dry season, copepoda contributed 39.0% of the dissimilarity, followed by ostracoda. Similar observation was recorded between the dam sites and R. Sawich (RS) (copepod 32.75% and ostracoda 28.19% respectively). The pairwise comparison between dam sites and R. Baraisni (RB) showed a leading contributor of the dissimilarity being cladocera 37.75% followed by copepod (30.0%). During the wet season, pairwise comparison showed the dissimilarity contribution between dam sites and RC being ostracoda (33.19%), but for dam sites and RS, cladocera (41.55%) was the highest dissimilarity contributor in the comparison of the dam sites and RB. However, it was noted that in both seasonal comparison of the dam sites and rivers, Rotifera contribution was the least despite being the most abundant taxa and most diversified during both seasons and in all the sites sampled.

Discussion

Diversity analysis showed that zooplankton varied according to the sampling sites and seasons. The diversity indices of Shannon (H) and Simpson (D) indicated that zooplanktons in all sampling sites and seasons exhibited high levels of diversity. High diversity indices show that the populations of zooplanktons are varied and uneven in their species and distributions (Picapedra *et al.,* 2020). In their study, Padovesi-Fonseca and Rezende (2017) established that nitrates, phosphates, light, and warmth are factors that drive the diversity of zooplankton in freshwater bodies n tropical regions. However, the concentrations of nitrates, phosphates, and temperature were not significant between seasons and sampling sites in this study. Picapedra *et al*., (2020) explain that rotifers, cladocerans, copepods, and ostracods contribute to wide diversity, and compositions of zooplankton.

Findings demonstrated that zooplankton community and the quality of water correlate in both wet and dry seasons. The data showed that DO, TDS, salinity, pH, turbidity and three nutrients PO_4, NO_3 and CO_3 had significant correlation with zooplankton taxa in Chemususu dam. The positive correlation of DO with rotifers and ostracoda showed that oxygen promotes the growth of these forms of zooplankton as demonstrated by Hosain *et al.* (2021). However, the negative relationship between DO and ostracoda reveals that these zooplankton are not sensitive to oxygen levels in water. As cladocerans exhibited a significant negative correlation with TDS, it implies that solids affect the growth of these zooplankton which are in agreement with the results of Zsuga *et al.,* (2021). The presence of a positive association between zooplankton and salinity, pH, PO_4, and NO_3 agrees with the results of Ismail and Adnan (2016) who observed that eutrophic freshwater encourage the growth of rotifers, copepods, and cladocerans because algal blooms provide food for these zooplankton.

In the dry season, a positive relationship was established to occur between temperature with rotifers and ostracoda. Dudeck *et al.* (2021) established that elevated temperatures promote food production and reproduction among zooplankton. However, DO, TSS, TDS, and pH had a negative relationship with rotifers, ostracods, cladocerans, and copepods. TSS, DO, and pH have marked influence on the zooplankton because they destabilize the ecosystems (Hosain *et al.,* 2021). The analysis of nutrients showed that PO_4 has a positive connection with cladocerans but negative relationship with copepods and rotifers. Eutrophication effect by NO_3 could have significant correlation with all zooplankton taxa in Chemususu dam as explained by Espinosa-Rodríguez *et al.,* (2021). During the wet season, the zooplankton exhibit significant relationships with the water quality parameters. Findings demonstrated that temperature had a significant positive influence on cladocerans and ostracoda. These findings are in tandem with those of Dudeck *et al.* (2021) who found out that temperature mediate the production of food and reproduction of organisms in freshwater ecosystems. The negative relationship of DO, TDS, and TSS implies that zooplankton in wet season are sensitive to high levels of pollution in water. Frau *et al.* (2021) explained that water pollution increases the levels of TSS and TDS in water, decreasing DO and affecting the growth of plankton. This explanation would explain why DO had negative relationship with TDS and TSS.

The current study is the first to report the canonical correspondence analysis (CCA) of the multivariate association between seasons, sampling sites and parameters of water quality in Chemususu dam. The triplot demonstrated that the first and second components account for a huge variation in both components. During the wet season, NO_3, DO, Cl, salinity and TDS had significant influence on the abundance of rotifers and ostracoda. Due to surface run-off and floods, the quality of water during wet season tends to have high levels of nitrates, solids and dissolved salts (Kadam *et al.,* 2021), this agrees with the current report. In contrast, during the dry season, turbidity, CO_3, conductivity and TSS had significance effect on the abundance of cladocera and copepod. Increased concentration of salts and other solutes in water happen in dry seasons, leading to changes in the abundance of zooplankton, such as copepods and cladocerans (Stoler et al., 2017; Cavicchioli *et al.,* 2019). Regarding sampling sites, temperature was noted to have a strong effect on rivers and dam sites. Ziemińska-Stolarska and Kempa (2021) explained the effects of seasonal factors and physical conditions of riverbanks and shores of dams determine water quality parameters, which is the case in Chemususu dam.

Similarity percentage analysis was used to rank the abundance of zooplankton in Chemususu dam. Pairwise comparison revealed that copepods contributed to abundance during dry season, while ostracods exhibit dissimilarity during the wet season. Seasonal dissimilarity of the abundance of zooplankton shows variation in water quality and unique adaptive features of organisms in the freshwater ecosystems (Thomas *et al.,* 2016). Moreover, in dry season similarity percentage of copepods in dam sites and rivers for copepods, cladocerans, and ostracods. In contrast, the similarity percentage in wet season in dam sites and rivers showed that ostracods and cladocerans had similarity that was wider. Shi *et al.* (2020) concluded that ostracoda and cladocerans were abundant species in wet and dry seasons. Since rotifers are dominant in both seasons and most diversified during both seasons, they significantly contributed to abundance of zooplankton but did not contribute much to the dissimilarity detected in the study. This trend could stem from wide abundance and composition implying that there is homogeneity, further rotifers are also adapted to freshwater bodies and seasonal changes have no significant effect on their abundance, diversity and dissimilarity.

Conclusion and Recommendations

Regarding correlation analysis, findings demonstrated that zooplankton and water quality correlate in both wet and dry seasons. In dry season, temperature influenced the occurrence of rotifers and ostracoda. In wet season, the zooplankton genera exhibited significant relationships with the nitrates, temperature, turbidity, DO, TSS, TDS, and salinity. Temperature has a significant positive influence on cladocerans and ostracoda, while DO, TDS, and TSS had negative relationships with zooplankton. Similarity percentage analysis revealed that copepods were the highest contributor to dissimilarity abundance during dry season, while ostracods contributed to dissimilarity during the wet season. The study indicated that continuous monitoring of water quality parameters is necessary to determine their trends over several years.

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